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Overcoming barriers to crop diversification uptake in Europe: A mini review

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Crop diversification (CD) encompasses practices such as extending crop rotation, cover cropping and intercropping practices, and growing minor crops. It has attracted increasing interest because it can produce both private benefits for farmers, including improved crop and soil health, and reduced inputs, and public goods for society, including greater biodiversity, carbon sequestration, and climate resilience. Nevertheless, CD is not widely practiced in Europe. This paper uses a conceptual framework based upon the literature on barriers to agricultural innovation and CD to guide a systematic-like literature review of existing review articles on the barriers to CD in Europe and a review of research from the European Crop Diversification Cluster, comprising six EU research projects. We compare barriers to CD uptake and identify opportunities to accelerate CD uptake, drawing four main conclusions. First, the barriers to CD are influenced by many factors: the specific crop, cropping method, geographical region, the farmer, the supply chain or market, and the institutional environment. Second, the barriers to CD uptake are interconnected and occur at multiple points along the supply chain; addressing barriers to CD uptake therefore requires a simultaneous and coordinated approach. Third, the inclusion of farmers' perspectives in the CD cluster research revealed novel barriers and solutions demonstrating that participatory and transdisciplinary agricultural research is needed to understand the on-farm reality and its influence on CD uptake. Lastly, farmers' decision-making warrants greater attention. The results highlight that farmers' decision-making is unpredictable and likely to focus on utility rather than profit maximization.

KEYWORDS

adoption, diversification practices, farmers, intercropping, legumes, value chain, supply chain

1. Introduction

Crop diversification (CD) encompasses practices such as extending crop rotations, cover cropping, intercropping practices, and growing minor crops[1]. It has attracted recent interest because it can produce both private benefits for farmers, including improved crop and soil health, and reduced inputs, and public goods for society, including greater biodiversity, carbon sequestration, and climate resilience (e.g., Kremen and Miles, 2012; Zander et al., 2016; Watson et al., 2017).

1 This review builds on work conducted by the corresponding author as part of a MSc thesis (Brannan, 2021).

Nevertheless, CD practices are not widespread in Europe. In 2014 grain legumes, which are frequently grown in diverse systems and therefore can be considered an indicator of CD, were grown on 1.5% of arable land in the EU compared with 14.5% worldwide (Watson et al., 2017). Similarly, the adoption of conservation agriculture in Europe, which includes CD, has been slow, although might be increasing (Lahmar, 2010; Kassam et al., 2015).

Some previous reviews have examined CD practices alongside other sustainable agricultural practices (Knowler and Bradshaw, 2007; Prager and Posthumus, 2010; Carlisle, 2016; Mills et al., 2020), but CD, which involves growing a marketable crop, introduces additional barriers at the farm-level as well as upstream and downstream of the farm. The existing reviews only covering CD practices in Europe tend to be limited to legumes; they identify agronomic performance and profitability as central barriers for farmers (Zander et al., 2016; Annicchiarico, 2017; Watson et al., 2017), strengthened by lock-ins to intensive farming systems from investment in breeding and agronomy, and sector networks, organization, and logistics (Voisin et al., 2014; Magrini et al., 2018; Meynard et al., 2018).

Between 2017 and 2023, a group of six independent research projects funded by the EU Horizon 2020 programme were conducted. The six projects can be divided into three groups: (i) research on intercropping at the farm-level (including Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability—DIVERSify and Redesigning European cropping systems based on species MIXtures—ReMIX); (ii) research on legumes covering markets and supply chains (including TRansition paths to sUstainable legume based systems in Europe—TRUE and Fostering sustainable legume-based farming systems and agri-feed and food chains in the EU—LegValue); and (iii) research covering a wider range of CD practices, including intercropping, multicropping, and extending rotation, and emphasize supply chains and low input systems (including: Diversification through Rotation, Intercropping, Multiple cropping, Promoted with Actors and value-Chains Toward Sustainability—DiverIMPACTS and Crop diversification and low-input farming across Europe: from practitioners engagement and ecosystem services to increased revenues and chain organization—Diverfarming).

These projects worked collaboratively as the European Crop Diversification Cluster[2] with the aim "to increase the impact of crop diversification research and encourage sustained uptake of diversification measures by European farmers and through innovations across the agri-value chain." This review aims to compare barriers to CD uptake identified in the CD cluster with those from existing reviews on the adoption and dissemination of CD in Europe, and identify opportunities to accelerate CD uptake. To achieve these aims, a conceptual framework was constructed from a review of the literature on barriers to agricultural innovation and CD (Figure 1). This framework guided a systematic-like literature review of review articles on the barriers to CD in Europe and a review of the CD Cluster projects' outputs.

2 https://www.cropdiversification.eu/about.html

2. Materials and methods

Two systematic-like reviews were conducted on: (i) the existing review articles on CD practices and (ii) the outputs from the CD cluster. Systematic-like reviews incorporate elements from the standard qualitative systematic literature review (Popay et al., 2006; Okoli, 2015; Xiao and Watson, 2019) but allow investigators to conduct the analyses faster than required true systematic reviews.

2.1. Literature search and data extraction and analysis

Articles were identified for the review of existing review articles on CD practices by searching electronic databases Web of Science and Scopus using keywords in a search string (see Supplementary Table 3) with Boolean operators. The documents identified for the review of the CD cluster were found on the projects' websites and through contact with the CD cluster.

The screening criteria applied for the electronic databases included: peer-reviewed review articles written in English, covering at least one CD practice, synonyms of barriers and enablers, and within the geographic region of EU-27, EEA, or the United Kingdom to ensure focus on agriculture within a similar institutional and market context. Six papers met the screening criteria. A similar screening was conducted for CD cluster review, but with no restriction on the document type, and therefore includes reports and peer-reviewed journal articles. A total of 17 documents fulfilled the screening criteria.

Data extraction was conducted separately for the two reviews. All documents underwent a full-text review to extract barriers, which were organized into broad categories informed by research on barriers to agricultural innovation and crop diversification (see Figure 1) and coded with keywords to aid analysis.

Data extraction and analysis was iterative, moving between reviewing the CD cluster documents, extracting barriers, and analyzing the results. Concept maps as graphs were used to explore connections between the barriers and the different levels of the supply chain. In addition, two synthesis tables of the barriers were used to analyse the results.

2.2. External validation

External validation is encouraged for systematic literature reviews (Popay et al., 2006) and for qualitative research (e.g., Ritchie and Lewis, 2003). To validate the results, a workshop, centered on eight guiding questions related to the two synthesis tables (see Supplementary Tables 1, 2), was carried out with researchers from the different CD cluster projects to ensure an accurate portrayal of the barriers. Both tables and the guiding questions were shared with the researchers beforehand. In addition, researchers discussed contradictions between the CDC projects and the literature review (see Supplementary material for details on the workshop).

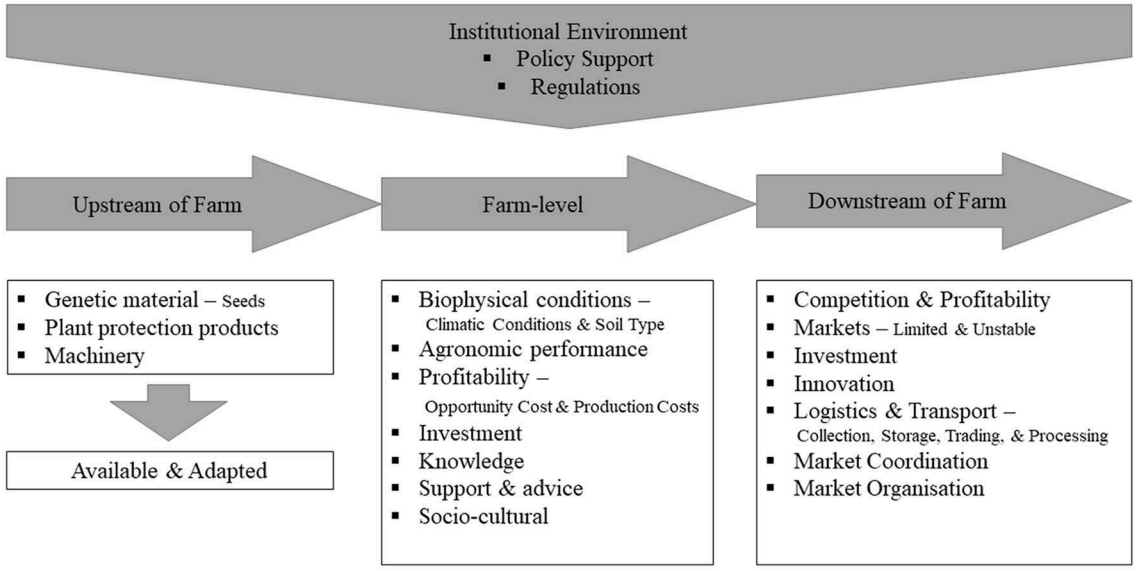

FIGURE 1
Conceptual framework of barriers to crop diversification based on a preliminary review of agricultural innovation literature and a review of literature on barriers to crop diversification (Prager and Posthumus, 2010; Carlisle, 2016; Wreford et al., 2017; Mills et al., 2020; Morel et al., 2020).

3. Results and discussion

The results and discussion are structured using the conceptual framework, working from upstream of the farm with the supply of inputs (Section Upstream of the farm), to the farm-level and farmer (Section Farm-level), and lastly analyzing the downstream markets and supply chains (Section Knowledge and decision-making). Overall, the barriers to CD are context-specific, interconnected, and occur at multiple levels simultaneously along the supply chain.

3.1. Upstream of the farm

A lack of locally-adapted varieties was a central barrier in the CD cluster for intercropping (Mamine and Farès, 2020), legumes (Balázs et al., 2019; Kelemen et al., 2019; Hamann et al., 2020; Kezeya Sepngang et al., 2020), and other CD practices (Morel et al., 2020). This was supported by the review literature emphasizing the limited genetic progress of legume yields compared with cereals in Europe (Zander et al., 2016; Annicchiarico, 2017; Watson et al., 2017) and for intercropping (Voisin et al., 2014). The limited genetic progress is frequently attributed to a lock-in favoring research and development of major crops because of their larger markets and higher return on investment (Meynard et al., 2013, 2018; Voisin et al., 2014; Magrini et al., 2016). For example, in 2015 there were 2,500 publicly registered wheat varieties compared with 400 for pea and fewer than 150 for beans.

Plant protection and adapted farm machinery were barriers for some farmers (Drexler et al., 2018; Hamann et al., 2020; Morel et al., 2020), particularly for intercropping (Barnes and Ferreira, 2018; Mamine and Farès, 2020; Hauggaard-Nielsen et al., 2021). The lack of suitable plant protection products (Howard et al., 2018; Maaß et al., 2018; Pearce et al., 2018; Morel et al., 2020) and farm machinery innovations (Barnes and Ferreira, 2018; Drexler et al., 2018; Morel et al., 2020) can be attributed to the same lock-ins that limit crop breeding: Watson et al. (2017) argue that development of herbicides for grain legumes was limited by their small production area. However, the variation in the results highlights that barriers are influenced by many factors.

3.2. Farm-level

3.2.1. Agronomic performance

Many factors influence the agronomic performance of CD: the specific practice, crop(s), inputs, machinery, knowledge, and biophysical conditions; and these need to be considered when examining barriers relating to yield quantity and stability. Although yield quantity was identified as a moderately important barrier in some of the CD cluster results (Drexler et al., 2018; Mamine and Farès, 2020; Morel et al., 2020), it was notably absent in others. This contrasts with the review literature on legumes where low yields were considered the main reason for European farmers not growing legumes (Annicchiarico, 2017; Watson et al., 2017).

Risk and uncertainty linked to CD practices was a barrier across all types of CD, with yield stability potentially more important than yield quantity (Smadja et al., 2019; Mamine and Farès, 2020; Morel et al., 2020). This aligns with the review literature showing that risk-averse farmers were discouraged from growing legumes by the perceived yield (and revenue) variability (Richthofen et al., 2006 cited by Watson et al., 2017 and Zander et al., 2016), although few studies have quantified the impacts of yield stability on uptake.

Within the CD cluster, yield quantity and stability were sometimes barriers, often less significant than other barriers, which could be more pivotal in farmers' decision-making. In addition, a better understanding of farmers' motivations for CD may explain

variation in the CD cluster results: Barnes and Ferreira (2018) found that a higher yield is not always the main consideration for farmers when intercropping. This aligns with Wreford et al. (2017) distinction between producing public goods and private benefits; farmers may indeed prioritize private benefits but not necessarily higher yield, instead they may aim to reduce inputs or improve soil quality, for example.

3.2.2. Economic performance

There was variation in the CD cluster on the degree to which economic performance was a barrier. Some CD cluster results identified low profitability as a barrier to growing legumes (Balázs et al., 2019; Kelemen et al., 2019), which was partly supported by the review literature (Zander et al., 2016; Annicchiarico, 2017; Watson et al., 2017). In France, the average gross margin was 2–6 times smaller for grain legumes than for non-legume major crops (Magrini et al., 2016), and for Europe, grain legume gross margins show shortfalls of €70–100s ha^{-1} compared with other crops (Zander et al., 2016). There is limited evidence regarding how the low profitability of CD practices influences farmers' decision-making of uptake. Voisin et al. (2014) is a notable exception, citing one study which found conventional farmers were unwilling to grow grain legumes due to the small gross margin from low yields and market price compared with cereals and oilseed rape (Carrouée et al., 2012).

The profitability of CD practices was not always a barrier to adoption in CD cluster results. In a survey on CD initiatives, profitability was more frequently an enabler (Drexler et al., 2018); for temporal CD, it was not a barrier (Morel et al., 2020); and for intercropping, higher market prices or reduced costs were seen to offset low yields and improve profitability (Barnes and Ferreira, 2018; Pearce et al., 2018). The review literature maintained that intercropping legumes can improve profitability because it stabilizes the yields and gross margins (Annicchiarico, 2017; Watson et al., 2017).

These mixed findings are influenced by several factors, primarily that standard gross margin calculations do not capture all of CD's benefits. Research using modified gross margin calculations—which includes nitrogen fertilizer savings due to legumes' fixing nitrogen, pest control savings due to break crop effects, and yield increases on subsequent crops—demonstrates more situations where legumes are competitive (Voisin et al., 2014; Zander et al., 2016; Magrini et al., 2018); these benefits encourage farmers to adopt CD practices (Barnes and Ferreira, 2018; Sears et al., 2021). Regardless, Watson et al. (2017) and Annicchiarico (2017) contend that even with a modified gross margin analysis, the economic performance of legumes is typically inadequate. However, other empirical research (Nilsson et al., 2022) has found that over time, CD practices improve economic performance and input self-sufficiency in Swedish agriculture.

3.3. Knowledge and decision-making

In the CD cluster, a lack of knowledge among farmers was a fundamental barrier to adopting CD practices (Pearce et al., 2018; Balázs et al., 2019; Kelemen et al., 2019; Morel et al., 2020), including the awareness of issues regarding specialization, access to independent knowledge, and the format of knowledge. Formal and informal networks, such as demonstration events or workshops, were valuable forms of knowledge exchange for farmers. The review literature refers to knowledge as a barrier (Voisin et al., 2014; Annicchiarico, 2017), but does not emphasize its importance for farmers adopting CD.

Likewise, the CD research (Barnes and Ferreira, 2018; Drexler et al., 2018; Pearce et al., 2018), and to less extent the review literature (Voisin et al., 2014; Magrini et al., 2018), show that access to support or advice is vital for farmers but often lacking.

This can be explained by focus of the review literature on agronomic and economic performance rather than on practical implementation on farms. Their research inadvertently assumes that farmers' decision-making is purely based on profit maximization, which is not borne out by the agricultural innovation literature (Prager and Posthumus, 2010; Carlisle, 2016; Mills et al., 2017, 2020), nor by the CD cluster's research, which shows that farmers adopt CD practices for many different agronomic, economic, and environmental motivations (Barnes and Ferreira, 2018; Pearce et al., 2018; Smadja et al., 2019). These include private benefits and public goods such as conserving on-farm resources, producing on-farm fodder, reducing inputs, enhancing biodiversity, and curiosity (Wreford et al., 2017).

Furthermore, different motivations for adopting CD practices influenced the significance of barriers for farmers (Barnes and Ferreira, 2018), but these require further validation. Lastly, other non-economic factors emerged in the CD cluster results, including farmers' perception of agriculture, farmers' perception of CD and the associated risk of adoption, concerns regarding neighbors, cultural barriers, and issues with farm succession.

3.4. Downstream of the farm

Both reviews underscore the significance of creating markets for minor crops. Market stability and small or absent markets were key barriers for different CD practices, and value chain actors (Drexler et al., 2018; Pearce et al., 2018; Smadja et al., 2019; Morel et al., 2020; Verret et al., 2020). The review literature argues that low consumer demand for legumes and market demand for feed hinder legume cultivation in Europe (Voisin et al., 2014; Zander et al., 2016; Watson et al., 2017; Magrini et al., 2018).

While trends favoring CD in Europe exist, including vegetarianism, demand for organic and non-GMO products, and rising prices of soya and fertilizer (Kootstra et al., 2017; Drexler et al., 2018; Hamann et al., 2019, 2020; Kezeya Sepngang et al., 2020), increasing consumer knowledge on the health and environmental benefits of legumes and CD practices is needed to reinforce these trends (Kelemen et al., 2019; Morel et al., 2020).

The CD cluster results show that minor crops often (but not always: Drexler et al., 2018) cannot compete directly with major crops in production and commodity markets (Weituschat et al., 2018; Tippin et al., 2019; Hamann et al., 2020; Kezeya Sepngang et al., 2020). Both reviews highlight two solutions. First, improving the economic and technical performance of CD practices to become

competitive with major crops (Zander et al., 2016; Annicchiarico, 2017; Watson et al., 2017). Second, expanding niche markets for minor crops (Voisin et al., 2014; Magrini et al., 2018). Indeed, longer, global value chains focused on commodities create more barriers, while local and relational-based value chains offer more flexibility, even with their associated barriers (Weituschat et al., 2018).

3.4.1. Commodity markets

Commodity markets generally comprise longer value chains with more linkages and specialized processes to enable economies of scale. These markets favor major crops which have received significant research and development in Europe and, therefore, outcompete minor crops on yield, gross margin, and standards (Zander et al., 2016; Watson et al., 2017; Magrini et al., 2018; Meynard et al., 2018).

A vicious cycle of low supply and demand may hinder minor crops from entering commodity markets in Europe. Small production volumes limit investment in infrastructure for storing, processing, and developing new products (Kootstra et al., 2017; Weituschat et al., 2018; Hamann et al., 2020; Morel et al., 2020). These deficiencies are compounded by cheap imports, lowering the market value, reinforcing the preference for major crops and imported protein, leading to farm-level barriers with product collection because volumes are small and dispersed (Weituschat et al., 2018; Mamine and Farès, 2020; Morel et al., 2020).

In addition, farmers need to comply with strict quality and purity standards for crops to enter commodity value chains and receive premiums (Pearce et al., 2018; Morel et al., 2020; Hauggaard-Nielsen et al., 2021). The lack of equivalent standards for minor crops and non-soya legumes reduces processors' willingness to use them (Weituschat et al., 2018; Hamann et al., 2020).

3.4.2. Niche markets

Niche markets frequently have shorter or local supply chains, fewer or no intermediary actors, are geographically closer to consumers, and target high-value products. In the CD cluster, this meant yield was sometimes less important because farmers could access local markets with higher values (e.g., Phaseolus-maize intercrops in Austria: Drexler et al., 2018; Pearce et al., 2018) and competition with mainstream producers was improved (Drexler et al., 2018).

However there are substantial barriers, including competition with imports (Morel et al., 2020); innovation and investment in cleaning, drying, and storage equipment (Morel et al., 2020); meeting standards like taste, nutrition, and production method (Meynard et al., 2017 cited by Weituschat et al., 2018); and distance from urban markets (Weituschat et al., 2018). Overcoming these barriers is vital to expand these markets and make CD more viable in Europe.

4. Concluding discussion

CD is a relatively young field of research and practice in modern farming systems in Europe. Using existing literature reviews and recent research findings from the CD cluster, this review draws four main conclusions.

First, the barriers to CD are influenced by many factors: the specific crop, cropping method, geographical region, the farmer, the supply chain or market, and the institutional environment. Therefore, the context of the farms and value chains should be considered, and barriers addressed accordingly. This aligns with previous studies concluding there are no universal determinants of, or barriers to, agricultural innovations or practices (Knowler and Bradshaw, 2007; Prager and Posthumus, 2010; Carlisle, 2016).

Second, the barriers to CD uptake are interconnected and occur at multiple points along the supply chain. Therefore, addressing barriers to CD uptake requires a simultaneous and coordinated approach (Voisin et al., 2014; Meynard et al., 2017; Magrini et al., 2018). It further highlights that holistic systems approaches are required to explore the connections between barriers in the supply/value chain, along with accompanying levers and solutions, as barriers frequently do not have singular or straightforward solutions.

Third, participatory and transdisciplinary agricultural research is needed to understand the on-farm reality and its influence on CD uptake. The inclusion of farmers' perspectives in the CD cluster research revealed novel barriers/solutions along with differences in the significance of barriers surrounding agronomic performance and profitability. However, the results should be interpreted with caution as CD cluster research involved farmers and stakeholders who were curious about, or practicing CD, which might lead to positive bias, as acknowledged in the CD cluster project documents (Drexler et al., 2018; Pearce et al., 2018; Smadja et al., 2019). Furthermore, barriers are influenced if farmers have adopted a practice (Carlisle, 2016), therefore, future research is required to validate these findings.

Lastly, the results reveal that farmers' decision-making warrants greater attention. CD stakeholders' perspectives were frequently absent from the review literature. Their limited inclusion assumes that farmers make decisions purely based on profit maximization. This aligns with agricultural research from persuasive or instrumental traditions (Leeuwis, 2004), which assumes that adoption follows when the technical or economic performance of CD practices is improved to offset its costs; farmers' decision-making is, however, less predictable (Prager and Posthumus, 2010; Carlisle, 2016; Mills et al., 2020) and likely to focus on utility rather than profit maximization. Specifically, future research should examine non-pecuniary factors which influence the adoption of market-orientated CD practices, and not only the adoption of pro-environmental practices for soil carbon and environmental management.

This research focuses on barriers to CD uptake in Europe, which is dominated by large farms (Lowder et al., 2021), although, globally, small farms often exhibit higher crop diversity (Ricciardi et al., 2021). Future research can consider comparing barriers and enablers to CD uptake against other industrialized countries worldwide and against small farms in Europe and globally.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1107700/full#supplementary-material

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