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Forever niche: Why do organically bred vegetable varieties not diffuse?

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A B S T R A C T

While organic food increased its market share in conventional food retail, virtually all organic vegetables are still conventionally bred. For decades, organically bred vegetable varieties remained a market niche, despite their socio-ecological benefits. This paper conceptualizes actors and activities around organic breeding as a Technological Innovation System (TIS) and analyzes what prevents these varieties from widely diffusing into conventional supermarkets. Investigated systemic barriers relate to knowledge, market formation, investments, and legitimacy. The study is based on interviews with food retailers and (commons-based) breeding initiatives across Germany. Theoretically, the paper adds an innovation system perspective on the diffusion of organically bred varieties, a blind spot in the emerging seed commons debate. Furthermore, it contributes to sustainability transitions literature by introducing a novel empirical topic and reframing the TIS framework to analyze agri-food innovations. Identifying barriers and vicious cycles might support practitioners and policymakers seeking to diffuse this agri-food niche.

1. Introduction

Across the world, socio-technical systems involve practices and technologies which lead to ecological crises and social injustices. Transition scholars investigate why and how socio-technical systems shift to more sustainable configurations (Markard et al., 2012). Literature traditionally focused on low carbon transitions in electricity, heating, or transport systems. Only recently, transition research on agri-food systems has gained traction (El Bilali, 2019; Hebinck et al., 2021), as their current and dominant modes of production and consumption contribute to climate change, biodiversity loss, soil degradation, malnutrition, and economic disparities (Eakin et al., 2017; Weber et al., 2020). Previous studies on agri-food transitions mostly emphasize grassroot movements and the development of socio-technical niches around innovations such as alternative agricultural production methods or regionalized marketing of local produce (Randelli and Rocchi, 2017; Rosin et al., 2017; Rossi, 2017; van Oers et al., 2018). However, there is little knowledge on how novel and sustainable food alternatives leave these niches, enter conventional grocery stores, and become widely accepted and sought after – or why they fail to do so. Only few alternatives have increased their market share and shelf-space in

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European food retail over the last decade, such as plant-based meat and dairy substitutes (Mylan et al., 2019; Tziva et al., 2020).

Despite presenting only a part of the agri-food system, vegetable food systems are increasingly acknowledged as crucial for addressing environmental, social, and health issues (Gaitán-Cremaschi et al., 2020). These systems are often characterized by lock-ins that impede the commercialization of alternative breeds. However, studies on these impeding conditions mostly focus on development activities for breeding and cultivating plant varieties (Vanloqueren and Baret, 2008; Nuijten et al., 2018; Orsini et al., 2020a; Sievers-Glotzbach et al., 2021). In this paper, we extend the analysis to diffusion activities across the entire value chain and ask which socio-technical barriers prevent alternative and novel vegetable varieties, which are not only raised but also bred organically, to gain market shares in conventional supermarkets. We base our analysis on a case study of breeding initiatives from Germany and interviews with representatives from conventional grocery stores. Organically bred varieties include a wide array of breeds specifically adapted for organic farming conditions (IFOAM, 2014; Sievers-Glotzbach et al., 2020). This separates them from conventional varieties (often grown from hybrid seeds), which are often used in organic farming but are more productive under high-input conditions of conventional farming methods (Osman et al., 2016). However, actors in organic breeding have not yet impacted the broader agri-food system beyond their niche (Sievers-Glotzbach and Tschersich, 2019) and organically bred vegetable varieties have very small market shares even within the organic sector.

To identify the relevant barriers for wide-scale diffusion, we conceptualize actors and activities around breeding, propagating, cultivating, marketing, and selling organically bred vegetable varieties as part of a Technological Innovation System (TIS). As this particular TIS is characterized by few actors, low market shares, and little growth, it is still in its formative life-cycle phase (Markard, 2020). We make use of recent TIS applications for agri-food innovations (Randelli and Rocchi, 2017; Schiller et al., 2020; Tziva et al., 2020) and emphasize conventional food retail, which is a crucial context for the TIS and important for the wide diffusion of alternative and sustainable food products (Willer and Lernoud, 2018). Food retail is part of further contexts – such as policy environments or customer preferences – which might go along with further diffusion barriers.

Overall, our paper offers a comprehensive account of diffusion barriers for organically bred vegetable varieties, which are related to knowledge flows, market formation, financial investments, and their legitimacy. We show how these barriers result from the interplay of actors, networks, institutions, and product characteristics within the TIS and with its context. While our empirical analysis focuses on barriers and challenges, such a stocktaking might provide starting points for practitioners who aim to strategically facilitate the diffusion of organically bred vegetable varieties. Theoretically, our paper provides a twofold contribution. On the one hand, we add a diffusion-based perspective on marketing and selling organically bred seeds and vegetable varieties, as this emerging debate so far mostly focuses on conditions for product development and breeding. On the other hand, we contribute to the literature on sustainability transitions by introducing a novel empirical topic to the debate and applying and refining TIS analysis to vegetable breeding, cultivation, and marketing.

The paper is structured as follows: First, we provide the theoretical background on TIS and diffusion (Section 2). As an interlude, we introduce organic breeding of novel vegetable varieties as our empirical topic (Section 3). Afterwards, we present the framework of our specific TIS analysis (Section 4) and explain our methods (Section 5). Then, barriers for the diffusion of organically bred vegetable varieties are analyzed (Section 6). Finally, we discuss results, limitations, and theoretical contributions of our analysis (Section 7) and summarize implications for practitioners and policy makers (Section 8).

2. TIS and their diffusion in the agri-food sector

In the following section (Section 2.1), we briefly introduce the TIS framework, which draws attention to a wide range of product-related and external factors that influence not only the development, but also the market roll-out of alternative products. In Section 2.2, we review previous TIS applications in agri-food transitions and summarize key insights relating to our research.

2.1. TIS and the diffusion of alternative products

The TIS framework covers the systemic and interactive process of introducing and utilizing socio-technical innovations. Actors, networks, and institutions that advance the development and diffusion of the investigated product are structural components of the TIS (Bergek et al., 2008). The notion of actors usually refers to organizations such as companies from along the value chain, research institutes, or political lobby groups, but also individuals who actively contribute to innovating and applying the product, such as pioneering entrepreneurs or dedicated end-users (Hekkert et al., 2007; Hekkert and Negro, 2009). Actors coordinate and exchange ideas or resources within informal network structures or formal networking organizations (Musiolik and Markard, 2011; Rohe and Chlebna, 2022). Institutions are usually defined as 'rules of the game' (North, 1990; Markard and Truffer, 2008): Laws, standards, norms, or expectations that control, enable, or constrain TIS actors. The interplay of these structural components might create positive externalities such as knowledge, financial investments, market access, or technological legitimacy. These externalities are framed as system functions or – as we do here – system resources. The latter conceptualization emphasizes their relational character (Binz et al., 2016; Musiolik et al., 2020). Resources are unevenly distributed and not all actors have equal access to them at any place and time. This potentially allows for an analysis of power – asking who controls the formation of and access to system resources – although this is often neglected in TIS analyses (Binz and Truffer, 2017; Rohe, 2021). Ultimately, the TIS framework allows researchers to identify system level factors that enable, accelerate, or block the development and diffusion of novel products (Weber and Rohracher, 2012; Wieczorek and Hekkert, 2012).

The speed and success of a product's roll-out is also influenced by multiple contextual conditions (Bergek et al., 2015) which affect functional dynamics across the TIS' value chain (Stephan et al., 2017; Rohe, 2020). For instance, the sectoral context represents companies, infrastructures, and (im)material assets that can be leveraged for the TIS. Yet, misalignments between the TIS and its sectoral context – such as land-use conflicts between food and energy production – can impede technological diffusion (Wirth et al., 2013; Markard et al., 2016). Also important is the political context, which is shaped by the regulatory environment, public funding, targets laid out in governmental plans, or political action from civil society stakeholders (Rohe and Chlebna, 2021; van der Loos et al., 2021). In this vein, research on mission-oriented innovation systems emphasizes that proactive and guiding state policies are needed to solve complex and interdisciplinary sustainability challenges (Mazzucato, 2018; Hekkert et al., 2020). In section 4, we specify the relevant context for the TIS in our analysis.

While the creation of new knowledge and the invention and improvement of new products is important in TIS studies, the framework also allows for the analysis of market dynamics, the role of demand, and the diffusion of alternatives (Martin, 2016; Rohe and Mattes, 2022). Binz and Truffer (2017) refer to this as product valuation and hold that characteristics of the product itself shape the complexity and spatiality of the valuation process and which actors are involved in it. Food retail is generally characterized by standardized valuation: Market formation is driven by economies of scale and price-based competition and legitimation shaped by relatively coherent user preferences across institutional contexts (Allaire and Wolf, 2004; Vivero-Pol, 2017). Contrary to standardized valuation stands customized valuation for complex products, which need to be adapted to local contexts and niche markets and for which consumer expectations or product standards do not (yet) exist (Binz and Truffer, 2017). Further product-related variables that impact diffusion rates include the product's relative advantage, its perceptibility, and trialability (Fichter and Clausen, 2021).

Overall, TIS share many characteristics with socio-technical niches, where non-competitive innovations exist in small and delineated protective spaces, such as dedicated research programs, communities of users, or regional settings. In transition studies, TIS is viewed as a viable framework for analyzing conditions that nurture niche innovations from an interactive and dynamic perspective (Bergek et al., 2008; Markard and Truffer, 2008). From the niche literature, two mechanisms can be derived that allow TIS to scale up widely: On the one hand, fit-and-conform dynamics, where TIS structures change and align themselves to dominant contextual structures. On the other hand, stretch-and-transform scenarios in which TIS actors work on adjusting contextual institutions to suit the innovation (Smith and Raven, 2012). Especially value-driven and bottom-up initiatives are often faced with tensions regarding the approach they should pursue. These initiatives may lose control about the desired approach in the innovation and scaling process and the initial ambition becomes lost as more and more actors adopt the innovation (Hermans et al., 2016). Sievers-Glotzbach and Tschersich (2019, p. 106369) urge these initiatives to "resist the tendency of the regime to absorb and reinterpret individual elements of niches without changing the regime's fundamental functional principles" as this "result[s] in narrow notions of sustainability that contradict initial intentions of niche actors […] and reinforces the status-quo".

2.2. TIS and previous research on agri-food transitions

Research addressing sustainability transitions in agriculture and food is rapidly emerging (El Bilali, 2019; Hebinck et al., 2021). Although applications of systems approaches (Vanloqueren and Baret, 2008) and the TIS framework have been limited (El Bilali, 2019), some contributions make valuable additions to TIS in research on agri-food transitions. Some researchers even specifically speak of agricultural innovation systems (Schiller et al., 2020).

First, an active role of consumers and the interplay between supply and demand is crucial in agri-food transitions (Long et al., 2016). Randelli and Rocchi (2017) for example draw attention to this in their case of alternative food networks, where feedback mechanisms from the demand side, in the form of active consumers sharing their experiences, recommendations, and warnings, influence the formation and diffusion of knowledge about food products. These feedback mechanisms might have negative consequences for the TIS and lead to vicious cycles. Schiller et al. (2020) comprehensively describe how deficiency in financial resources by farmers in the TIS for agroecology in Nicaragua leads to a lack of consumer knowledge about agroecology, which in turn decreases demand for these agricultural products, impeding market formation and, as a consequence, diminishing financial resources for the TIS actors. Contrarily, Tziva et al. (2020) describe a virtuous cycle in the TIS for plant-based meat substitutes. This cycle is initiated by consumers who perceive higher prices for these alternative products as legitimate and are willing to pay, because personal health benefits are associated with eating meat substitutes. Furthermore, the emerging debate about mission-oriented policies in agriculture recognizes "worried citizens and consumers" as triggers for the set-up of transformative policies (Klerkx and Begemann, 2020, p. 3).

Second, the normative criteria along which alternative agricultural products are evaluated are crucial for their diffusion success. As mentioned above, food retail is characterized by a standardized valuation, where food is considered a commodity. Food commodities are "unbranded or undifferentiated items from multiple producers, such as staple grain, beef meat or fresh vegetables […] largely valued by price [… and other] tradable features, namely durability, external beauty and the standardization of naturally-diverse food products" (Vivero-Pol, 2017, p. 445). Actors from the agricultural sector who share this "hegemonic" perception of food as a commodity tend to favor incremental reforms of the system, while those actors who evaluate food as a commons and recognize its further values (e.g. as a cultural determinant or essential ingredient for a healthy life) favor more substantial system transformations (Vivero-Pol, 2017). So-called norm entrepreneurs, for example vegetarians or environmental NGOs challenging the appropriateness of meat consumption, have been shown to induce a shift away from standardized valuation. Often driven by ethical considerations, these norm entrepreneurs facilitate knowledge diffusion among consumers to convince others of the norms surrounding a product. This ultimately strengthens the legitimacy of alternative food products (Tziva et al., 2020).

Third, considering the 'length' of the value chain, it is important to not just analyze processes surrounding production and consumption, but also processing, distribution, retail, storage, and waste disposal (Ericksen, 2008; Horton et al., 2017). The type of value chain as well as the coordination among its actors can influence support for food innovation (Morel et al., 2020). For instance, in the case of small organic agroecological and organic agri-food systems in Chile, Gaitán-Cremaschi et al. (2020) describe how value chains rely on informal coordination mechanisms such as transparency, frequent and direct producer-consumer relations, and trust. However, these tight-knit value chains also reinforce limited market volumes and “a lack of ubiquitous outlets”. While explicit TIS studies in the agricultural sector often focus on farming technologies at the core of a value chain (Eastwood et al., 2017), the approach also provides a perspective on the complex and interlinked downstream value chain segments. This is also important considering the dynamic, continuously evolving nature of products (Randelli and Rocchi, 2017).

Our paper aims to underpin the pertinence of TIS analyses to agri-food systems on the example of organically bred vegetable varieties and their potential to transcend a niche context and enter conventional food retail. The current research described above demonstrates the applicability of the TIS framework to less-technology focused sectors[1], the importance of considering interactions between production and consumption sides, as well as valuation processes along the entire value chain. Before summarizing the analytical framework specifically adapted to our case in Section 4, we now introduce the empirical object and context of our investigation.

3. Organic breeding and the seed sector

Seeds are the basic ingredients of agricultural systems. However, current developments in the industry pose several sustainability-related environmental, social, and economic challenges (Clapp, 2021). In the context of ongoing privatization and commercialization of seeds through the extensive use of intellectual property rights such as patents, the global market is largely controlled by three companies with a market share of over 60 % (Bonny, 2017; Clapp, 2021). Their primary business model is one of economic optimization: Selling a narrow set of genetically uniform varieties which promise high yields. However, resistances against pests and weeds are often not sufficiently developed. Thus, high yields for these varieties depend on optimal growing conditions, plant protection products, and mineral fertilizers (Messmer, 2014; Horneburg, 2016). This creates economic dependencies for farmers, social injustices, and power imbalances (Bonny, 2017). Furthermore, supply chains are less resilient towards external shocks, as can be observed in the food crisis caused in part by extreme peaks in fertilizer prices as a result of the invasion in Ukraine (New York Times, 2022).

Conventional varieties are usually cultivated from hybrid seeds. Thus, they cannot be reproduced with the same characteristics, and farmers hence cannot harvest new seeds. This business model also leads to negative environmental outcomes (Rasmussen et al., 2018) and genetic erosion (van de Wouw et al., 2010) of plant varieties, continuously reducing the level of agrobiodiversity.

3.1. Tackling the sustainability challenges in vegetable farming

While organic agriculture provides an alternative to the highly input dependent industrialized agriculture, it is estimated that about 95 % of organic agriculture is still based on varieties bred for conventional farming (Lammerts van Bueren et al., 2011)[2]. Legally, seeds are considered as organic and can therefore be used in organic agriculture if they are propagated under organic conditions for at least one generation, or, for perennial crops, for two growing seasons (Art. 12 lit. i, European Organic Regulation 834/2007). However, since these varieties have been developed under the conditions and according to the needs of conventional agriculture, they are often not well suited to the low input conditions of organic farming (Lammerts van Bueren et al., 2011).[3] Contrarily, all steps in the organic breeding process (cultivation, selection, and propagation) take place under organic conditions and are adapted to the specific requirements in organic farming. The developed vegetables are then called organically bred varieties. In organic breeding, methods or biotechnological means are refused that limit the natural reproductive ability of plants (e.g. terminator technologies), or interfere with the genome and cell as impartible entities (Lammerts van Bueren, 2010).

Additionally, organic breeding applies social principles of organic farming such as participation and transparency, thereby adding a process-oriented dimension that reaches beyond material product-characteristics. In this context, the development of organically bred vegetable varieties is usually associated with commons-based approaches, so-called Seed Commons (IFOAM, 2014; Sievers-Glotzbach et al., 2020).[4] They explicitly challenge the (conventional) property regime described above. Those initiatives and their approaches are diverse and reach from seed sharing networks or communal seed banks to organic or participatory breeding initiatives (Sievers-Glotzbach et al., 2020). Seed Commons provide a particularly interesting case in light of innovation processes. As outlined in

[1] Food processing, packaging, and conventional agricultural practices can be described as low and medium technology industries. They are characterized by low investments in R&D and incremental changes in processes, organizational set-ups, and marketing. However, the breeding of new plant varieties itself is a knowledge-intensive process with similarities to bio-chemical or life-science industries, which rely on high-tech, science and technology driven innovations (Randelli and Rocchi, 2017; Trott and Simms, 2017).

[2] Comprehensive and up to date numbers on market shares in this segment are not available. For specific crops, there are some more recent estimates that confirm continuous low diffusion rates of organically bred vegetable varieties. For instance, Orsini et al. (2019, p. 38) report for organic carrots in Europe that about “90 % of the seed is from conventionally bred and conventionally multiplied cultivars, 9 % of organically multiplied and only 1 % of organically bred cultivars”.

[3] Low input farming systems such as organic agriculture aim to minimize or totally restrict the usage of external inputs (e.g. pesticides, chemical-synthetic fertilizers) by optimizing the usage of internal natural resources and concurrent management practices (e.g. cover crops, crop rotations) (Migliorini and Wezel, 2017).

[4] In Germany, organically bred vegetable varieties are almost always bred and produced by commons-based initiatives. Empirically, both approaches are inseparable (in this country), but they pose two distinct theoretical levels. We are mostly interested in organically bred vegetable varieties because this theoretical level is more tangible in empirical praxis. However, we also address commons-based principles in the empirical analysis if they directly relate to diffusion barriers of organically bred vegetable varieties.

Sievers-Glotzbach et al. (2020), such initiatives take collective responsibility for preserving plant genetic diversity and developing new plant varieties, recognizing the historic and present contribution of farmers to developing the cultivated plants. They refrain from the use of private property rights such as patents or variety protection on seeds or biotechnological means that could limit the natural reproducibility of plants. Seed Commons thus reject the usage of those instruments for protecting and commercializing innovations and rather adopt alternative measures such as collective ownership (ibid.). Moreover, breeding is organized in an open innovation process, where resources are managed collectively in polycentric structures (ibid.). These structures embody multiple, independent centers of autonomous decision-making that take collective decisions on central values or goals. Additionally, participants share formal and informal knowledge on their seeds and breeding processes within and beyond the initiatives (ibid.).

Fig. 1 summarizes the three distinct characteristics that are fulfilled by the organically bred vegetable varieties we investigate in this paper. Their crops are cultivated under organic farming conditions, their seeds have been propagated under organic farming conditions, and the varieties have been bred for the conditions of organic farming, often following Commons principles.

3.2. Research focus: zooming into the German seed value chain

In this paper, we focus on Germany. With its geographical and institutional context, it provides a suitable and interesting empirical case for three reasons. First, it is an industrialized country with a highly regulated and formalized seed sector (Tschersich, 2021) and thus representative of similar countries in the Global North. Second, a range of organic breeding initiatives have emerged that challenge the current regulative system (ibid.). Third, the food market in Germany is a highly developed demand market where retailer as well as consumer awareness is a key factor (Nuijten et al., 2018). We further limit our research to fresh produce and neglect processed food as the evolving value chain would prove too complex for a contingent analysis. Furthermore, previous studies find that the longer the value chains are, the less likely it is for farmers to use organic seeds (Orsini et al., 2020b; Winter et al., 2021). This suggests that organically bred varieties would face even more difficulties in long value chains for processed food.

The seed system as we understand it does not stop at farmers as buyers of seeds. Instead, our perspective reaches from breeding to consumption (and back), including key actors and institutions. A simplified value chain (Fig. 2) shows relevant actors and value creation stages. Breeding, seed propagation, and crop cultivation (colored in blue) form the TIS (as will be discussed in Section 4). We do not differentiate between different vegetables (for instance cucumbers, broccoli, carrots), because breeders and farmers usually work with multiple types of vegetables, as do buying agents in retail who are usually responsible for the entire vegetable shelf. The curved arrows in Fig. 2 represent the 'non-linearity' of the value chain. Hence, we recognize that actors and activities interact across value chain segments. We briefly introduce each segment in the following.

To breed new varieties, parental varieties are retrieved from conservation sources like (inter-)national and corporate gene banks or (in-)formal sharing among farms and conservation initiatives. Afterwards, novel varieties must be registered according to criteria of distinctiveness, uniformity, and stability (DUS criteria) at the German Plant Variety Office. At this point, it is also possible to apply for variety protection to ensure intellectual property rights. Actors in Seed Commons waive that option as described above. Seed retailers buy or lease new varieties from breeders and organize seed multiplication and sales to farmers. Activities at this stage include marketing, customer service, packaging, transport, and logistics. Farmers choose seeds that fit their (local) requirements and farming approach and cultivate vegetables from them. They then sell their produce through one or several retail channels.

Food retailers[5] buy vegetables directly from farmers or through wholesalers. German conventional food retail is in a strong bargaining position because of market concentrations and farmers' time constraints to sell their perishable produce. In 2019, German food retail had a turnover of 253 billion € including non-food. Five corporate groups (Edeka, Rewe, Schwarz, Aldi, Metro) combine about 75 % of market shares, of which the Edeka group has the highest share with about 25 % (DBV, 2021). Consumers buy food for their everyday consumption at retailers and mostly pick vegetables according to appearance and visual traits (Revoredo-Giha and Renwick, 2012). In general, consumers are unaware of which variety they buy (Nuijten et al., 2018).

4. Towards an analytical framework

In the following, we summarize our TIS approach to analyze the systemic process of product diffusion (cf. Section 2) in the empirical context of organically bred vegetable varieties (cf. Section 3). We apply the framework to capture the barriers for the wide-scale diffusion of these varieties.

As described in Section 2.1, actors, networks, and institutions are the foundational structural elements of any TIS. The relevant actors in the system for organically bred vegetable varieties are depicted in the value chain (Fig. 2). The interactions and relations between these organizations and individuals build the network structure of the TIS. Relating to our discussion in Section 2.2, we pay specific attention to how supply-demand interactions and coordination mechanisms across the value chain influence barriers for the product's diffusion. Institutions structuring the analyzed TIS include regulations such as variety registrations requirements (Desclaux and Nolot, 2014), but also shared goals and values in the community of breeders and farmers. Finally, as the characteristics of a product also influence its development and diffusion, we add this structural feature to our TIS. Also relating to Section 2.2, we pay

[5] We differentiate between conventional and organic food retail. Whereas conventional food retail may offer organic products as part of a larger product portfolio, organic food retail encompasses all retailers that solely sell organic products. Supermarkets (large shops with a large product portfolio) and grocery stores (generally smaller portfolio) are subtypes of conventional food retailers (Han et al., 2012) that we focus on in our paper.

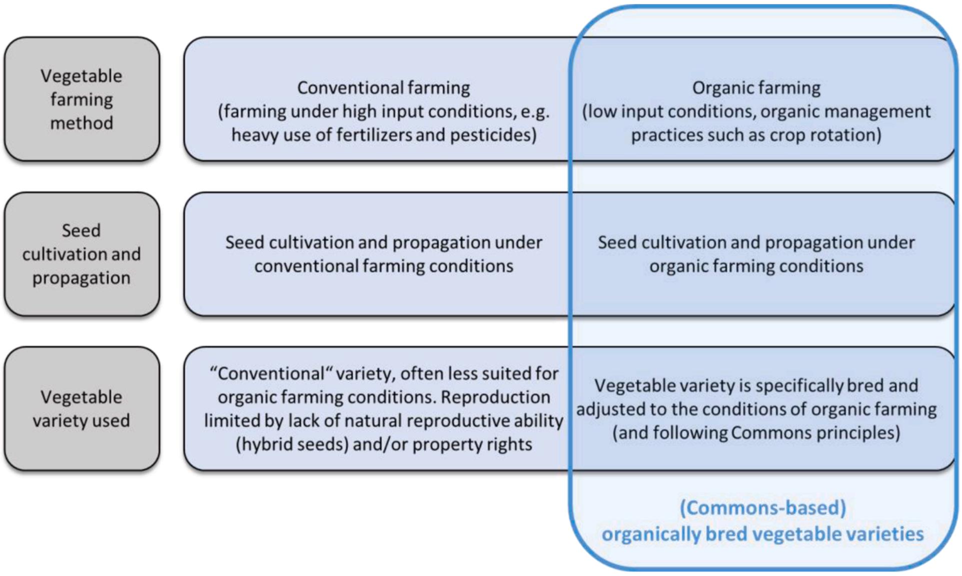

Fig. 1. Conceptualization of (commons-based) and organically bred vegetable varieties (own figure).

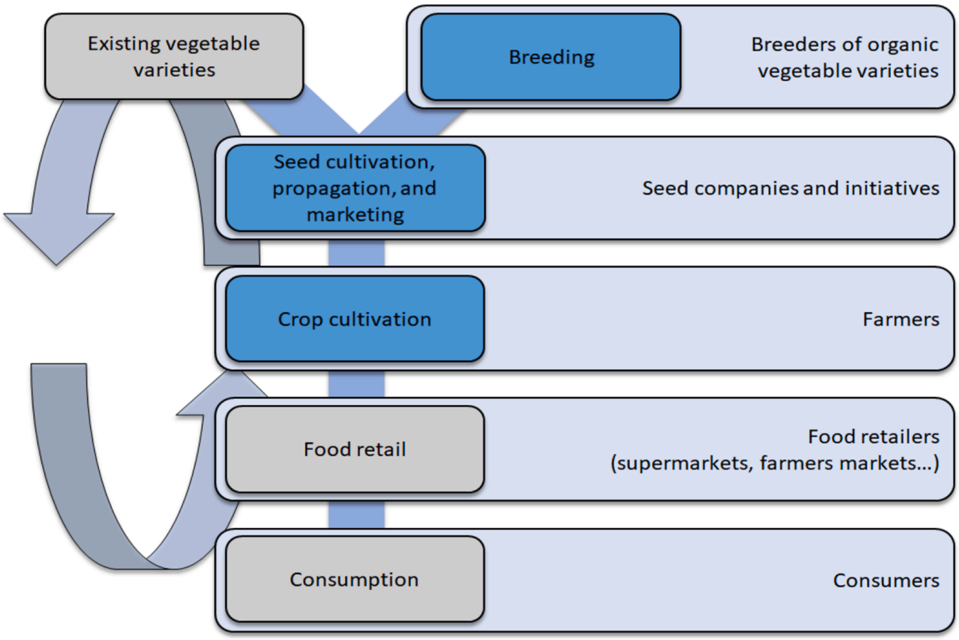

Fig. 2. The simplified value chain for organically bred and commons-based vegetable varieties (own figure).

attention to how the interplay of institutions and product characteristics shapes the valuation mode of the analyzed vegetables and how this might pose barriers to their diffusion.

Regarding the context of the TIS, four environments are influential in the diffusion of new products in the agri-food sector: Business, policy, users, and wider publics and culture (Mylan et al., 2019). We focus on the business environment of conventional food retailers and the barriers for the large-scale diffusion of organically bred vegetable varieties that persist in this context. The TIS is also directly embedded into other business environments, such as farmers markets or businesses that sell vegetable boxes directly to consumers. But

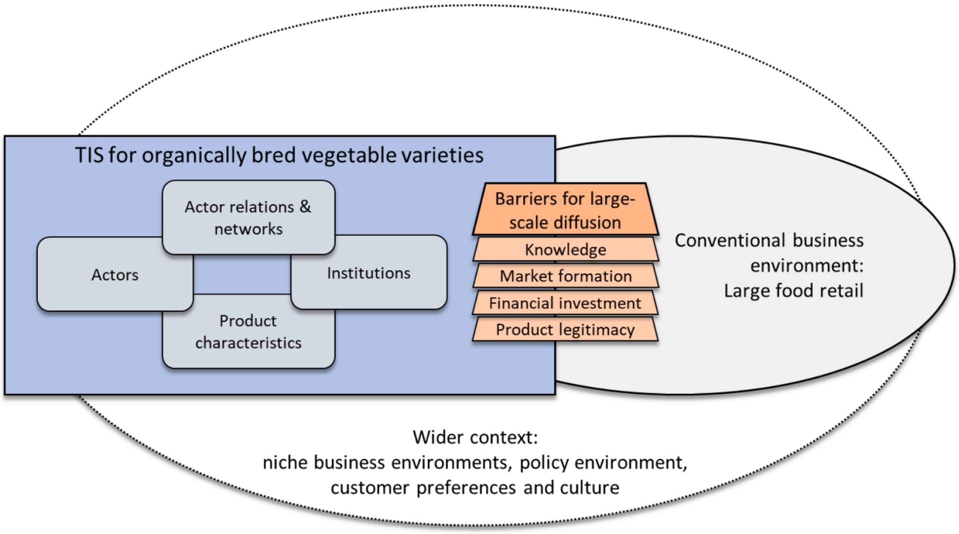

Fig. 3. Framework for analyzing barriers for the wide-scale diffusion of organically bred vegetable varieties (own figure).

since these distribution channels have a low market share (DBV, 2021), we instead analyze the actions and perceptions of conventional food retailers, who are powerful actors with immense buying power. Other environments form the wider context that both the TIS and conventional food retailers are embedded in (Deuten et al., 1997; Mylan et al., 2019):[6]

- Customer preferences and culture: As cultural norms and customer expectations are deeply intertwined in the food sector and shape how food products are evaluated (cf. Section 2), we combine these two product environments. This analytical category covers broader market and customer demand trends that supermarkets need to cater to. Examples include general price expectations, overarching trends like growing health concerns, or strategic campaigns from norm-entrepreneurs that seek to delegitimize established products such as processed meat through shocking graphic images or other, less controversial tactics (Enthoven and Thelken, 2022).
- Policy environment: Governmental regulations and public subsidies influence the production, marketing, and consumption of agri-food systems in general. Examples include subsidies for farming or public labels like the EU organic logo. Such labels can help bridge information asymmetries and guarantee sustainability-related attributes of products which are otherwise not verifiable for consumers during purchase or consumption (Kliem and Wolter, 2022).

Fig. 3 shows the resulting framework for our subsequent analysis. We hold that barriers for the wide-scale diffusion of the varieties can be located within the value chain of the TIS itself, within the business environment of large-scale food retailers and their wider context, and/or in the systemic relation and interplay between these elements. We use the resources knowledge, market formation, financial investment, and product legitimacy as analytical categories to systematize the kind of barriers that exist. Persisting barriers in any resource dimension, or existing misalignments across multiple ones (vicious cycles), might impede the uptake of the entire TIS (Hacker and Binz, 2021).

5. Empirical methods

For the empirical identification of diffusion barriers, we provide a qualitative case study of the TIS for organically bred vegetable varieties in Germany. This approach is commonly used in transition studies (Hansmeier et al., 2021), as case studies are well suited for understanding the complex and systemic processes driving or impeding socio-technical change (Sovacool et al., 2018). Since little research has yet been conducted concerning the diffusion of organically bred varieties, theory building and hence answering 'why' questions is required (Yin, 2018), for instance why these varieties remain a niche phenomenon.

A total of 22 semi-structured expert interviews are our central source of evidence. Interviews were carried out in German and mostly face-to-face. Subsequent quotes from the interviews were translated by the authors. In 2018 and 2019, representatives of a leading German organic breeding initiative and some of their associated breeders were interviewed. All of them own or work on commercial organic farms, which are spread decentrally throughout Germany (with a slight overhang to the geographical west of Germany). The initiative has been active as a working group since the mid-1980s and became a registered association in the mid-

[6] We recognize that the ecological context might also influence the diffusion (and availability) of new vegetable varieties indirectly (Nuijten et al. 2018). This includes for example regional soil conditions, regular crop diseases, or climate change impacts on agriculture. Since we focus especially on the diffusion of fresh produce, we largely neglect the ecological context.

1990s. Under this umbrella, the efforts of breeders and cultivators from around 30 farms are coordinated. The initiative carries out breeding for almost all vegetables, ranging from salad and tomato, over beetroot and broccoli, to carrots, cabbage, and cale. Around 130 new vegetable varieties have already been developed and registered. In 2022, we carried out additional interviews with intermediary distributors and buying agents from large food retailers in the German north to include the perspective of these crucial stakeholders from the conventional business environment into the analysis (cf. to Annex 1 for a detailed interview list).

To analyze the interviews, we conducted a qualitative content analysis of the transcribed material with the use of the MAXQDA software. Specifically, we followed a categorical deductive application proposed by Mayring (2014): We started by deducting a system of categories and subcategories based on our theoretical framework and research question. On a set of sample interviews, we then tested the category system and set up and refined definitions, anchor examples, and coding rules for each category. Each interview was analyzed and discussed by multiple researchers from our group to increase inter-coder reliability. The final category system, which was then applied to all interviews, can be found in Annex 2. In an internal workshop, we then clustered the identified diffusion barriers according to structural components and TIS resources and identified interrelations and vicious cycles.

6. Results: Barriers for the diffusion of organically bred vegetable varieties

We now present the results of our empirical study. Table 1 summarizes the empirically identified barriers for large-scale diffusion of organically bred vegetable varieties in conventional food retail. They are categorized according to TIS resources and to the actors, networks, institutions, and product characteristics of the TIS and/or the context where barriers are most prevalent. In each following section, we analyze how structural TIS elements and contextual factors contribute to diffusion barriers related to knowledge, market formation, financial investments, and product legitimacy.

6.1. Knowledge-related barriers

The most fundamental knowledge-related barrier to the diffusion of organically bred varieties is that relevant actors in the vegetable value chain have never heard of or do not understand the concept of organically bred vegetable varieties (I_retail buyer02).

> *"I tried to do research on the subject [before the interview] and found very little... This is incredible because you usually find anything on the internet! [...] You do not hear much about these organically bred vegetable varieties and if you know so little about it, the farmers are just not interested in it."*

(I_retail buyer01)

Interaction between the organic breeding community and conventional food retailers is also rare and arduous (I_breeder08). As collective awareness is limited, farmers must constantly (re)establish contacts to and attention of food retailers to market their produce, which demands time and energy (I_breeder03). This in turn restricts knowledge flows about organically bred varieties and growing conditions across the value chain (I_retail buyer01). Frequent face-to-face interactions and trust among actors from the TIS and the conventional retail system are therefore rare, which was exacerbated by cancelled farm visits due to the pandemic. Informal value chain arrangements are even more challenging to establish for imported vegetable varieties from places like Spain or Italy, where wholesalers function as additional intermediaries (I_retail buyer03).

This lack of knowledge applies not only to farmers and procurement managers, but also to customers. For most vegetables (the exceptions being potatoes or tomatoes), customers do not realize the existence of different varieties. Knowledge gaps are not surprising, as media coverage on this topic is scarce. TIS actors also lack a coherent and coordinated communication concept.[7]

> *"I think many customers are indeed looking to buy organic vegetables [in general], but not in the sense of organically bred [varieties]. There might be few people who shop in the health food store, who really deal with this issue."*

(I_retail buyer02)

Breeding initiatives themselves also face knowledge-related challenges. This primarily concerns the development of novel organically bred varieties: The physical and legal availability of vegetable varieties for organic breeding is diminishing, for instance because powerful conventional companies hold property rights on potentially suited input varieties. Knowledge on the characteristics of non-conventional varieties is also often limited and/or not easily or digitally accessible (I_breeder09).

The organic breeding process is not always entirely systematic and scientific (I_breeder03, I_breeder07). In part, this is caused by the lack of personal and financial resources (cf. Section 6.3) and "*deficits [in scientific] knowledge and skills*" (I_breeder05). However, it is also caused by the norms, values, and goals shared among much of the breeding community. Many breeders follow an anthroposophical philosophy[8] which makes their breeding approach and method less objective (I_breeder02).

[7] Efforts are made regularly by organic breeding associations to raise awareness with their core customers, for example with the *'Kernkraft – ja bitte!'* campaign in collaboration with two German organic supermarket chains. However, coverage on these issues has not reached a wider consumer range.

[8] Anthroposophy is a spiritual and esoteric world view adopted by parts of the stricter organic movement. It is especially popular in German-speaking parts of Europe. Anthroposophic concepts and methods in the agricultural sector can be subsumed as 'biodynamic agriculture'. The organic association *Demeter* is the largest certification organization in this sector.

Table 1
Empirically identified barriers for the diffusion of organically bred vegetable varieties (own table).

	Knowledge	Markets	Investments	Legitimacy
Actors	• Organic breeders draw on diverse types of knowledge; not all adhering to (established) scientific methods and standards, but some based on intangible experiences. Modern (bio-technical, genome-based) breeding methods are rejected for ethical reasons • Stakeholders do not know or understand the concept of organically bred varieties	• Cultivators and farmers of organically bred varieties do not usually aim to market their produce to conventional food retailers, but rather to organic supermarkets	• Companies and initiatives in the organically bred seed TIS generally have few and limited financial and human resources	• Conventional supermarkets have other sustainability issues on their problem agenda (e.g. packaging)
Networks	• Little knowledge exchange and coordinated interaction between breeding community, vegetable producers, and buying experts from supermarkets	• Difficult to establish long-term and reliable cooperation between farmers and large buyers to remunerate breeding efforts	• Networking with financiers difficult, as organic breeding is not a known sustainability topic and complex to explain • Established companies reluctant to finance additional costs for organically bred varieties	• Additional value of organically bred varieties is lost and/or difficult to communicate across the value chain
Institutions	• Widespread norms and values in the breeding community (e.g. anthroposophy) result in use of rather subjective breeding methods which are not (always) backed scientifically • Esoteric world view within breeding community inhibits a formulation of values compatible to a wider range of (sustainability) actors	• Breeding goals focus rather on ecological resilience, nutritional and (subjective) taste quality, and sustainability than on economic potential (divergent market logics) • Economization and growth of organic vegetable sector in general decreases margins; less room for price mark-up on organically bred varieties • Guidelines and regulations for variety approval and marketing are too strict and do not match the needs of organic breeders	• As the commons-based breeding community rejects variety protection, they cannot generate income from this revenue stream • Economic survival in organic breeding community depends on scarce donations and public funding (e.g. for R&D)	• Lack of public labels that guarantee 'organically bred variety' as a product characteristic • Entire sector views product characteristics of hybrid varieties as standard/norm • Generally low appreciation for the value of (organic) food from customers; price as the de facto most important buying criteria
Product Characteristics	• Diminishing genetic variety (availability of old breeds) limits input for selection process • Established knowledge on characteristics of potential input varieties for breeding is difficult to access	• Low agricultural yields from organically bred varieties • High heterogeneity within organically bred varieties	• Using novel and more heterogeneous organically bred varieties is associated with increased (short-term) financial and economic risks for cultivators and farmers	• (Selection) characteristics of the organically bred varieties (e.g. resilience towards pest) do not match customer expectations (e.g. taste, appearance)

"And so I select plants not only from the point of view of 'which has the most grains', but also whether I respond positively to them or not."

(I_breeder02)

Indirectly, this knowledge base influences the (economic) diffusion potential of the organically bred varieties. Breeding methods do not aim to optimize yields, making these varieties less appealing to most farmers and food retailers and posing a competitive disadvantage vis-à-vis hybrid vegetables.

"Variety development is a creative activity, promoted by exchange and [...] hindered by overly strict specifications of profitability. If, [...] - as I learned in my former conventional company - every decision between two plots or two breeding lines must be based on what will maintain the profit [...], then this restrictive thinking hinders creativity. [...] Surprisingly, however, these companies are still creative and very successful."

(I_breeder16)

Yield potentials are directly related to market potentials in conventional food retail, as is discussed in the following section.

6.2. Market-related barriers

For the interviewed breeders, the main goal is the creation of varieties with ecological resilience and high (subjective) quality. Whether varieties cater to the standardized commodity logic of (conventional) farmers and customers is usually a secondary breeding target (I_breeder16), because "*profit expectations play a smaller role*" (I_breeder07).

"Take the example of cucumbers or outdoor tomatoes [...]. I do not just look at the suitability for commercial gardening. For instance, if I have extremely resistant lines, I continue them also. Even if I have to say, there are perhaps still too many with a bitter taste in it. Or no one grows outdoor tomatoes in our climate anyway. But if I have something that [is so resistant], then I have to maintain it. So that I stay as diverse as possible."

(I_breeder04)

This approach to breeding is mirrored in the characteristics of the organically bred vegetable varieties. As mentioned above, they generally have smaller yields – 80 to 90 % of what to expect from conventional hybrid breeds (I_breeder01, I_breeder03, I_breeder08). Furthermore, individual plants and their vegetables of the same organically bred variety show a greater heterogeneity – in taste or growth rate, for instance (I_breeder09). This also makes these breeds less attractive to conventional supermarkets, which demand stable and reliable delivery volumes (I_retail buyer02) and seed cultivators, who then carry greater risks (I_breeder05).

Paradoxically, a growing market share of organically farmed vegetables in conventional stores (which are largely bred conventionally) is making it more difficult for the TIS around organically bred vegetable varieties to diffuse. This results from "*extreme price pressures*" (I_breeder16) on the organic segment in general, which more and more competes directly with conventional vegetables to be bought by consumers. In this institutional context of economization, procurement managers feel that organically bred varieties with further mark-ups on prices would not be appealing (I_retail buyer02).

"[Larger retailers] now all want to play in the organic sector. At the same time, [the segment recently] no longer recorded double-digit growth for the first time [...]. Some buyers suddenly say, "We just have to concentrate on our day-to-day business now, let's not talk so much about non-hybrid seeds and stuff like that." [...] If economic circumstances are difficult, I have to secure my own livelihood before I go out on a limb and take new breeds of mine into production on my own farm, where there are more risks concerning harvest rates."

(I_breeder03)

Considering this business environment, many actors from the TIS do not even think of marketing (parts of) their produce to conventional food retailers and instead focus on direct distribution channels or target the premium segment of organic food retailers and health food stores (I_breeder03).

On the demand side, conventional retailers themselves could actively build awareness for organically bred varieties. However, introducing new products is a resource-intensive and long-term process. Therefore, introducing new organically bred products does not appear attractive to these powerful conventional food retailers and food processing companies in the current market environment (I_breeder03, I_breeder10). Proactive market formation via the demand side is thus limited.

"The important thing is the price, the taste, the quality, and the consistency of the item. If you have a vegetable that works well all year round, tastes good, and is relatively stable in price, we have won over the customer. Then, of course, the customer must learn to buy the item, which takes a lot of effort, usually money, and consistency."

(I_retail buyer02)

Finally, guidelines and regulations for required variety recognition on EU level (DUS criteria) and marketing limit diffusion potentials (I_breeder03). Fulfilling the requirement of high uniformity of individual plants within a variety is particularly challenging for organically bred varieties, and can hence present an important barrier for distributing these seeds on the market (Tschersich, 2021). Registration and field growing trials also require significant time and financial resources. Alternatively, varieties can be registered in a simplified procedure as amateur varieties. Yet, these may only be sold in small packaging and along with the denomination of amateur varieties, which significantly impairs marketing to commercial farmers (Tschersich, 2021).

6.3. Investment-related barriers

The market-related barriers show that the business model of most actors in the TIS for organically bred vegetable varieties is not economically viable in the dominant market environment and hence companies and initiatives have little financial resources. Restraints in terms of staff are associated with people – who are motivated by non-economic values – often working overtime for a small pay (I_breeder07, I_breeder17). These shortages in human resources, in turn, limit the ability of actors to strategically drive forward diffusion (I_breeder01) or attract public funding.

> *"On our farm, there is actually a half-time employer writing applications to foundations so that the farm can continue to run. This is simply a huge problem because this work cannot be used for breeding."*
>
> (I_breeder06)

Such funding from the public sector, non-profit foundations, or private donors is the most relevant source of income for organic breeding initiatives. From the perspective of these initiatives, funding is not at an appropriate level (I_breeder14), compared to the public goods character, ecological value, and long-term assurance of organic agriculture. Particularly, financial resources for public research on breeding methods for new varieties are scarce, which presents a challenge also due to the long-term character of breeding (I_breeder01). Creating income from variety protection is not an option either, as such protection regulations stand against the commons-based norms of the breeding community. Organic breeders therefore join calls for a sort of basic income from the state as one solution to dissolve financial dependencies (I_breeder09, I_breeder17). However, it does not appear that this option will be politically enforced in Germany in the (near) future (I_breeder04).

Established companies from conventional breeding possess far more financial resources, which could significantly drive forward the development and diffusion of organically bred varieties. However, these companies currently *"do not jump at growing anything extra for organic agriculture"* (I_breeder03) and many TIS actors even fear such a scenario because of their fundamentally different values and resources for competition (I_breeder07). As alluded to in Section 6.2, even food processors and buyers that already use the varieties are reluctant to proactively finance additional costs and thus contribute resources to the long-term growth of the TIS (I_breeder03). Again, due to the complexity of organic breeding and its invisibility as a sustainability topic, the communication and interaction with potential financiers proves difficult. Also, cultivators and farmers are exposed to financial risks when using novel and heterogenous organically bred varieties.

> *"And the question is whether you get paid for the work you invest. And particularly cultivators bear this risk. Threshold values exist of the vitality in terms of quality, which is defined for each variety. And if you are one, two percent below, it's possible that the whole work was for nothing, that it's not usable. And this does not happen infrequently."*
>
> (I_breeder05)

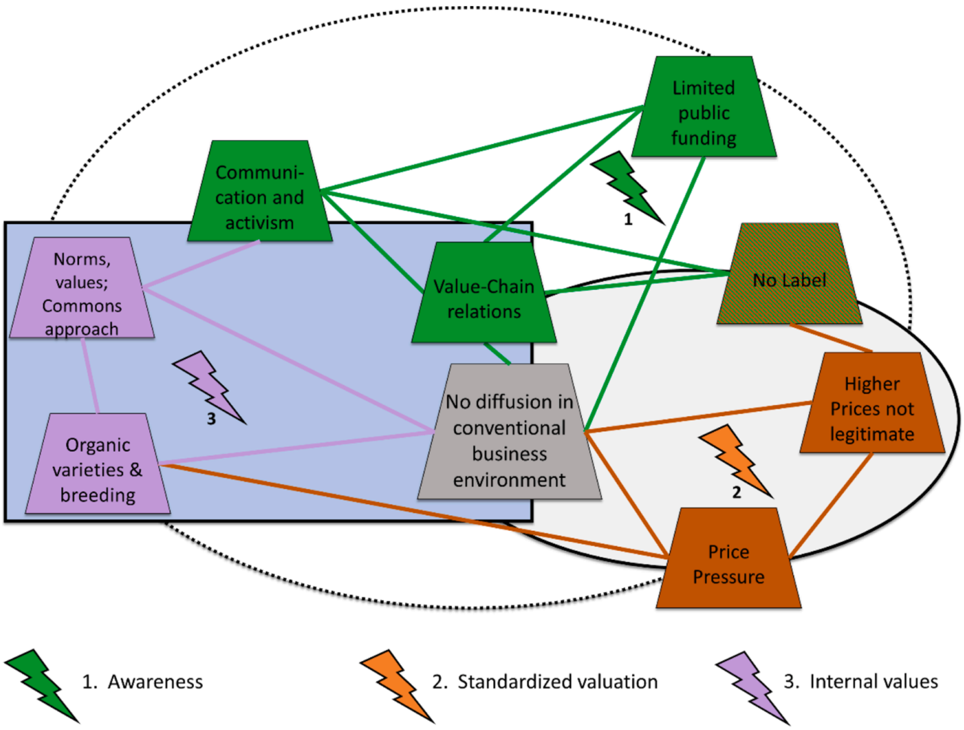

Fig. 4. Vicious cycles of barriers in the diffusion of organically bred vegetable varieties (own figure).

Customers, retailers, or farmers co-financing breeding efforts by buying produce with dedicated labels could be an option, which would redistribute a share of the generated income to the breeding community (I_breeder09, I_breeder10). These models are framed as *Züchter-Cent* (Breeder-Cent) or *Saatgutfonds* (Seed-Fund). Whether such models work also depends on the evaluation, acceptance, and willingness-to-pay of customers and is analyzed in more detail in the following section.

6.4. Legitimacy-related barriers

To receive a positive evaluation from key stakeholders, especially consumers, organically bred vegetable varieties must be recognizable as such. Currently, they lack visibility in comparison to organic, fair-trade, or regional produce which all are marked by widely recognized labels and rank higher in customer's sustainability concerns (Kliem and Wolter, 2022). There is no label for organically bred and cultivated (vegetable) varieties. Hence, information about the added-value and ecologically and socially beneficial product characteristics are lost throughout the value chain (cf. to Section 6.1). This de-legitimizes higher consumer prices for these vegetables.

On a broader scale, TIS actors lament that there is too little appreciation of the value of vegetables and food in general, and that customers are often unwilling to pay the appropriate price for food. Most consumers still rank price above all other attributes.

> *"This is not a question of breeding, but a societal question. There needs to be a paradigm change. If German consumers only invest less than 10 % [of their income] into food products, more appreciation of food cannot evolve. This is solely a matter of price. [...]"*
>
> (I_breeder09)

Different, partly divergent preferences and values along the value chain are a recurring topic. Product characteristics such as diversity or resilience, which are vital in the breeding community, are not compatible with the preferences of most customers, who look for tasteful vegetables with a flawless appearance (I_breeder09). Most consumers seem insusceptible to value other "food dimensions" of the organically bred varieties (Vivero-Pol, 2017).

The additional value of organically bred vegetable varieties is difficult to communicate across the value chain and identified as one of the biggest challenges (I_breeder09, I_breeder10). The importance of breeding tends to fade into the background (I_breeder09). If comprehensive communication was successful and all actors understood the challenges (e.g. lower yields, heterogeneity) and value (e.g. contribution to a healthy ecosystem) of organic breeding, this could legitimize higher prices. However, this necessary paradigm shift (see above) is difficult to induce.

In contrast to organically bred varieties, product characteristics of hybrid varieties are seen as standard by the entire sector and taken for granted. This especially concerns farmers: "*You do not say that open-pollinating varieties are the standard. [...] No, hybrid varieties are 100 % and everything else is below that*" (I_breeder10). Economic performance is of major importance, and this is, in the existing agri-food system, only possible with high-yielding and uniform varieties. Besides, for conventional food retail it is crucial that farmers deliver a specified, constant, and high quantity of vegetables because retail wants to sell as many product units as possible.

> *"Therefore, conventional fruit and vegetable varieties are popular among us. They are always available, fast to reorder, and processes and guidelines are not as complicated as for organic products"*
>
> (I_retail buyer01).

Nevertheless, rising awareness towards ecological challenges can be observed from consumers and value chain actors. This cultural shift might over time contribute to legitimizing the TIS. However, while food retailers increasingly introduce sustainability units in their organizations, they are currently tackling other issues (e.g. food packaging or animal welfare) and do not have organic breeding on their agenda (I_retail buyer02). Furthermore, potential norm-entrepreneurs like environmental activist groups do not focus their strategic efforts and communication campaigns on the topic.

7. Discussion

The previous section sheds light on the barriers for the diffusion of organically bred vegetable varieties, focusing on distinct resources. This section deducts overarching vicious cycles from the empirical analysis. Based on these interrelating vicious cycles, we discuss the wider contributions of the empirical case for the literature on TIS and transitions in the agricultural sector. Furthermore, we summarize some of the theoretical contributions and limitations of our study.

Fig. 4 summarizes the observed barriers on a schematic level and locates them within the TIS (blue square in the background), in the conventional business environment (smaller gray circle), or in the wider context (larger dotted circle). The links between the barriers indicate if one barrier leads to another or if they mutually influence each other. Based on these interrelations, three distinct clusters can be identified as reinforcing vicious cycles. All of them result in a shortage of resources that the TIS would need to diffuse in conventional business environments.

The first vicious cycle concerns the *lack of awareness* about organically bred vegetable varieties: Stakeholders – including buying agents at food retail stores or customers – do not hold a fundamental understanding of the benefits or even existence of these varieties. This prohibits value chain actors to engage more proactively with the TIS, be it farmers choosing to grow the varieties or retail stores and investors to proactively push new vegetable products on the market. TIS actors lack (financial resources to fund) a coherent marketing and communication strategy, and potential norm-entrepreneurs are focused on other sustainability issues in the agri-food sector. Thus, there is little public pressure to increase public funding for vegetable varieties specifically bred for organic farming, even though it might be warranted considering their social and ecological benefits (such as open knowledge sharing, resilience towards climate change, and an increase in agrobiodiversity). A recognized label conferring the characteristics and values of the organically bred varieties does not exist either. This vicious cycle is mostly applicable also to diffusion environments outside of conventional food retail.

The second vicious cycle is about the *standardized valuation* mode and (increasing) price pressures in conventional food retail. Organically bred vegetable varieties are currently not price-competitive compared to (the taken-for-granted standard of) varieties from conventional hybrid seeds. Without a label, it is even more challenging to legitimize higher prices to consumers and retailers. Furthermore, organically bred varieties do not align with uniform commodity standards that farmers and buying agents are often looking for.

The third vicious cycle therefore mirrors the second one and refers to the *internal values* of TIS actors. Because of their organic breeding goals, their lack of resources, and the philosophy held by some breeders, organically bred varieties are not as much geared towards yield optimization (even under organic farming conditions) as would be possible. Shortages in financial resources for breeders are further exacerbated by the commons-based 'business model' of waiving intellectual property rights. Existing state regulations also favor conventional breeding approaches over organic ones. As some values of the TIS actors are misaligned to the broader sustainability movement or potential norm-entrepreneurs lack awareness, organic breeders have few allies to support them in lobbying for changes in the dominant regulatory environment or for more public resources. Overall, a mismatch of norms and approaches to the valuation of food (the interplay of the second and third vicious cycle) deeply impedes the wide-scale market diffusion of organically bred vegetable varieties.

As a result of these conflicting value systems, diffusion in conventional retail would likely require fit-and-conform strategies aligning the system to dominant contextual structures and the standardized valuation in the food retail sector. However, most of the interviewed organic breeders and farmers do not seek to market their products to conventional food retailers and thus reject the business environment promising large-scale growth. They are also reluctant to cooperate with actors from the conventional regime of vegetable breeding, as this upscaling might result in 'losing control' and giving up on power over the currently decentral mode in which the breeding process is governed. In this regard, the commons-based breeding community with their deep value-orientation (not including economic growth) presents an interesting deviation from commonly held assumptions in the TIS literature that actors are generally interested in widely establishing, diffusing, and growing the technologies and products at the center of the TIS (Markard, 2020). Based on this finding, future TIS studies could systematically compare diffusion dynamics within TIS mostly driven by private, profit-oriented companies vis-à-vis those driven by public actors and/or commons-oriented initiatives.

While adhering to dominant institutional logics of growth and materialism could limit the transformation potential of the TIS, it nevertheless needs growth and diffusion, because actors consistently lament shortages in (financial and human) resources and investments. This is a typical challenge faced by grassroots and niche innovations in any innovation sector: "In order to win some of the mainstream over […], advocates will have to prove their worth on conventional terms of innovation policy; when ideally they wish to change those terms" (Smith et al., 2014, p. 123). Furthermore, organically bred varieties aspire to address and solve multiple sustainability-related challenges in agriculture. For this purpose, organically bred vegetable varieties need to be cultivated at a wider scale. From the point of the TIS for organically bred vegetable varieties, this should therefore be achieved through stretch-and-transform strategies and by tackling the vicious cycles of lacking awareness and standardized valuation. This adds a novel perspective to the innovation systems literature, which usually frames the process and dynamics of valuation as mostly determined by the complexity of a product and holds that the valuation of more established technologies often becomes more standardized over time (Binz and Truffer, 2017). Based on our study, we can transfer from agri-food studies (Vivero-Pol, 2017) to the TIS literature the insight that the mode of product valuation is dynamic, socially contested, and shaped by the underlying norms of both the TIS and context.

Another counter-intuitive observation from our analysis suggests that a growing organic market in general might even constrain the diffusion success of organically bred vegetable varieties in the short term and exacerbates price pressures in the vicious cycle of standardized valuation. This is because customers, activists, and other stakeholders currently focus on other sustainability-related challenges, such as reducing meat consumption or consuming organically grown vegetables. We hypothesize that certain baseline sustainability innovations must become clearly established and reach wide market shares first before more complex innovation of a 'higher-order sustainability' have a chance to diffuse. Analogous examples from the (widely analyzed) electricity sector could be technologies and business models like prosuming, contracts for certified 'regional electricity', or sector coupling technologies such as hydrogen. These have existed for decades but might only pick up growth once the transition has progressed enough so that core technologies (PV-modules, wind power) have diffused sufficiently and companies, regulators, and customers turn their attention to other, more complex TIS in the sector. Similar discussions took place in the past concerning organic food in general (Latacz-Lohmann and Foster, 1997), which remained a stable niche for a long time. Future studies could compile more empirical examples of such phenomena. A systematic comparison of these stable niches across sectors and countries would .unveil the potential existence of common patterns that prevent long existing sustainability innovations to widely diffuse into conventional market environments. The analysis of interaction dynamics between different (stable) niches and between dominant agri-food systems and niches, as well as the formation of alliances between actors across systems, sectors and countries could provide more nuanced perspectives on the diversity of agri-food systems.

The barriers for the diffusion of organically bred vegetable varieties are presented in our analysis as relatively uniform across Germany. On the one hand, we believe this to be credible, as we interviewed breeders from across the country. While we only interviewed retail buyers from the German Northwest, their companies operate nationwide. Furthermore, based on their standardized valuation approach it is plausible they are representative of conventional market demand across the country. On the other hand, we did not investigate in detail the geographical context, which usually includes issues like place-specific institutions, local demand, or the spatial levels along which innovations are upscaled (Hansen and Coenen, 2015; Hermans et al., 2016; Losacker and Liefner, 2020). For instance, there might be specific diffusion barriers for organically bred vegetable varieties in urban centers with many ecologically conscious consumers, as compared to rural districts characterized by intensive conventional agriculture. Future studies might tackle these limitations by identifying and comparing region-specific barriers. As another means to account for space and scales, future studies could look at transnational linkages of the organic breeding community in Germany and how the TIS actors might be able to overcome barriers by importing or exporting system resources from other places (Miörner and Binz, 2021; Heiberg and Truffer, 2022) or by jointly addressing international (legal) norms that impede commons-based and organically bred varieties (Tschersich, 2021).

8. Conclusion

In this paper, we conceptualized the supportive structures around organically bred vegetable varieties as a Technological Innovation System (TIS) and analyzed barriers for large-scale diffusion based on interviews with actors along the value chain in Germany. This empirical study adds a notable case to the literature on sustainability transitions, where most of the commonly investigated technologies experienced a rather quick diffusion over the last decades (Bento and Wilson, 2016). Contrarily, the wide-spread diffusion of organically bred varieties has not yet taken up and this sustainability innovation remains a relatively stable niche within the transitioning agri-food sector. Overall, our qualitative analysis of these barriers thus responds to recent calls for “more research on the less successful diffusion processes in the agriculture [and] food […] sector” (Fichter and Clausen, 2021, p. 47). Furthermore, the study contributes an innovation system perspective with an explicit focus on market diffusion to the emerging debate on organic breeding and Seed Commons (Sievers-Glotzbach and Christinck, 2021; Tschersich, 2021). Our analysis of the barriers faced by the TIS of organically bred vegetable varieties also contributes to unfolding the diversity of (vegetable) food systems from an innovation system perspective and emphasizes the valuation process along the value chain.

Our focus on barriers for diffusion should not leave readers with an impression that is too bleak or pessimistic regarding the prospects of organically bred vegetable varieties. On the contrary: Studying existing diffusion barriers makes it possible to identify concrete and realistic leverage points for both policy makers and practitioners from within the TIS that wish to facilitate their diffusion.

Commons-based and organically bred vegetable varieties provide several public values, which justifies but also requires proactive engagement by the state (Mazzucato, 2018). On the side of developing and fostering innovation, mission-oriented innovation policies would articulate goals and directions of the future system for (organic) vegetable breeding clearly. To overcome the vicious cycle of lacking awareness, such clarity is also needed in public communication. To mitigate observed investment-related barriers, the state needs to provide high quality funding for various experimentation projects that is relatively risk free, leverages further investments from the private and third sector, and thus strengthens internal value chain relations (Klerkx and Begemann, 2020). Our diffusion-centered analysis emphasizes further policy recommendations: First, public funding for vegetable production should take a more holistic valuation approach (Vivero-Pol, 2017). It should recognize and subsidize farming methods that create public value such as open-access seeds, biodiversity, or robust vegetable varieties which are bred to be resilient in shifting climate conditions. Second, the state needs to enable and create new markets (Mazzucato, 2016) – in our case, this might be best secured and scaled through a public label that confers information on this product characteristics. To further overcome the vicious cycle of standardized valuation, public actors (e.g. municipalities, schools) could create demand for organically bred varieties through public procurement, which has been shown to spur innovations (Edler and Georghiou, 2007; Losacker and Liefner, 2020). Finally, and as is often the case in agri-food system transformations, exnovation policies are needed (Klerkx and Begemann, 2020) that phase-out institutional conditions, which are favorable to the business model of globally active seed companies selling limited sets of genetically uniform and legally protected plant varieties for high-input farming. Such policies would decrease the observed power imbalances and facilitate stretch-and-transform dynamics as described in the previous section.

For actors and practitioners within the TIS, several practical recommendations can be deduced from our study: Breeders and farmers should continue to individually market their product in niche business environments like farmers markets or community supported agriculture. Additionally, these TIS actors should be encouraged to further develop a coherent marketing campaign to communicate the existence, benefits, and characteristics of organically bred vegetable varieties to all stakeholders. This contributes to raising awareness among powerful decision makers in the downstream value chain. Breeding initiatives should also aim to draw activists to their cause, as these two groups could jointly increase market awareness through complementary and mutually strengthening tactics (Enthoven and Thelken, 2022) for pressuring politicians to induce the previously described mission-oriented policies (Klerkx and Begemann, 2020). So long as a state-sponsored public label does not exist, private TIS actors could build communication campaigns around one or two flagship varieties, where customers already expect a certain diversity (e.g. tomatoes in the German context). Price mark ups on labelled organically bred varieties could also be linked to profit sharing agreements with breeders, who lack income from variety protection licensing. Such supply chain partnerships are already discussed and tested in the food sector (Schäfer and Messmer, 2018). Considering these potentials, organically bred vegetable varieties do not necessarily have to stay forever niche – their ecological and social benefits prove an important puzzle piece in the transition towards sustainable food and agricultural systems.

Declaration of Competing Interest

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

Data availability

The data that has been used is confidential.

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Annex

Annex 1. List of interviews

Interview code	Representative of	Date of interview
I_breeder01	TIS for organically bred vegetable varieties	Jan 18
I_breeder02	TIS for organically bred vegetable varieties	Jan 18
I_breeder03	TIS for organically bred vegetable varieties	Jan 18
I_breeder04	TIS for organically bred vegetable varieties	Jan 18
I_breeder05	TIS for organically bred vegetable varieties	Jan 18
I_breeder06	TIS for organically bred vegetable varieties	Jan 18
I_breeder07	TIS for organically bred vegetable varieties	Jan 18
I_breeder08	TIS for organically bred vegetable varieties	Jan 18
I_breeder09	TIS for organically bred vegetable varieties	Jan 18
I_breeder10	TIS for organically bred vegetable varieties	Sep 19
I_breeder11	TIS for organically bred vegetable varieties	Sep 19
I_breeder12	TIS for organically bred vegetable varieties	Sep 19
I_breeder13	TIS for organically bred vegetable varieties	Jul 19
I_breeder14	TIS for organically bred vegetable varieties	Jul 19
I_breeder15	TIS for organically bred vegetable varieties	Jul 19
I_breeder16	TIS for organically bred vegetable varieties	Jul 19
I_breeder17	TIS for organically bred vegetable varieties	Jul 19
I_breeder18	TIS for organically bred vegetable varieties	Sep 19
I_breeder19	TIS for organically bred vegetable varieties	Sep 19
I_retail buyer01	Conventional food retail	Feb 22
I_retail buyer02	Conventional food retail	Feb 22
I_retail buyer03	Conventional food retail	Feb 22

Annex 2. Codesystem

Code	**Subcode**
TIS	Actors
	Networks
	Institutions
	Product characteristics
Value chain	Breeding of (novel) vegetable varieties
	Seed production and marketing
	Cultivation
	Intermediation
Context	Conventional food retail
	Customer preferences and culture
	Policy environment
	Niche business environment
	Power
Resources	Knowledge (creation and diffusion)
	Market (formation)
	(Financial) investments

(*continued on next page*)

(*continued*)

Code	Subcode
	Legitimacy (product legitimation)
Dynamics	Drivers for development (of organically bred varieties)
	Barriers for development (of organically bred varieties)
	Drivers for diffusion (of organically bred varieties)
	Barriers for diffusion (of organically bred varieties)

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