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Evidence Synthesis

CROPDIVA – 1.1

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Contents

1. LIST OF ABBREVIATIONS

EU – European Union
FHB – Fusarium Head Blight
ROW – Rest of the World
WoS – Web of Science

2. EVIDENCE SYNTHESIS

2.1 Introduction

This evidence synthesis aims to collate and evaluate existing research to support decision making for the EU Horizon 2020 CROPDIVA project. This report will consider three aspects of existing evidence. Firstly, an evaluation of the gaps not currently addressed by running and recently terminated European projects, most of which are within the Crop Diversification Cluster. Secondly, synergies will be created by integrating available results and platforms to systematically map where relevant research applies to the six underutilised crops defined in the CROPDIVA project. Thirdly, beyond the state-of-the-art opportunities will be identified, ensuring that CROPDIVA's activities are of added value compared to existing knowledge and projects, which can be fine-tuned during the project according to the stakeholder's needs.

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The CROPDIVA project consists of seven work packages. Of these, four focus on specific areas of interest relating to the underutilised crops: the development and use of genomic tools and breeding approaches; introduction of the selected underutilised crops into cropping systems for biodiversity; the development of new food/feed and non-food products of the harvested crops to boost local value chains; and investigating how socio-economic relations are shaping value chains for new food products using the underutilised crops and creating research-based strategies for marketing. The evidence review is designed to inform these work packages. The remaining work packages focus on the collation of project-related data and the dissemination and communication of all project results and outputs.
In addition to the specific topic areas, any state-of the art opportunities were also considered for inclusion in the evidence review.

2.2 Methods

A three-stage approach was used to obtain and investigate the data as follows:

1. Recent and ongoing European projects relating to the underutilised crops
   The CORDIS (https://cordis.europa.eu/projects/en) database was used to find information on projects involving any of the six underutilised crops. Each crop name and synonyms were searched for individually within the database. Deliverables relating to one of more of the underutilised crops were recorded and categorised by topic area. A heatmap of the distribution of research relating to each of the underutilised crops was produced using EviAtlas (Haddaway, *et al.,* 2019) (https://estech.shinyapps.io/eviatlas/).
2. Rapid review (systematic map) of existing research relating to the specific work packages
   A rapid review, following systematic map principles (James, *et al.,* 2016) was undertaken to establish current knowledge gaps and inform the trial objectives for the CROPDIVA project. An a-priori protocol was prepared to inform the systematic map methods (*Annex 1*). The final search string is shown in within the methods in Annex 1. Of the three databases searched, all articles found were extracted from Web of Science and a subset of articles (based on relevance) extracted from CAB Abstracts (10,000 articles) and Scopus (2000 articles). Duplicate articles were removed, and articles were screened at title level and then again at abstract. Articles that met predefined inclusion criteria were included for data extraction. Data from accepted articles were coded from their abstracts, using a simplified coding tool (*Annex 2*), and where articles had more than one study within the research multiple “outputs” were recorded. Figures were produced using Microsoft Excel (version 2201) and EviAtlas (Haddaway, *et al.,* 2019) (https://estech.shinyapps.io/eviatlas/).

Throughout this document an “output” refers to the results of an individual study within an article. This means that one article, which has multiple studies within it, will have multiple outputs recorded and used in the analysis for the systematic map.

3. Topic modelling of wider literature relating to the underutilised crops

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To investigate additional themes and patterns relating to the underutilised crops within the wider literature, the full results from the systematic map search string were used for topic modelling of broader topics that were not directly searched for or coded in the systematic map, but that may offer further support to the CROPDIVA project. In addition, a separate topic modelling exercise was also carried for two specific sub sections on of the primary topics within systematic map (agronomy and socioeconomics). These were carried out in SWIFT-Review (Howard, *et al.,* 2016) and the results are presented in the relevant subsections.

2.3 Results

2.3.1 European Projects

The data collected from the European project databases indicates that most of the research currently being conducted within Europe concerns the protein crop faba bean (56 out of 113 deliverable focal points) (**Figure 1**). There are several projects (e.g., EUFABA, EUROLEGUME, FABASHAPE, TRUE and LEGATO) that focus either specifically on faba bean or on legumes generally. Within the literature there is a precedent for studying legumes as alternative crops in 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 utilisation of these crops.

No current (or recently terminated) European project has focused any resources on hull-less barley. This justifies inclusion of this crop in the CROPDIVA project. Hull-less barley is generally an understudied crop when assessing the state of research within the literature (81 outputs were found out of 2,229 in the systematic map). This could explain why there is no current inclusion of this crop in any recently terminated or ongoing studies within the EU. The **gaps in the knowledge** with regards to this crop will be analysed and discussed further in section *2.3: Literature relating to specific work packages* under each appropriate topic of study.

Oats are currently a focal point in certain EU projects, but the focus on many projects appeared to be on diets for disease control, such as that of coeliac disease (e.g., projects GLUTEN EPITOPES IN C, CD-CHEF, which characterised regions causative for coeliac disease and ELISA kits to detect 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 – will also **help farmers and industry prepare for the changes pending under the EU Green deal, including reduced use of fertilisers and pesticides.**

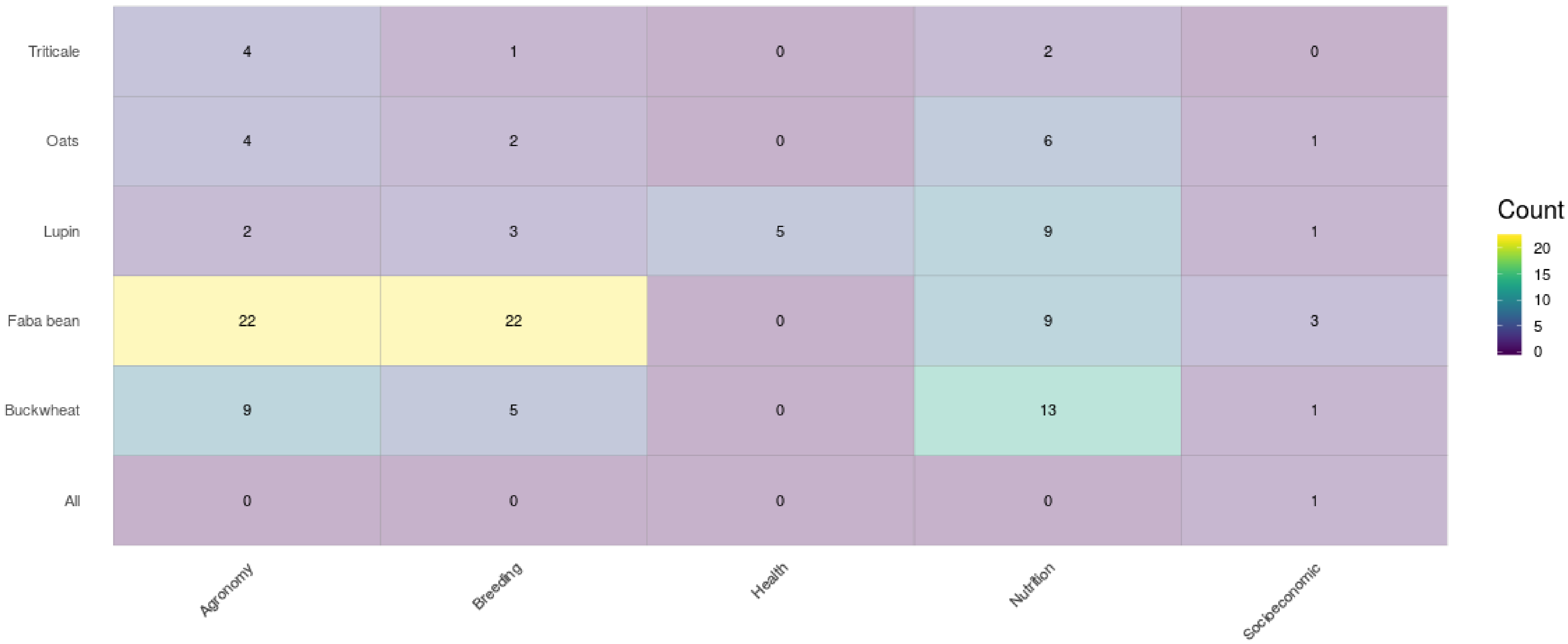

Figure 1: Distribution of research topics (along the x-axis) recently completed or currently on going within EU funded projects in relation to the relevant crops within the six underutilised crops (along the y-axis) in the CROPDIVA project.

2.3.2 Systematic map

A total of 34,522 articles were collected from the three databases searched for the systematic map. From these 5,853 duplicates were removed and 28,669 articles were screened at title level for inclusion for further screening. The 3,503 articles that passed screening at title level were further screened using their abstract and all accepted articles included were simultaneously coded for inclusion in the systematic map. Articles were not read at full text, therefore certain information (such as exact geographic location) was not extracted. The tool (*Annex 2*) was used to code each relevant output from the included articles. A total of 1,346 articles were included in the systematic map. There were 2,229 outputs recorded in the database from all articles included. **Figure 2** shows the yearly distribution of all research related to the six underutilised crops with a clear upwards trend in total number of studies.

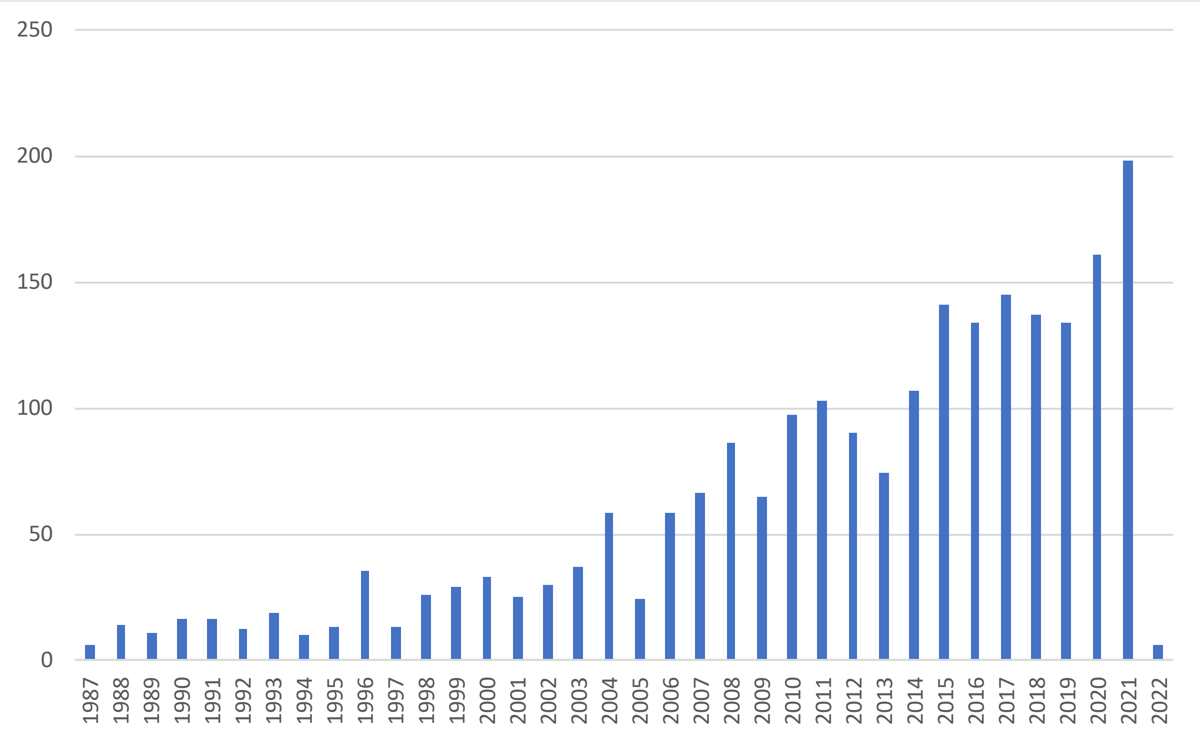

Figure 2: Yearly distribution of all articles relating to the six underutilised crops set out by the CROPDIVA project.

The research was not distributed evenly for each crop. Faba bean was the most studied (34.7 % of all outputs), 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 %). This will be further discussed in section "*2.3: Literature relating to specific work packages*", as will the distribution of topics within the research for each crop (Also shown in **Figures 4 and 5**).

Figure 3 shows the overall distribution of topics studied in all outputs from the included literature. Agronomy was the most studied area (> 1000 outputs), followed by studies relating to breeding and nutrition.

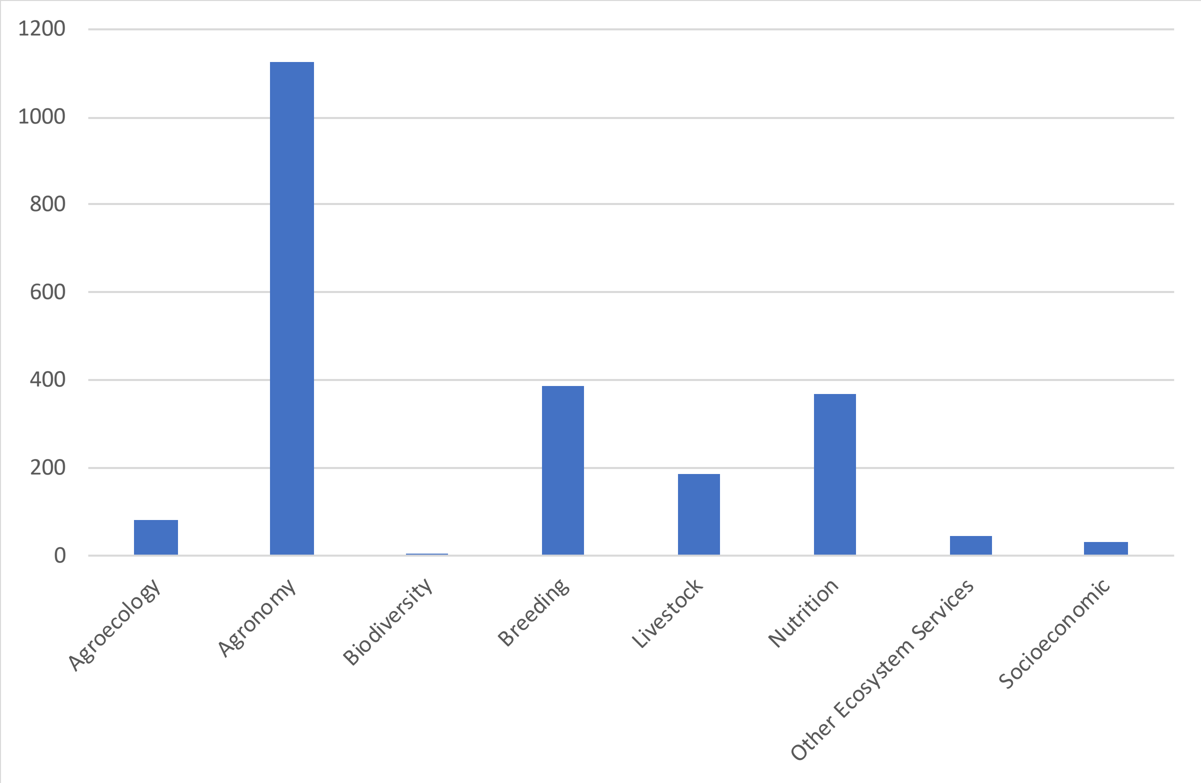

Figure 3: Total distribution of outputs by topic of all underutilised crops and countries of research origin.

The distribution of literature produced on the six crops for European countries (**Figure 4**) and for the rest of the world (ROW) (**Figure 5**) show similar trends, with a focus on the agronomy related topics (agronomy, agroecology, other ecosystem services and biodiversity) at 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). The Figures also show that much of the research has focussed on faba bean, oats, and triticale. The implications of these numbers for each work package will be discussed in the subsequent sections.

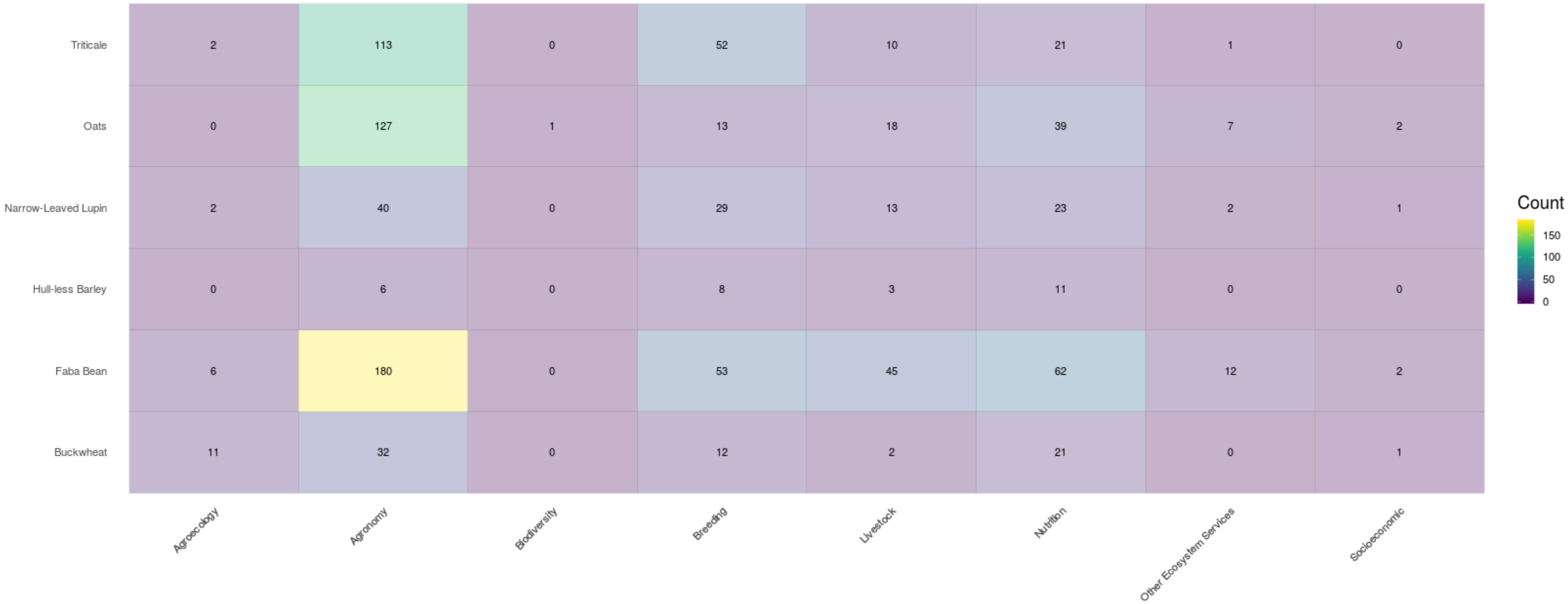

Figure 4: Distribution of article topic (along the x-axis) research outputs in relation to the six underutilised crops (along the y-axis) within European countries. A total of 983 outputs were extracted from literature originating from within Europe.

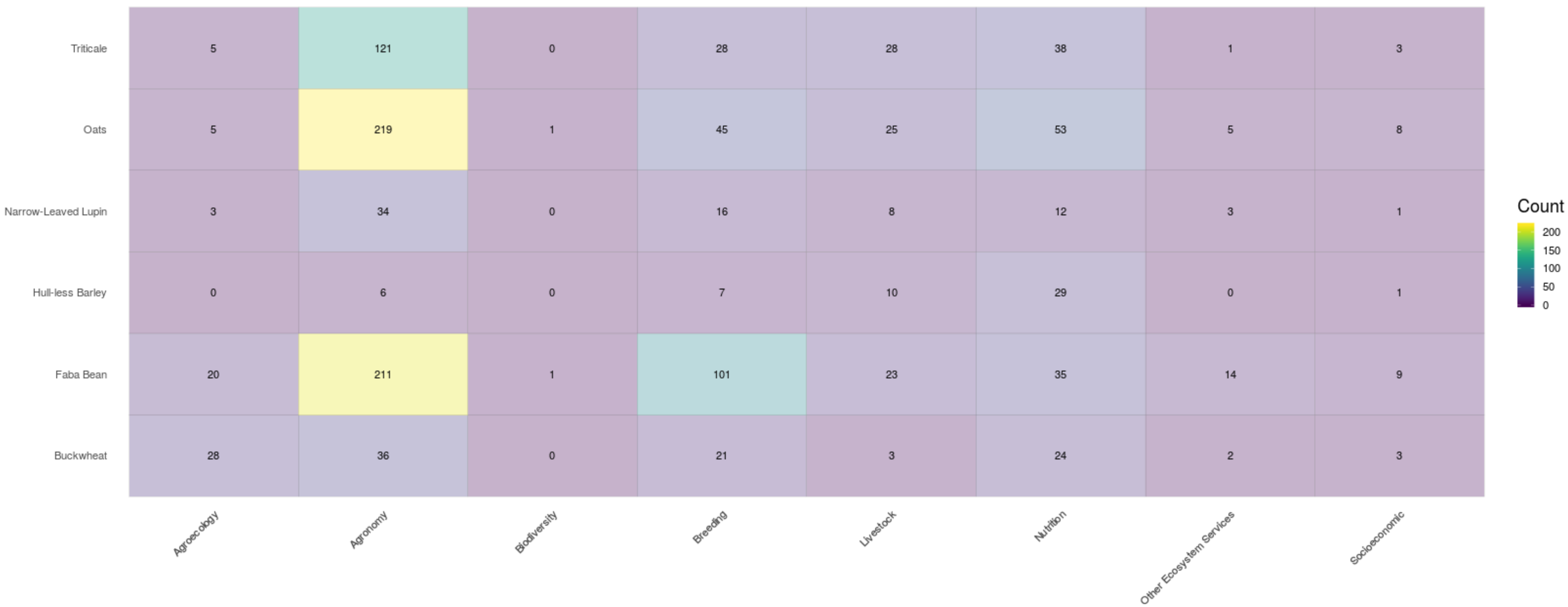

Figure 5: Distribution of article topic (along the x-axis) research output in relation to the six underutilised crops (along the y-axis) within countries in the ROW. A total of 1,236 outputs were extracted from literature originating from outside of Europe.

2.4 Literature relating to specific work packages

2.4.1 Work Package 2: Breeding

Work Package 2 focuses on the enhancement of genetic diversity by identification of valuable genotypes from underutilised crops and improving their competitiveness with the development and usage of new genomic tools and breeding approaches. Each sub-work package the focuses on each of the individual crops separately.
Of the 2,229 outputs 385 (167 Europe and 218 ROW) of those were categorised within the “Breeding” topic, these will be further analysed below as per the subtasks stated in the CROPDIVA proposal.

2.4.1.1 Task 2.1 Oats

Task 2.1 is researching the development of breeding tools for enhanced abiotic stress tolerance, milling and nutritional quality of oats. A total of 58 (13 European, 45 ROW) outputs were concerned with the breeding of oats. Very few of the studies focused on the breeding tools specifically relating to stress tolerance, milling or nutritional quality, but instead on breeding oats for yield (15 out of 58 of recorded outputs) and agronomical traits (11 out of 58 outputs), with recent examples in Ethiopia and Turkey (Tessema & Getinet, 2020; and Çalişkan, *et al.,* 2020, respectively). There have been a couple of studies on breeding techniques within the 2020s that research breeding cost (Mellers, *et al.,* 2020) and speed of breeding (González-Barrios, *et al.,* 2021) in oats, showing a growing interest in breeding techniques. With regards to research into breeding and disease resistance in oats (10 out of 58 outputs), much of the literature is focused on evaluating genotypes and oat germplasm for resistance to stem rust (Yuan, *et al.,* 2014) and crown rust (Klos, *et al.,* 2017).

Despite the focus on breeding for yield, agronomic traits, and disease resistance, there is some research into abiotic stressors of oats, but these are pre-2000 except for one study on drought tolerance (Sadras, *et al.,* 2017). There are also six recent studies on various nutritional qualities of oat varieties and genotypes, such as mineral content (Mehta, 2018), protein content and beta-glucan content (Ahmed, *et al.,* 2015). This research into nutritional quality relates to varietal differences and not the breeding tools required for the traits.

Overall, the focus of existing research is into breeding for desirable, agronomic, and economic traits and genetic analysis, as well as evaluation of cultivars and genotypes of oats. Research into breeding tools to enhance trait selection for abiotic stress tolerance and nutritional quality is relatively limited in comparison, highlighting a need to focus on breeding tools for oats. The CROPDIVA project will aim develop breeding tools to enhance trait selection for abiotic stress tolerance and nutritional quality.

2.4.1.2 Task 2.2 Triticale

Task 2.2 is researching the development of breeding tools for improvements of yellow rust resistance and stem digestibility using marker-trait associations in triticale. A total of 80 (28 European, 52 ROW) outputs were concerned with the breeding of triticale. The research was split between breeding triticale for yield and agronomical traits, as well as the introduction of new cultivars, genetic variability, and disease resistance.

Four of the eight the current literature concerned with disease resistance in triticale focused on Fusarium Head Blight (FHB) (Ittu & Ittu, 2008., Góral, *et al.,* 2013, and Kalih, *et al.,* 2015) and leaf (brown) 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). With 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 breeding tools for targeted resistance and desirable traits within triticale that CROPDIVA can hope to fill.**

No studies within the literature have directly dealt with stem digestibility within triticale breeding, with most focusing on either yield of triticale (e.g., Diordiieva, *et al.,* 2020) or on quality of triticale for forage (Bilgili, *et al.,* 2009). Within the parameters measured in Bilgili, *et al.,* (2009), stem components were measured, but stem digestibility was, seemingly, not directly measured (based on the abstract).
Due to the hybrid and commercial nature of triticale, much 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.

2.4.1.3 Task 2.3 Hull-less Barley

Task 2.3 is researching the selection of lines and improvement of their breeding for yield, free threshing, and beta-glucan content in hull-less barley. Literature on hull-less barley is limited, with only a total of of 15 (8 European, 7 ROW) outputs found that were concerned with the breeding of hull-less barley. A third of these (5 outputs) were evaluating yield differences in hull-less barley cultivars and were focussed mainly on how these cultivars performed under different agronomic or climatic conditions (e.g., Hosseinpour, 2012; Sturite, *et al.,* 2019).

Beta-glucan content has been studied in relation to its nutritive benefit in hull-less barley in more recent literature (e.g., Dicken, *et al.,* 2011; Abdel-Haleem, *et al.,* 2020), both studies look at environmental and agronomic management or health benefits of hull-less barley genotypes, but **no research has been conducted into the improvement of breeding for beta-glucan content specifically**. This will be a key output of this subtask in the CROPDIVA project. It will also provide a good opportunity for CROPDIVA to improve knowledge on breeding for hull-less barley with regards to it agronomic and economic traits, processing traits and its nutritional content.

2.4.1.4 Task 2.4 Narrow-Leaved Lupin

Task 2.4 is deciphering genetic variation for acceleration of narrow-leaved lupin breeding for their alkaloid content, yield, and quality traits. A total of 45 (29 European, 16 ROW) outputs were concerned with narrow-leaved lupin breeding. Most of the focus (9 of 45 outputs) was on disease resistance (e.g., Ruge-Wehling, *et al.,* 2010), yield and agronomic traits (12 outputs) (e.g., Kurlovich, Stoddard & Laasonen, 2011; Abraham, *et al.,* 2019) and various plant characteristics (7 outputs) studied via trait-marker research, such as root trait diversity (e.g., Chen, *et al.,* 2016).

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. Two of the studies within the literature in the systematic map were focused on alkaloid content in narrow-leaved lupin (Maknickienė & Ražukas, 2007 & Plewiński, *et al.,* 2019). Maknickienė & 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. This combined with previous research into molecular markers in a core collection of the crop for desirable traits. (Chen, *et al.,* 2016) developed methods in which to unlock rapid breeding techniques to better utilise narrow-leafed lupin as a protein source and within diversified cropping systems. By filling in some of the knowledge gaps, the CROPDIVA project aims to support the increased use of narrow leafed across European nations.

2.4.1.5 Task 2.5 Buckwheat

Task 2.5 is researching a diversity evaluation of genetic resources and the development of new approaches for agronomically important traits in buckwheat. A total of 33 (12 European, 21 ROW) outputs were concerned with buckwheat breeding.

Literature that investigates buckwheat breeding and genotype comparison concentrate on genetic resources (11 outputs) (e.g. Matsui, *et al.,* 2007; Joshi, *et al.,* 2019) and nutritional quality and protein content (11 outputs) (e.g. Janovská, *et al.,* 2021; Saeed, *et al.,* 2021). With this research into 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 outputs researching abiotic stress tolerance of buckwheat; flood tolerance (Sakata & Ohsawa, 2006), & aluminium tolerance (Yokosho, *et al.,* 2014), but there is only one such study in the way of focused research on agronomically important traits, and this study also focuses on morphological traits of buckwheat (Habuš Jerčić, *et al.,* 2020). This provides a crucial opportunity to be explored within the CROPDIVA project to try to understand, develop and implement new approaches to breeding for agronomical traits of buckwheat to complement existing research into breeding for nutritional qualities.

2.4.1.6 Task 2.6 Faba Bean

Task 2.6 is to evaluate the parameters with relevance to intercropping in faba bean and other crops under different climatic conditions. A total of 154 (53 European, 101 ROW) outputs are concerned with Faba bean breeding (this equates to 40 % of all outputs in the breeding topic of all six crops – 31.7 % European and 46.3 % ROW) (Figure 4). The literature shows Faba bean breeding studies have researched many different topics such as yield traits (e.g., Ghaouti, Schierholt & Link, 2016), weed resistance (e.g., El-Fatah, Bahaa & 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.,* 2016), and agronomic and plant traits (e.g., Maalouf, *et al.,* 2015). This supports the decision for CROPDIVA to not focus on the breeding of this crop, but rather on its inclusion in intercropping systems (work package 3) and its inclusion in food/feed products (work package 4), utilising the current state of knowledge on Faba bean breeding, as well as agronomic information to investigate the best breeding parameters for including this crop in diversified cropping systems.

2.4.2 Work Package 3: Agronomy, Agroecology, Biodiversity & Other Ecosystem Services

Work Package 3 focuses on enlarging biodiversity in agricultural systems by introducing the selected underutilised crops in various cropping systems. Under this work package, three different tasks will research and further the knowledge of intercropping practices, the yield and environmental effects of diversified cropping systems, and off-crop habitats associated with and incorporating, all six underutilised crops.

The agronomy, and associated topics, of these crops are the most widely studied of all topics in this evidence synthesis (56.39% of articles across all countries).

It can be seen in **Figure 5**, that oats and faba beans are widely included in agricultural systems, whereas narrow-leaved lupin, buckwheat and hull-less barley can be considered as orphan crops. Despite their more extensive use, oats and faba bean are included in the CROPDIVA project as they are regarded as underutilised when compared to more "traditional" crops such as wheat, soybean, maize. Often oats and faba bean are considered rotational/break crops rather than focal, cash crops. However, more important in the CROPDIVA project, is that these crops will be part of intercropping systems, which are still understudied for all six crops. **When using a search string "intercrop*" AND "faba bean" AND "triticale" only 8 hits on are returned on WoS. Thus, there is a knowledge gap on how these crops can be combined in intercropping systems which are more robust than monocropping systems**.

Much of the research into the more underutilised crops (narrow-leaved lupin, buckwheat, and triticale) is focussed 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, as can be seen in Figures 4 and 5, there is a gap in the research of the agronomy of this crop, with only some research into hull-less barley 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 need to study these underutilised crops further, and how they can be incorporated into a diversified cropping system. This is a key aim of this work package and is an area in the knowledge of these crops the CROPDIVA project hopes to fill.

With regards to oats and faba bean, there is a focus on intercropping (figure 6 shows an overview of all intercropping related treatments within the database) and yield and agronomical traits within the current literature compared to the other underutilised crops (45.4 % of output within the agronomy topic for oats and 62.9 % for faba bean related to intercropping-based treatments). Many of these studies considered yield parameters of both crops in relation to different cereal-legume intercropping regimes. Other literature investigated various agronomical traits, weeds, pest, and disease suppression, as well as some literature on nutritional content output by various crops within an intercropping regime. However, when considering intercropping in relation to nutritional value, the literature suggests that there is less research into this area with many of the outputs 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 & Cannon, 2020).

2.4.2.1 Topic modelling for Agronomy

Within the systematic map 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 2,112 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 being studied in the CROPDIVA project, “Topic 20” is most likely in relation to Faba bean research, as the species *Orobanche crenata* is a parasitic herb that is commonly found attacking the crop.

Figure 6: Intercropping related treatments of all outputs related to the six underutilised crops. Treatment is along the x-axis and underutilised crop along the y-axis

2.4.3 Work Package 4: Nutrition, Livestock & Health

Work Package 4 focuses on the development of new food/ feed and non-food products of the harvested underutilised crops to boost local value chains. This is interlinked with the other trial work packages as it will use information from work package 2 to find the best performing genotypes and work package 3 for relevant cropping systems to develop the food and non-food products. It will also link with work package 5 with utilising market studies and value chain development to develop the new products.

From Figure 5, nutritional outputs related to narrow-leaved lupin are rarely found, most of these 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 protein crop has similar properties to a more traditional protein crop, for example soybean (widely researched, data not shown) and faba bean, thus, exploring the potential of narrow-leaved lupin food products is a line of research hoping to be explored in CROPDIVA. The same holds true for buckwheat and hull-less barley when compared to oats. For the latter there is already quite some knowledge on the inclusion in food/feed products. For buckwheat, also a gluten-free (pseudo) cereal less research is done, although its potential as a food source for humans is beginning to be investigated (Kılıç & Elmacı, 2018), as well as its gluten-free product potential (De Arcangelis, *et al.,* 2020). This knowledge gap will be tackled in CROPDIVA.

This is also true for the other crops in CROPDIVA, many of which are used as alternative crops within fodder and animal feed, with around 50% of the outputs in the nutrition topic also relating to livestock and animal feeds. 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 & Keles, 2021); Triticale (e.g., Kokoszyński, *et al.,* 2018); Hull-less barley (e.g., Janocha, *et al.,* 2020).

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), whereas for oats, there is more research into nutritive content such as beta-glucan content (e,g., Wang & 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, for the remaining three CROPDIVA study crops (triticale, narrow-leaved lupin and hull-less barley) the majority of the literature 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), within food produce, namely flour (e.g., triticale, Jonnala, *et al.,* 2010; hull-less barley, Liu, *et al.,* 2020) or potential health risks for animals and humans (e.g., narrow-leaved lupin, EFSA Panel on Contaminants in the Food Chain, 2019).

2.4.4 Work Package 5: Socioeconomic studies

Work Package 5 focuses on the understanding of socio-economic relations that are shaping value chains for new food products using underutilised crops and facilitate their marketing by creating research-based strategies. The topic "*Socioeconomic"* was rarely used in literature relating to the crops studied in CROPDIVA. As shown in Figures 4 and 5 a total of 31 (6 European, 25 ROW) out of 2,229 outputs were considered purely "socioeconomic". These outputs addressed namely economic benefits, comparisons, and efficiencies of some (oats, Faba bean, triticale, and narrow-leaved lupin) of the underutilised crops (16 of the 31 outputs). This may indicate that most studies focus on the previous aspects in the value chain from breeding to agronomy to food/feed production, but not focus on the associated socio-economic aspects of these crops. Some of the yield studies also consider socio-economic factors but were categorised under the agronomy topic as that was the key focus.

2.4.4.1 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 with the approach of the socioeconomic topic. This knowledge gap will be (partially) closed in the CROPDVA project.

2.4.5 Topic modelling of the entire database

To investigate broad themes within the entire literature base that was obtained from the initial systematic map searches (before inclusion criteria was applied), a topic modelling algorithm (Latent Dirichlet allocation) was run on the selected publications in ‘R’. Before the algorithm was run, a pre-processing was done, punctuation, stopwords (and, or the, etc.), numbers, Latin names, etc. were removed to reduce unnecessary noise within the dataset. The purpose of this was to identify any themes that may have been not considered during the systematic map process.

In Figure 7 the top 10 terms for the 20 topics topic model are given (topics with the highest per-topic-per-word probabilities, called β).

The most frequently appearing topic, topic 10, deals with “economy” and the development of food product 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 here the main crop mentioned. 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 CROPDIVA crops. Topics 15 and 13, ranked 5 and 6, deal with cereals and yield. Indicating that the current literature mainly focusses on yield and not on the other eco-system services. This is thus an opportunity for CROPDIVA.

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.

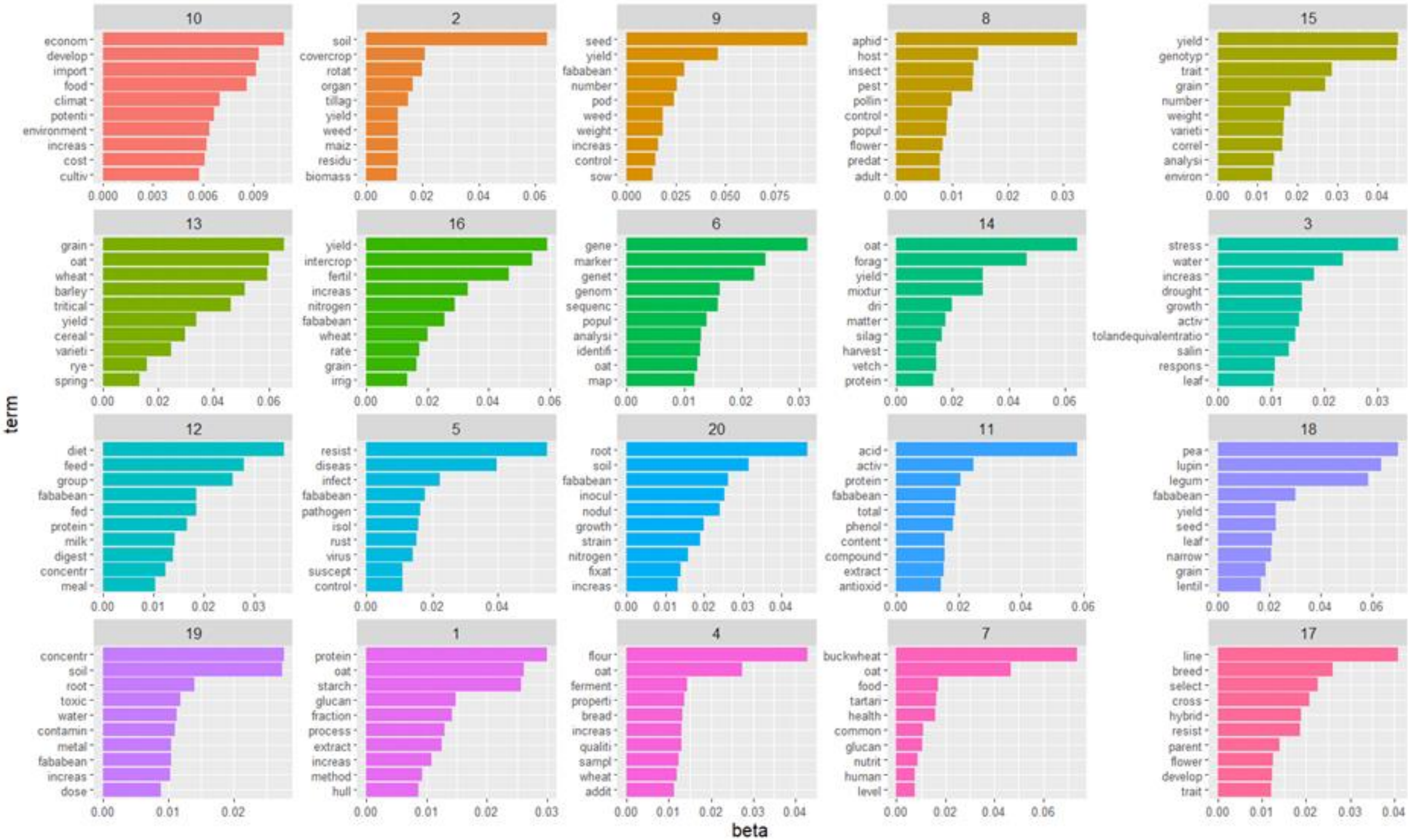

Figure 7: Top 10 most commonly used terms for the 20-topic topic model in function of beta using R. Each topic includes studies that contain all of the key words identified

2.5 State-of-the-art opportunities and future challenges

This section summarises any state-of-the-art research identified from the literature or European studies, together with any future challenges specific to individual work packages that have been identified by the authors of the included articles.

2.5.1 Work Package 2 breeding

State-of-the-art

The literature indicates that there are opportunities on to expand the breeding of hull-less barley and narrow-leaved lupin suited for cultivation in Europe. Although a lot has been done on the breeding of Faba bean, there is still an opportunity to focus on the intercropping ability of (winter) Faba bean and thus to breed for traits interesting in intercropping systems. The same holds for triticale. Specific state-of the art research topics identified by study authors include: speed breeding, genomic tools, integrated breeding & genomics, molecular markers, recombinant DNA methodologies, identification of tolerance responsive genes (drought), use of different markers such as ISSR markers, microsatellite markers, ROPD markers, and low key mapping.

Future challenges

Future challenges relating to breeding, primarily focus on selection and adaptation for environmental effects and for production. Specific examples include: adaptation to summer sown cultivation, winter adaptive varieties, resistance breeding, selection for competitiveness (e.g. for weed suppression), disease resistant lines, productivity in organic systems, correcting trait deficiencies, and ways to deal with yield variations.

2.5.2 Work Package 3 Agronomy, Agroecology, Biodiversity & Other Ecosystem Services

State-of-the-art

For the agronomy, cultivation of narrow-leaved lupin, hull-less barley, and buckwheat under the European conditions there are still opportunities. Moreover, biodiversity aspects related to the six CROPDIVA crops is limited, making it worthwhile to dive deeper into this aspect in CROPDIVA. Specific state of the art topics identified by individual study authors include: diversified crop rotations, and new cultivar designs for target traits.

Future challenges

Some of the future challenges identified by the authors of individual studies include: the need for genotypes for different environments, establishment issues, concerns around optimum sowing time for weed suppression, creating green manures, alternative approaches to forage production, disease control, mitigating greenhouse gas emissions, and establishing the nutrient requirements of the underutilised crops.

2.5.3 Work Package 4 Nutrition, Livestock & Health

State-of-the-art

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No *101000847*. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or [name of the granting authority]. Neither the European Union nor the granting authority can be held responsible for them.

Compared to breeding, nutrition related to the underutilised crop species is under researched, but some specific state of the art areas of research relate to blood glucose and cholesterol lowering properties, and to new cereal-based products

Future challenges
Future challenges include research into different variations on development of new products (e.g., gluten-free produce), and health benefits (e.g., how underutilised crops can be used to ease the symptoms of diabetes).

2.5.4 Work Package 5 socioeconomic

State-of-the-art
As mentioned above, the term socio-economic was not frequently found in literature. There are thus certainly opportunities to focus on this research area. State of the art research identified by study authors include investigations into utilisation of the underutilised crops for new cereal-based products, microbial fuel cells, high gravity technology, and for biogas production

Future challenges
No specific future challenges were identified by authors, but the lack of overarching socioeconomic studies may be a challenge itself.

2.6 Conclusions

In conclusion, there is a variation in not only the number of studies per crop, but also the topic outputs that are being collated.

Within breeding, much of the focus in the literature and current EU projects are focused on legumes (namely faba bean), with much consideration for yield, agronomic and nutritional traits with this crop. With oats and triticale there is enough literature on yield and agronomic traits, a need for development of breeding tools is required. For the more understudied crops of buckwheat, narrow-leaved lupin and hull-less barley, further research into the breeding of desirable traits is necessary.

For the agronomical studies of all six crops, most of the research lies with oats, faba bean and triticale. With a need to further research various agronomical traits of buckwheat, narrow-leaved lupin, and hull-less barley, with much of the research into these crops are utilising them as cover crops and not part of a diversified intercropping regime.

Nutritional studies of the crops show that much of the research with all six crops is focused on livestock, animal feed and fodder and silage. This shows a gap in the research for human nutrition and non-food related products to be developed with these crops.

As a result of the classification of topics within this evidence synthesis, pure socio-economic topics seem sparse with these crops. This may indicate that most studies lie with previous aspects of the value chain and not focus on socio-economic aspects of the six crops.

There are several state-of-the-art opportunities with these crops, from breeding and genomic tools to diversified cropping systems, and new cereal-based food and health products. There are also many opportunities within socio-economics to improve the value chains of the crops and advance certain technologies.

The future challenges with these crops lie throughout the value chain. From the selection and adaptation of varieties through breeding; to agronomic and nutritional traits and environmental practices of the agronomy of the crops; right through to the development of new products and health benefits of all six crops.

This evidence synthesis shows that CROPDIVA has an opportunity to plug knowledge gaps and unique state-of-the-art capabilities in relation to all six underutilised crops.

ANNEX

1. Systematic map protocol

Objective of the review

The aims of this review are to identify, collate, and describe relevant published research relating to the value of ecosystem services and socioeconomic value of six underutilised crops: Oats; Triticale; Hull-less Barley; Narrow-leaved Lupin; Buckwheat; and, Faba Beans. The ecosystem services investigated will be including, but not limited to: 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; plant breeding. This will also be investigated alongside any potential socioeconomic value of all six of the crops. The map will be taken for literature from all countries and will consist of a report describing the review process, a searchable database describing the identified relevant studies, and an interactive, web-based geographical information system (GIS) displaying the contents of the database.

Primary Question	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	What are the traits of the underutilised crops that might offer these ecosystem services, and how can the target crops best be adapted and grown to offer important traits? To what extent has this research focussed on the use of these crops in diversified cropping systems? Or What is public opinion to these crops?
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-leafed Lupin; Buckwheat; Faba Beans.
Comparator	Alternative, “traditional” crops
Outcome	Outcomes will be included iteratively as they are identified within the relevant literature and will be coded accordingly

This review aims to look at a wide range of research related to the underutilised crops, and to do so this review will have the PICO question set out above for the main body of research being reviewed but will also require a PO question to process research related to specific plant traits. This research will namely be related to nutritional content articles of each crop as often these articles will not have a relevant comparator or even a desired outcome for inclusion in the above PICO framework.

Population	Six underutilised crops (as identified above)
Occurrence	Specific plant traits – These include but are not limited to research relating to articles focussing on nutritional content or those research breeding for desired plant traits.

Methods

Searches

Bibliographic databases and searches

A comprehensive search will be undertaken using multiple information sources to capture an un-biased sample of literature relating to the underutilised crops and their ecosystem service and socioeconomic value. The following academic and grey literature databases will be searched for studies using English search terms to ensure a full, un-biased spectrum of the literature:

Academic databases:

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

Due to the broad nature of the proposed topics some searches were narrowed after scoping. The first 10000 articles were extracted from CAB abstracts after articles around 10000 were tested for relevance. To test this the first 200 papers were reviewed at title (and abstract level if appropriate) for each 1000 papers (at article 7000, 8000, 9000, 10000 and 11000) these were then given a percentage relevance and extracted at the appropriate level. The first 200 papers at 7000, 8000 and 9000 numbered articles returned relevance over 10% (20%, 17% and 12% respectively). Once article number 10000 was reached on relevance they dropped below 5% (3% for both the first 200 articles at 10000 and 11000).

Grey literature for specialist searching:

1. CORDIS (https://cordis.europa.eu/projects/en)

Some grey literature searches will consist of searching for EU projects currently running research the crops that are being used in CROPDIVA. These will be coded for in the PO coding tool. Search strings will be simplified and noted in the next section when changed for other search engines.

Search string

The following search string will be used as a basis for searches within each of the above databases:

(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 identified through a scoping process. Firstly, key words were generated by stakeholders as to the topics of research that were of interest to the project in relation to the underutilised crops being studied. All key words were then assembled and tested both individually and in combination. Terms that resulted in very large numbers of results and assessed as yielding “too broad” results were excluded from the final search string.

The search yielded a total of 22,522 results in Web of Science Core Collection using a ‘topic word’ search on 06/12/2021. Abstract and title level screening demonstrated that a subsample of the search results had a proportional relevance of 37% (n=100).

Screening

All articles identified through searching will be screened at title, abstract and then full text levels for relevance using predefined inclusion criteria (detailed below) and any duplicates across the initial search will be disregarded. Consistency in the application of the inclusion criteria will be tested by comparing agreement between two reviewers at abstract level screening, using a subset of 2000 abstracts. Disagreements will be discussed, justified and the inclusion criteria will be refined where necessary and required. Agreement will be tested formally using a kappa test, and if agreement score falls below 0.4, a further reviewer will be consulted and a further 500 abstracts will be screened following resolutions of disagreements.

Inclusion criteria

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 are 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.

Critical appraisal

Critical appraisal will not be undertaken within this map due to the high variability of output measurements across the various topics being researched for this map. A very basic quality assessment will be undertaken of the study quality will be made, making note of any unreliable research that should be excluded, or any serious deficiencies that should be noted in those studies that will be included in the map. This will be in the form of a 'free text' variable in the database with a brief description of the issues and decisions made on the study.

Data coding strategy

Meta-data (the descriptive data describing the methods and setting of each study) will be extracted from each relevant study that will be included in the systematic map and entered in a searchable database. This database will be populated with several variables, each given a category set out in coding tool provided by the authors (additional file X). These parameters will be tested out on a subset of X studies to ensure all complex data are extracted reliably.

This information will be entered into a systematic map database for all included studies that are available and passed screening as a relevant study at full text. As per the coding tool provided by the authors (additional file x) the following types of information to be recorded will be: study details (i.e. authors, title, publication date and reference type); location data (i.e. location, country, latitude and longitude, climate zone); crop type (both study target crops and "traditional crops"); research output; farming system; measurement season; study design; experimental design; sampling design; measured outcome; data location; and, critical appraisal comments.

2. **Simplified coding tool**

Coding Tool – PICO & PO Question – Simplified Tool

The following will be entered into the systematic database for all included studies that are available and are deemed as relevant at full text through the screening process:

1. Author
2. Title
3. Publication date
4. Publication type (Journal, EU Project etc) (drop down list)
5. Reference type (Article, Conference Paper, Project Summary, etc) (drop down list)
6. DOI number (not relevant for EU project)
7. Location (free text) (can be multiple locations – or "Multiple Countries" if not possible to extract)

8. Article topic (Biodiversity, Nutrition, Socioeconomic, Ecosystem Services) [multiple choice tick box] (NA if required)
9. Sub-Topic (e.g., Predator diversity, pollinator diversity, protein content, economic threshold, nitrogen fixation, molecular markers, etc) (NA if required)
10. Underutilised Crop - Intervention (Oats, Triticale, Hull-less Barley, Narrow-leaved Lupin, Buckwheat, Faba bean) [multiple choice tick box]
11. Traditional Crop - Comparator (Wheat, Rye, Oilseed Rape, Maize, Other Legumes, etc) [multiple choice tick box] (NA if required)
12. Treatment Category (Intercrop Vs Monocrop; Rotation; Underutilised crop vs Traditional crop; Traditional crop bordering underutilised crop vs Traditional crop bordering traditional crop (TC bordering UC vs TC bordering TC); Mixed cropping; Other etc) [multiple choice tick box] (NA if required)
13. Treatments (free text) (only if other is selected in 12) (NA if required)
14. Measured Outcome (what is the effect measured e.g., density or yield)
15. Farming system (conventional, organic, not described)
16. State-of-the-art (identified by author)
17. Future challenges (identified by author)
18. Further details (Free text) (If anything key or of interest/ relevance)

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