The Organic Fruit Breeding sector through the lens of Social Innovation: Unpacking the transformational potential

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Abstract

The shift from conventional to organic fruit farming, driven by EU policies and research initiatives, highlights the need for multi-trait varieties adapted to organic practices and specific local conditions. Genetic diversity and inclusive stakeholder participation are essential to advancing an effective agroecological transition. In this context, social innovation (SI) plays a key role in shaping successful organic fruit breeding (OFB) models. This article examines the transformative potential of different forms of SI in enhancing the sustainability of the OFB sector. Based on an analysis of 43 SI initiatives across 10 European countries, we demonstrate the relevance of SI across all stages of the OFB process—from genetic resource management to market integration. We identify distinct SI models based on governance structures and strategic orientations, analysing their ambition to contest and reshape the dominant OFB paradigm. Our findings show that inclusive stakeholder engagement and transformative knowledge exchange are crucial for assessing the scalability and institutionalisation of locally driven innovations, and thus their capacity to foster broader systemic change. A key contribution of SI lies in ensuring that societal goals remain central to technological development—maximising the impact of breeding, avoiding input-substitution approaches, and enhancing the transformative potential of organic practices. We conclude that diverse and complementary forms of SI collectively strengthen the OFB sector's capacity for transformation. Alongside more radical approaches, both institutionalised and market-oriented initiatives contribute to creating the enabling conditions necessary for a more sustainable and socially embedded transition in OFB.

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Introduction

Genetic resources in agriculture are far more than simple inputs; they are foundational to shaping the structure and sustainability of entire agricultural systems (Demeulenaere and Goldringer, 2017; Goritschnig et al., 2025). Yet, over the past century—and especially in recent decades—there has been a significant decline in food biodiversity. This erosion has led to an increased reliance on a limited number of plant species worldwide and a narrowing of genetic diversity within those species, thereby weakening the system's resilience (Gepts et al., 2012; Khoury et al., 2022). The replacement of diverse populations with genetically uniform cultivars, such as pure lines, is evident across both crop and fruit sectors (Chable et al., 2020; Badenes and Byrne, 2012). For crops, this trend has been exacerbated by the consolidation of the seed industry: a few global corporations—including Monsanto, DuPont, and Syngenta—now control around 50% of the market. Their dominance has displaced public breeding initiatives and smaller enterprises, further undermining genetic diversity (Howard, 2009).

Fruit breeding, especially for perennial crops such as apples, pears, and cherries, poses unique challenges. The primary goals are to increase yield per unit area at low cost while enhancing resistance to biotic and abiotic stresses (Karanjalker and Begane, 2016). Breeding in this sector is inherently long-term, typically requiring 10 to 20 years to release a new variety. This extended timeline reflects both the delayed onset of fruit production and the complexity of evaluating traits such as disease resistance, which must be assessed under field conditions over multiple years to ensure their durability and environmental stability (Johnson, 2000).
While these prolonged cycles—alongside limited policy support for variety development and registration—have inadvertently slowed biodiversity loss in the fruit sector compared to others (European Commission, 2020), they also impose significant economic constraints. In response, conventional breeding increasingly relies on intellectual property rights to secure returns, particularly in high-value crops such as grapes and apples. This model has fostered greater farmer dependency on large breeding companies, which control access to planting material and promote club varieties—proprietary cultivars governed through exclusive licensing arrangements that centralise control over propagation, quality standards, and marketing (Clark et al., 2012; Wolter and Sievers-Glotzbach, 2019).

This context raises critical political and ethical questions about which agricultural innovations should be prioritised and which warrant critical reassessment. As Faure et al. (2018) note, perceptions of innovation are shaped by societal values, as exemplified by enduring controversies over genetically modified organisms (GMOs). In France, widespread opposition to GMOs spurred movements advocating for farmer-managed seeds and alternative breeding models aligned with social and environmental goals (Thomas and Bonneuil, 2009).

These debates are especially pertinent in fruit breeding, where limited access to plant material constrains the conservation of local varieties, landraces, and overall genetic diversity (Badenes and Byrne, 2012). This has prompted growing recognition of the need to redesign breeding systems—both to improve access and to address broader ecological and societal challenges—supporting a transition towards more sustainable and resilient food systems.

Organic fruit breeding (OFB) is gaining traction, driven by growing consumer demand in Europe and North America (Granatstein et al., 2016; Willer et al., 2020). The sector faces a dual challenge: meeting market expectations—flavour, appearance, shelf life—while ensuring ecological performance, including pest resistance, nutrient use efficiency, and climate resilience.

Despite its potential, organic fruit production remains heavily reliant on cultivars bred for conventional, high-input agriculture. Around 95% of fruit varieties used in organic systems were developed under conditions involving synthetic fertilisers and pesticides (Nuijten et al., 2017), limiting their suitability for the agroecological complexity of organic farming (Chable et al., 2020). This dependence reflects institutional lock-ins rather than lack of interest in alternatives: long breeding cycles, high sunk costs in perennial systems, proprietary control over planting material, and concentrated nursery markets limit organic actors' ability to influence breeding priorities. As a result, producers often adapt varieties from standardised, high-input value chains to low-input contexts rather than shaping breeding objectives upstream. By contrast, annual crops such as vegetables and grains, with shorter breeding cycles and stronger participatory breeding traditions, can more quickly develop user-oriented, agroecologically adapted varieties (Ceccarelli et al., 2009; Chable et al., 2020).

Meeting the needs of organic fruit systems requires multi-trait varieties that can tolerate multiple stresses without chemical inputs while supporting broader ecological functions, including biodiversity conservation, soil health, and climate resilience (Altieri, 2018; Pareek et al., 2017). Developing these varieties necessitates reorienting breeding programmes to reflect the specific conditions and values of organic systems. Such innovations can also generate co-benefits for landscape preservation, public health, and rural livelihoods (Desclaux and Chiffoleau, 2009), aligning with EU policy priorities on agroecology and sustainable food systems (Tittonell, 2020; EU Research Partnerships on SFS and Agroecology).

However, transforming fruit breeding systems cannot rely on technical innovation alone. It also requires social innovation (SI)—understood as the reconfiguration of social relations, institutions, and governance structures to better meet sustainability goals (Westley and McGowan, 2017; Klerkx et al., 2012). While often invoked as a broad umbrella term (Pol and Ville, 2009), SI in the context of OFB demands a more targeted and context-sensitive approach (Chiffoleau and Loconto, 2018).

This paper addresses the central question: *How do social innovations in OFB contribute to the transformation of breeding systems toward more sustainable, resilient, and socially responsive food systems?* To answer this, we pursue two interconnected objectives: (i) mapping SI across the phases of the OFB process—examining their goals, governance, and outcomes; and (ii) assessing through which models SI generates broader systemic change and what this implies for the sector's transformative capacity.

The paper begins by outlining the specific challenges of the OFB sector and presenting our conceptual framework on SI, which emphasises innovation systems rooted in local biodiversity and actors' participation. We then describe our methodology, based on qualitative analysis of selected initiatives. The results section identifies core elements of SI at different stages of the OFB process. Then, we propose a clustering matrix to position SI initiatives according to their approach and governance. Finally, the discussion considers the diffusion and institutionalisation of locally developed innovations, and their potential to contribute to systemic transformation in fruit breeding.

A new paradigm in OFB: co-design, locality and biodiversity

In this paper, 'conventional breeding' refers to the dominant socio-technical model of fruit breeding rather than to a specific set of techniques. It is characterised by centralised breeding programmes, a clear separation between breeders and users, proprietary control over genetic resources, and market-driven selection criteria (e.g. uniformity, yield, shelf life), with limited integration of local knowledge, biodiversity, and participatory processes. This configuration provides the baseline against which OFB articulates its SI dynamics. While conventional programmes increasingly incorporate traits related to resilience and stress tolerance, their underlying governance and incentive structures remain primarily oriented toward large-scale, standardised markets, which constrains their capacity to address context-specific sustainability challenges, particularly in marginal and low-input systems.

One structural limitation of this model lies in its weak responsiveness to the needs and preferences of end users. In the early 20th century, breeders in North America and Europe frequently collaborated with farmers through on-farm trials to identify desired traits (Ceccarelli et al., 2009). However, the industrialisation of agriculture and the professionalisation of breeding gradually sidelined farmers' involvement—a shift later replicated in the Global South during the Green Revolution.

Research shows that ignoring farmers' and consumers' trait preferences significantly limits the adoption of new varieties (Thiele et al., 2021). In the West, while conventional breeders may conduct consumer testing, these consumers often act as passive testers rather than active decision-makers, swayed by market dynamics rather than their own preferences. Gender differences in preferences—shaped by distinct roles in production, processing, and marketing—are overlooked (Weltzien et al., 2019). Such challenges reflect the top-down nature of conventional breeding, where decision-making is centralised among researchers and farmers are treated as passive recipients rather than active co-creators (Pimbert, 2006; Cartagena et al., 2025).

Against this backdrop, a new paradigm in OFB is emerging—grounded in user-oriented and participatory approaches that seek to reconfigure power relations, knowledge flows, and innovation processes. Given that the organic business community tends to pursue a differentiation strategy based on sustainability, quality and ethical values, these approaches promote inclusive, gender-responsive, and context-specific breeding practices (Wolter and Sievers-Glotzbach, 2019), thus ensuring breeding outcomes are both relevant and equitable (Colley et al., 2022). Participatory methods also help address the long breeding cycles typical of perennial crops by aligning ecological and social priorities from the outset (Korsgaard and Toldam-Andersen, 2024).

Stakeholders—particularly farmers—are engaged early through trait prioritisation exercises such as surveys, focus groups, and choice experiments (Valle et al., 2022). This is followed by participatory evaluation, where varieties are tested under real-world conditions by farmers, processors, and consumers. Iterative feedback loops ensure continuous alignment with users' needs, sometimes evolving into full co-design processes that involve shared decision-making and co-ownership. This collaborative model exemplifies SI in OFB, fostering inclusion, mutual learning, and long-term engagement.

Locality is the second dimension of SI in OFB. While conventional breeding prioritises broad geographical adaptability and high performance (Byrne, 2012; Ortolani et al., 2017), OFB emphasises local adaptation—crucial in systems that cannot rely on synthetic inputs. Participatory plant breeding (PPB), widely applied in annual crops, engages farmers in selecting and evaluating varieties within existing breeding programmes and has informed OFB practices. A 2000 international review concluded that PPB should be integral to breeding programmes for low-input systems, which are too heterogeneous to be served by centralised breeding strategies (Ceccarelli et al., 2009).

In OFB, locality translates into the development of varieties adapted to specific soils, climates, pests, and cropping systems (Migliorini and Wezel, 2017), while also encompassing regional knowledge, food cultures, and markets (Desclaux et al., 2008). Co-developing varieties with local communities improves adoption, preserves cultural heritage, and reinforces territorial food systems. Anchoring breeding in place fosters territorial innovation via seed networks, value chains, community marketing, and geographical indications. Locality thus both underpins OFB and drives SI, embedding change in place-based practices and values.

The third interrelated dimension is biodiversity, serving both as a resource and a guiding principle. Organic agriculture strongly depends on enhancing and sustainably managing biological diversity, as emphasised in IFOAM standards, which call for ecological processes adapted to local conditions. Biodiversity contributes to ecosystem services, nutritional diversity, and socio-cultural resilience (Chable et al., 2020), while advancing broader goals such as food security and sovereignty (Goldringer and Rivière, 2018).

Biodiversity management in OFB encompasses conservation, sustainable management, and valorisation

(Mariani et al., 2022). Conservation efforts focus on safeguarding genetic resources both ex situ (e.g., gene banks) and in situ (e.g., heritage orchards or community collections). Sustainable management refers to the dynamic use of this diversity through on-farm selection and reproduction under local conditions. Farmers' traditional knowledge plays a vital role here, contributing to the renewal and resilience of agrobiodiversity (Orlove and Brush, 1996). Finally, valorisation involves enhancing the cultural, nutritional, and market value of biodiversity, particularly via local markets, origin-based labelling, and community branding. Storytelling and place-based marketing can turn biodiversity into a lever for rural development and cultural revitalisation (Mariani et al., 2021).

Increasingly, OFB links to participatory and community-based biodiversity management approaches that fully integrate farmers and end users in both breeding and conservation (Altieri, 2018; Nuijten et al., 2017). This alignment of varieties with local practices and cultural preferences boosts adoption and embeddedness (Chable et al., 2020), and resonates with agroecological principles that emphasise ecological integrity, community agency, and local knowledge (Wezel et al., 2009). In parallel, a reconfiguration of Agricultural Knowledge and Innovation Systems (AKIS) in OFB supports cross-level learning and collaboration by integrating diverse forms of expertise (Chiffoleau and Desclaux, 2006; EU SCAR, 2019).

In sum, SI in OFB is structured around three interlinked pillars: co-design and inclusive actor engagement, locality, and biodiversity. The Horizon Europe Innovative Organic Fruit Breeding and Uses (InnOBreed) project defines SI in this context as follows:

> *Social innovation in the organic fruit breeding sector refers to the development of new perspectives and social practices that address social, environmental, and market challenges faced by the sector, particularly organic fruit growers, as well as broader society and the planet. It involves a reconfiguration of social relationships based on trust, participation, and knowledge exchange among different actors, from farmers to consumers. Its objective is to enhance the well-being, empowerment, and inclusion of all stakeholders in the organic fruit sector while promoting long-term social, economic, and environmental sustainability. (Mariani et al., 2024)*

Through this lens, OFB pursues SI by reshaping social relationships based on trust, participation, and knowledge exchange, embedding breeding in local contexts, and integrating biodiversity, offering new pathways for more resilient, equitable, and context-driven food systems.

Conceptual framework: Transformational SI within the OFB socio-technical system

In this paper, innovation is understood as a complex, multi-dimensional system shaped by social, institutional, and economic contexts. In agriculture, innovation approaches alternative to the 'linear model' (Kloppenburg, 2005) proposed by the Green Revolution have long been analysed as non-linear processes embedded in these broader environments (de Roo and Miller, 2019). This has been theorised through various systemic frameworks, including innovation systems (Lundvall, 1992), socio-technical systems (Geels and Kemp, 2007), innovation ecosystems (Granstrand and Holgersson, 2020), agricultural innovation systems (World Bank, 2012), and the EU AKIS framework (EU SCAR, 2012, 2019). These different approaches converge on a key idea: innovation is not reducible to technology alone, but depends on networks, institutions, and knowledge flows that shape how change emerges and stabilises across national, regional, and sectoral contexts (Touzard et al., 2015). They also support the identification of bottlenecks in the development and uptake of innovations (Sartas et al., 2020), which is particularly relevant in sectors such as OFB, where long breeding cycles, regulatory constraints, and fragmented actor constellations limit the emergence of alternatives. Within such systems, innovation is both an individual and a collective endeavour (Hekkert et al., 2007), involving diverse actors whose interactions are shaped by shared concerns or change drivers (Hall et al., 2001; Klerkx et al., 2012; Thompson and Scoones, 2009).

The Multi-Level Perspective (MLP) explains how transitions emerge through niche innovations—protected spaces where alternative practices are nurtured (Geels and Schot, 2007). These niches, when reinforced by broader landscape pressures, can disrupt and eventually transform dominant regimes like conventional breeding systems, reshaping norms, technologies, and institutions (Pigford et al., 2018; Meynard et al., 2017). This framework is useful for positioning OFB initiatives in relation to the dominant fruit-breeding regime and for understanding how alternative practices may gain traction under favourable conditions.

However, while MLP helps situate innovation within broader transition dynamics, it is less precise in accounting for the social mechanisms through which change is constructed, negotiated, and institutionalised. As highlighted in the sociology of agriculture and food, transition approaches can underplay actor heterogeneity, everyday practices, mediation processes, and the co-production of new norms and meanings (Chiffoleau and Loconto, 2018). Understanding the transformative potential of OFB initiatives therefore requires complementing MLP with an approach that takes seriously the social relations, forms of collective action, and normative orientations through which innovation unfolds.

The integration of SI has enriched our conceptualisation of innovation by highlighting the essential, yet frequently underappreciated, social dimension—from the identification of needs to the shaping of processes and societal impacts (Moulaert, 2013). SI is grounded in multi-actor, collective processes that emerge locally to address pressing social needs inadequately met by market mechanisms or existing social policies. These processes typically involve diverse stakeholders—including civil society organisations, grassroots movements, public institutions, and private actors—collaborating to develop context-specific solutions (Moulaert et al., 2013; Cajaiba-Santana, 2014). Their emergence and trajectories are strongly shaped by local and institutional contexts, which influence how initiatives develop, stabilise, and scale (Chiffoleau and Paturel, 2016; van Wijk et al., 2019).

At the same time, following Chiffoleau and Loconto (2018), SI in agri-food systems should not be treated only as a policy buzzword or a generic label for participatory initiatives. Their contribution is important because it reconnects SI to two stronger sociological lineages: the sociology of social movements, which emphasises collective action, contested values, and aspirations for social change (Touraine, 1981; Laville, 2014); and Science and Technology Studies, especially Actor-Network Theory, which conceptualises innovation as a process of socio-technical co-construction involving heterogeneous actors, material arrangements, and situated knowledge (Callon, 1986; Callon and Rabeharisoa, 2008). This sociological grounding is particularly relevant in OFB, where innovation concerns not only new cultivars, but also the redefinition of breeding goals, actor roles, governance arrangements, and relations between scientific, experiential, and market knowledge.

Transformational SI: a catalyst for systemic change

Building on the understanding of SI as a collective and situated process, we mobilise the Transformative Social Innovation (TSI) perspective to assess its contribution to systemic change. In line with Avelino et al. (2019), TSI refers to the process through which SI challenges, alters, or reproduces dominant institutions, involving deep changes in social relations, values, norms, governance models, and institutions, aimed at addressing complex societal challenges while promoting equity, sustainability, and well-being. In this paper, SI refers to the empirical processes under study, while TSI is used as an analytical lens to assess their transformative potential. TSI focuses on the social mechanisms through which change is constructed at different interdependent levels, including power relations, collective learning, and normative orientations, highlighting the empowerment (or disempowerment) of actors as a central element in the transformation process (Avelino et al., 2019; Pel et al., 2020). This approach calls for the integration of multiple perspectives on system innovation—socio-technical, socioecological, socio-political, and socioeconomic (Avelino et al., 2019)—recognising that different innovators and stakeholders bring distinct visions and ambitions, and that transformation may emerge from their confrontation and negotiation. These interactions may involve tensions, conflicts, and partial alignments rather than consensus. In this sense, TSI complements transition approaches by foregrounding the relational and political dimensions of transformation that are less visible in system-level analyses.

In agri-food systems, these dynamics have been empirically highlighted by Rossi and Bocci (2018), who show that the transformative potential of SI depends not only on the emergence of alternatives, but on processes of social learning, coordination, and institutional embedding. Transformation is therefore not linear: it unfolds through experimentation, negotiation, and what they define as 'anchoring', through which innovations are stabilised, translated, or partially integrated into existing systems. These processes determine whether SI initiatives remain localised or contribute to broader structural change.

From a sociological perspective, SI emerges through interactions among heterogeneous actors and involves the co-production of knowledge, practices, and meanings (Chiffoleau and Loconto, 2018). Participation, however, does not imply shared values: actors hold different interests and degrees of power, and their interactions are shaped by negotiation and partial alignments (Chiffoleau and Loconto, 2018; Rossi and Bocci, 2018). In OFB, where diverse actors engage in long-term breeding processes, the transformative capacity of SI depends less on inclusion per se than on whether participation reconfigures decision-making and enables the negotiation of alternative breeding priorities.

Applying the TSI framework to OFB

In light of this conceptual distinction between SI as empirical process and TSI as analytical lens, we apply the framework to OFB to examine how different initiatives reconfigure governance, knowledge flows, and breeding orientations, and with what transformative implications. In the context of OFB, TSI holds the potential to radically reshape the sector. It can introduce new forms of governance, participatory breeding practices, and market dynamics that prioritise ecological sustainability and social inclusion. By encouraging multi-actor collaboration and grassroots innovation, SI can help rethink breeding processes, land use, and consumer engagement. This holistic approach is crucial for addressing the unique challenges of the OFB sector, including the need for varieties better suited to organic farming and the rising consumer demand for healthier, sustainably produced fruits.

To provide a comprehensive understanding of the diversity and transformational potential of SI initiatives within the OFB sector, as already done by Desclaux et al. (2009) for organic participatory wheat breeding, this paper adapts the classification matrix proposed by Sylvander et al. (2006) to the specificities of OFB. While the axis on management and governance of Sylvander et al. (2006) is maintained, the socio-technical axis has been adapted to the objective of this paper. This matrix helps to acknowledge the plurality of actors and perspectives involved in a changing system and to categorise different approaches to organic agriculture along two key axes:

- *Governance axis*: This axis distinguishes between governance models that are individually oriented, focusing on corporate or personal objectives, and those that are collectively driven, where cooperative efforts toward common goals are prioritised. This dimension captures the diversity in stakeholder involvement and the degree to which individual interests versus collective aspirations shape innovation processes.
- *Socio-technical axis*: This axis differentiates between a reductionist approach, which focuses on compliance with specific standards or practices on a factor-by-factor basis, and a holistic approach, which seeks to redesign agricultural systems comprehensively. This spectrum reflects the varying levels of ecological integration and the extent to which innovation is embedded in agroecological principles.

By integrating these axes, we can better categorise and understand the role of SI in the OFB sector. Through this lens, we assess how SI initiatives contribute to systemic change in OFB in terms of governance, ecological integration, and social inclusion.

Methodology

The study employed a comprehensive two-step methodology to investigate SI within the OFB sector, utilising a case study approach based on qualitative data collected within the InnOBreed project.

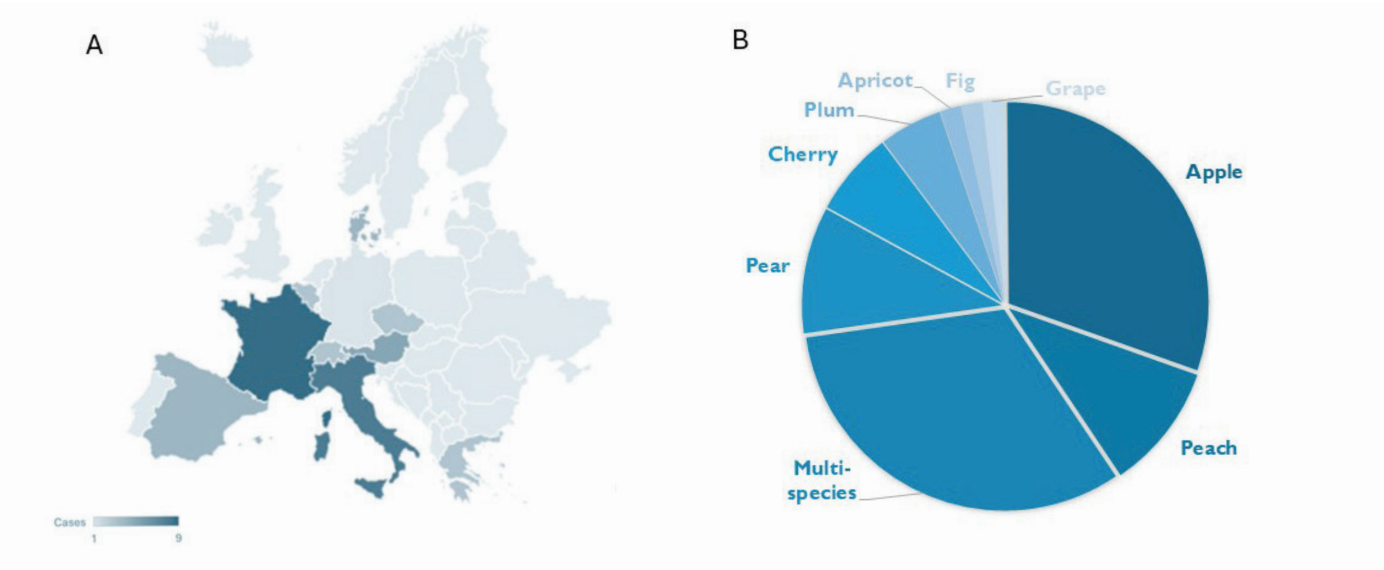
Mapping and characterisation of SI initiatives

This study identified 43 SI initiatives[1] across 10 European countries through a structured mapping process conducted within the InnOBreed project in 2024. In this paper, a SI initiative refers to a set of practices or organisational arrangements that reconfigure social relations, governance, or knowledge flows in OFB to address social, environmental, or market challenges (e.g. participatory breeding, collaborative biodiversity management, or market-oriented valorisation of local varieties). The 43 initiatives are treated as empirical cases identified through the mapping.

A shared definition of SI in OFB was first developed and validated with project partners, as presented in section 2. Mapping data were collected using a common template completed by partners (e.g. researchers, breeders, practitioners). Initiatives were selected if they met the definition of SI in OFB.

To reduce consortium bias, the mapping was opened to external actors through six national workshops, where farmers, civil society organisations, and other stakeholders contributed additional cases and validated both the definition and case selection. Semi-structured interviews with 20 initiatives were conducted in 2025 to further validate and deepen the analysis. While the sample reflects the project network and may not be exhaustive, these steps helped broaden coverage beyond partner-led cases. All participants were informed about the research objectives and consented to data collection and use. The 43 SI initiatives covering the main fruit species studied by the InnOBreed project (see Figure 1) were then characterised by focusing on their objectives, processes, and outputs at various stages of the breeding process: (i) genetics and pre-breeding, (ii) breeding and testing, and (iii) release and use of new cultivars.

Figure 1: Number of initiatives by country (A) and by fruit species (B)



Source: authors' elaboration

Scoring and clusterisation of the mapped initiatives

The analytical framework of this study, built on Sylvander et al. (2006) and Desclaux et al. (2009), is tailored to SI in OFB. The two-axis matrix defines four theoretical models, which account for the empirical diversity of

[1] The dataset used in this study is publicly available on Zenodo: Mariani, M., & Ortolani, L. (2026). The Organic Fruit Breeding sector through the lens of Social Innovation [Data set]. Zenodo. https://doi.org/10.5281/zenodo.19693802.

SI initiatives. Each quadrant represents different poles that initiatives tend toward, capturing unique patterns of implementation and change-making capacity. To validate these models, each of the 43 initiatives was scored using the two-axis matrix, positioning them relative to the four poles. This scoring followed a systematic coding of case texts, based on the completed mapping templates, ensuring comprehensive data.

The authors used a bipolar scale to score each case from -2 (minimal alignment) to +2 (maximum alignment) on each axis, reflecting their collective-systemic orientation and challenge to the conventional breeding paradigm. Scoring was guided by three questions for each axis, based on Sylvander et al. (2006) and adapted for the SI context in OFB:

Regarding the governance axis, scoring aimed to distinguish individual logics from collective governance: (i) Does the initiative prioritise collective goals or individual interests? (ii) Is it oriented toward global systemic change or only local challenges? (iii) Does it engage in advocacy to support the broader OFB community? Regarding the socio-technical axis, the purpose of scoring was to distinguish analytical from systemic approaches: (i) Does it aim to transform systems rather than comply with standards? (ii) Does it build resilience and empower actors? (iii) Does it advocate for agroecological policy change?

Initially, individual scores were provided, followed by a consensus-building approach (Leising et al., 2024) to combine these values. A dataset of the initiatives, including metadata on country, crop species, phase, and axis scores, is made available as supplementary material.

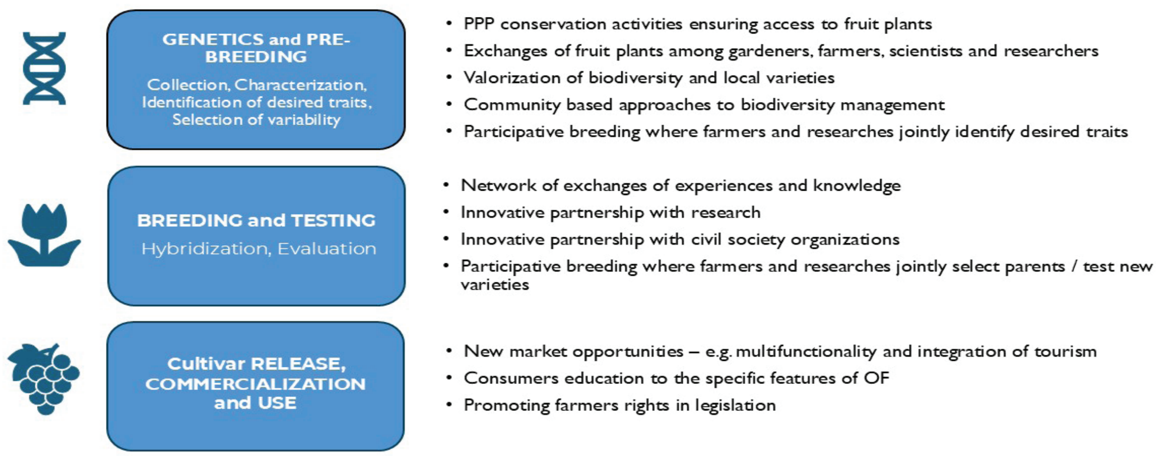
Results: complementary models of SI in OFB

The results are presented in three stages. First, in section 5.1, we examine the presence of SI across the main phases of OFB, highlighting key elements essential for implementation. Then, in section 5.2, we operationalise SI in OFB based on the developed matrix defining four complementary SI models identified in OFB, offering a practical tool for understanding SI initiatives in this sector. Finally, in section 5.3, we test the developed models with the identified initiatives to explore patterns and relationships.

How SI contributes to different phases of OFB

Mapping of SI initiatives across 10 EU countries reveals they are primarily led by research institutions (20 initiatives), followed by private companies (10), local authorities (7), and civil society actors (6). These initiatives span all main phases of OFB: (i) Genetics and Pre-breeding, focused on accessing and preparing genetic material; (ii) Breeding and Testing, involving selection, hybridisation, and performance evaluation; and (iii) Cultivar Release, covering registration, multiplication, commercialisation, and adoption. Figure 2 provides examples of SI corresponding to each phase.

Figure 2: Main phases of breeding and corresponding examples of SI



Source: authors' elaboration

Most initiatives are concentrated in early phases, with 11 initiatives focusing on genetics and pre-breeding, and 9 on breeding and testing. At this stage, several community- and region-based initiatives prioritise biodiversity conservation and the transmission of local varietal knowledge. However, a significant number of initiatives (20) intervene in the later stages—cultivar release, commercialisation, and use—often emphasising varietal valorisation, educational outreach, and the creation of enabling political environments through advocacy. A smaller group (3) spans multiple phases, highlighting the systemic and cross-cutting nature of SI in OFB.

Analysis of the goals, processes, and outcomes of these initiatives shows that while the overarching aims of SI often cut across the entire OFB cycle, their dynamics and outputs are largely phase-specific. SI in OFB typically addresses neglected positive externalities (Santos, 2012), with three central objectives emerging across cases: to establish sustainability pathways that embed diversity and resilience; to reclaim agency over varietal development in response to climate pressures; and to safeguard agricultural biodiversity and associated cultural knowledge, often by rehabilitating neglected fruit varieties.

In the genetics and pre-breeding phase, SI frequently involves community-based management practices that foster trust and collaboration, leading to the establishment of conservatories and seed banks to secure genetic diversity. During breeding and testing, participatory approaches dominate, with farmers, researchers, and marginalised actors (e.g., prisoners) jointly developing breeding methods attuned to environmental sustainability. In the cultivar release and use phase, end-user engagement becomes central—particularly through producer-consumer linkages, transparency, and responsiveness to demand. Outputs at this stage include the direct marketing of traditional varieties, the creation of quality labels (e.g., for non-sprayed, high-stem orchards), artisanal processing (cider, vinegar, dried fruit), and forms of multifunctionality that integrate tourism and education.

Despite contextual variation, all initiatives share three foundational elements that distinguish SI in OFB from conventional breeding paradigms. First, they collectively aim to enhance genetic diversity, countering the narrowing varietal base promoted by conventional breeding. Second, they rely on participatory, multi-actor governance, ensuring inclusive and legitimate decision-making. Third, they foster knowledge exchange networks that support continuous learning and adaptation across the breeding ecosystem. Without these elements, there is a risk that organic practices may be absorbed into dominant agronomic paradigms, losing their transformative potential. Social and governance innovations are thus indispensable not only for preserving the integrity of OFB, but also for realising its broader socio-environmental aspirations.

Four models to understand the transformational role of SI in OFB

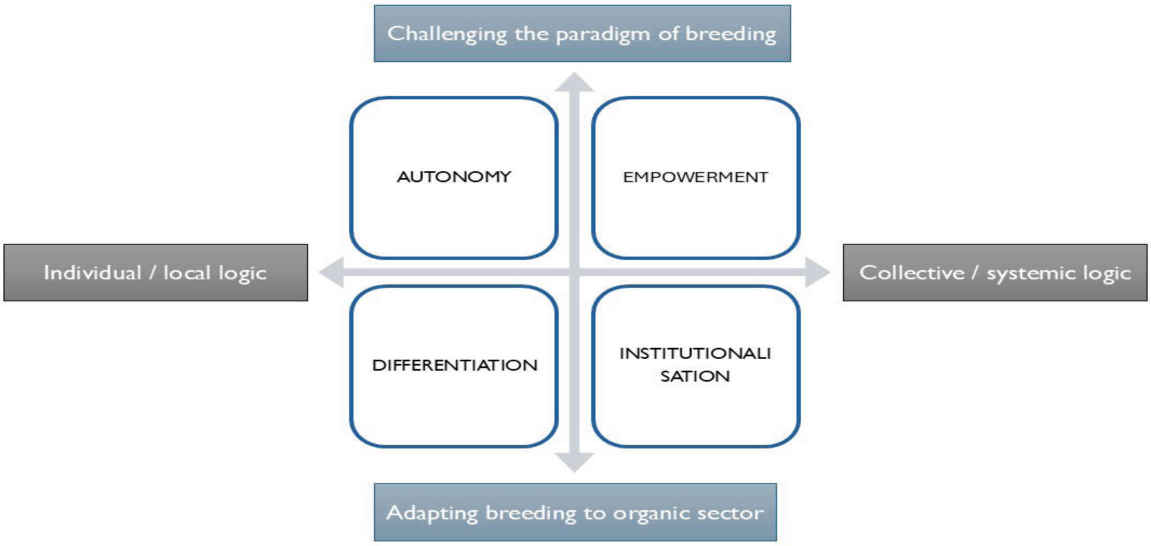
The need to develop an analytical framework that recognises the plurality of SI in OFB arises from the theoretical framework of this paper and the analysis of 43 case studies. A diverse range of SI models may exist within OFB, reflecting the varied visions and values of the stakeholders involved.

As discussed in the methodology section, a classification matrix with two axes has been established to comprehensively describe four theoretical models that categorise existing and future SI experiences in OFB, considering their transformational potential. This matrix identifies four emerging SI models by analysing initiatives grouped in similar quadrants. The models—(i) Empowerment, (ii) Autonomy, (iii) Differentiation, and (iv) Institutionalisation—are based on common characteristics identified through this method (Figure 3).

Empowerment

These initiatives are characterised by collaboration among diverse actors, including farmers, researchers, and community organisations. They aim to connect local efforts to broader advocacy activities, enhancing the collective voice in decision-making processes.

Figure 3: A conceptual matrix to unpack diverse models and potential outcomes of SI in OFB



Source: authors' elaboration

Empowerment-focused initiatives prioritise the general interest, promoting the free exchange of knowledge and fostering the maintenance of genetic diversity in fruit crops. They often establish networks that support participatory breeding and community engagement.

Autonomy

Initiatives in this category are typically led by local actors, especially farmers, who seek to assert control over the entire production chain—from accessing Plant Genetic Material (PGM) to marketing their products. The emphasis is on reducing dependency on external inputs and enhancing farm-level autonomy. These initiatives often promote local 'heritage' varieties, ensuring that farming practices align with local ecological and cultural contexts.

Differentiation

Differentiation-focused initiatives are driven by producers or firms motivated to expand their product range and distinguish themselves in the market. These initiatives often seek to develop unique fruit varieties with specific traits that appeal to consumers.

By tapping into niche markets and emphasising quality, these initiatives aim to enhance the economic viability of organic fruit production while fostering consumer awareness about the benefits of organic and sustainable practices.

Institutionalisation

This model represents initiatives that respond to new requirements or opportunities presented by public policies, particularly those supporting organic certification and agrobiodiversity preservation.

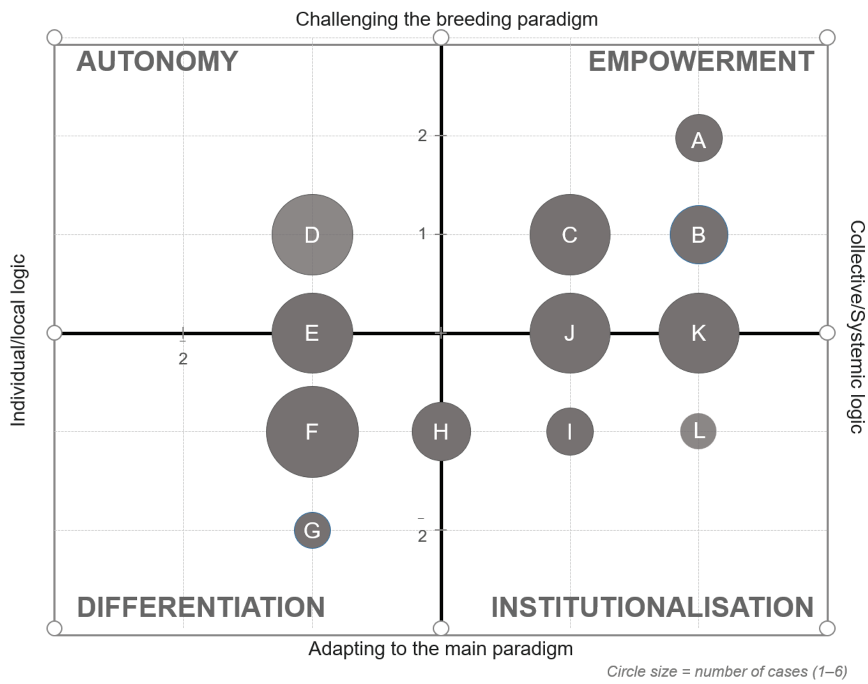
Institutionalised initiatives focus on creating formal shared requirements, such as certification standards and production protocols. They often involve collaboration among various stakeholders to collectively manage and enhance local varieties.

Testing the matrix with empirical cases

Building on the four models derived from the classification matrix adapted from Sylvander et al. (2006) and

Desclaux et al. (2009), the 43 SI initiatives were scored and clustered following the procedure outlined in Section 4.2 (see Figure 4). Several notable patterns emerge. Most initiatives fall into intermediary spaces, combining adaptive and transformative traits; yet a substantial number clearly pursue a transformative ambition, challenging established norms through participatory governance and context-responsive strategies.

Figure 4: Matrix situating case studies



Source: authors' elaboration

<u>Empowerment</u>

The most paradigmatically challenging and collectively organised initiatives appear in the Empowerment model. The initiatives displaying the strongest transformative potential (A) are collectively organised and challenge dominant paradigms in the most explicit way. These include, for example, a Spanish network that advances farmer-led breeding and seed sovereignty through participatory management of genetic resources, and a French initiative that works to restore traditional fruit varieties and biodiversity in the Pyrenees by creating alliances between farmers, researchers, and local authorities. Although located in the same quadrant and referring to the same model, a second group of cases (B) is slightly less radical in orientation but maintains a strong collective dimension while experimenting with breeding alternatives beyond the conventional Distinctness, Uniformity, and Stability (DUS) criteria used to evaluate plant varieties. Among these, one Austrian case promotes decentralised seed evaluation through stakeholder collaboration, while a Belgian non-profit association promotes the use of local fruit cultivars by developing official quality labels, a search platform connecting farmers, consumers and other value-chain actors to plant materials and services, and by raising awareness of scientific research on local fruit diversity and its positive carbon footprint.

All the SI initiatives aiming at the empowerment model mobilise diverse actors, integrate local and extra-local scales, and support breeding models that combine collective governance, genetic diversity and alternative regulatory vision. This constellation of practices challenges the conventional breeding approach while opening spaces for more democratic, resilient and territorially rooted approaches to OFB.

<u>Autonomy</u>

Looking at initiatives aiming at the Autonomy model (D), the main actors are individual farmers who seek to exercise direct control over the entire production pathway, co-developing Plant Genetic Material (PGM) in collaboration with researchers and other AKIS actors to strengthen farm-level autonomy. Notable cases include an Italian conservatory safeguarding local fig varieties while supporting agritourism, and a Greek ecological farm devoted to the participatory evaluation of apple, pear, and other local genetic resources for disease tolerance, robustness, and fruit quality traits, while also welcoming consumers through open farm days.

Empowerment and autonomy models operate as complementary logics of transformation. Both cultivate collective governance of genetic resources, broaden participation in breeding, and open regulatory and organisational space beyond conventional standards. However, the Empowerment model emphasises advocacy and institutional pressure for transformation, while the Autonomy model focuses on building coherence within specific experiences, often operating outside established rules regarding the reproduction and sharing of PGM.

Differentiation

In contrast, the Differentiation model includes initiatives (F and G) that focus less on systemic transformation and more on market differentiation through varietal diversity. For example, an Austrian case promotes rare fruit varieties from extensive orchards as high-value table fruits, offering consumers a distinctive product while supporting extensive farming systems. Within this quadrant, the most adaptive initiative (G) stands out for its full integration into conventional market channels. It involves a Swiss group developing apple varieties with specific flavour profiles tailored to supermarket demand, emphasising product innovation over systemic change.

Notably, no initiatives are located in the extreme left quadrants that would represent highly individual or purely local strategies—whether transformative or adaptive. This absence suggests that SI in OFB tends to emerge through collective, networked dynamics and is rarely driven by isolated actors or efforts.

Institutionalisation

In the Institutionalisation model, three cases (I and L) follow a collective and often institutionally led logic, though they do not significantly question existing breeding paradigms. Rather, they focus on local development and conservation via quality schemes or place-based strategies. A Protected Designation of Origin (PDO) in northern Spain (L), for example—the case with the highest collective orientation in this quadrant—enhances biodiversity and rural livelihoods by valorising traditional cider apple varieties.

Finally, two subgroups cluster toward the centre of the matrix. One shows a strong collective dynamic but limited transformative ambition (K). These cases typically combine conservation, valorisation, and public engagement functions—ranging from participatory breeding programmes and transborder public-private partnerships to community orchard initiatives and regional conservatories—often bridging institutional and grassroots logics without fundamentally challenging existing breeding norms. The other subgroup reflects a moderate collective orientation with an adaptive approach (J), and includes initiatives centred on heritage variety restoration, genetic resource communication for non-specialist audiences, and open farm or gene bank events. While these experiences do not directly challenge the breeding model, they foster broader social innovation through knowledge exchange, public awareness, and the gradual involvement of new actors in fruit diversity conservation.

Clustering the SI initiatives reveals their unique contributions and collective potential for socioeconomic transformation in the OFB sector. Each model addresses specific aspects essential for the viability and scaling-up potential of SI: Empowerment focuses on collaborative goals; Autonomy emphasises local control; Differentiation seeks market expansion and unique product traits; and Institutionalisation aligns with formal policies and quality standards.

Discussion: the potential of SI to challenge existing paradigms in the OFB sector

This study shows that SI contributes to structural transformation in fruit breeding to meet the distinct requirements of the organic sector. While the importance of user-oriented breeding is well established (Ceccarelli et al., 2009; Almekinders and Hardon, 2006), our findings show that SI goes beyond improving tools or technical performance—it actively questions dominant paradigms and reshapes who drives innovation and how. From a sociological perspective, this confirms that innovation in OFB is not only a technical process, but an 'innovation in the making', shaped by collective action and the interaction of heterogeneous actors who co-construct breeding goals, practices, and norms (Chiffoleau and Loconto, 2018).

Existing literature has documented the increasing involvement of non-traditional actors, particularly farmers, in participatory and user-centred plant breeding, especially for annual crops (Thiele et al., 2021; Ceccarelli et al., 2009). Tools such as trait prioritisation workshops and on-farm evaluations have been promoted to make breeding more relevant to end users (Colley et al., 2022), and these approaches are often seen as complementary to conventional breeding, enhancing adaptability in diverse contexts (Ceccarelli et al., 2009; Almekinders and Hardon, 2006). However, while PPB has contributed to challenging conventional breeding by integrating farmers' knowledge and decentralised selection, it often remains embedded within existing breeding frameworks. SI initiatives in OFB more frequently extend this challenge beyond breeding practices to include governance, market organisation, and the valorisation of biodiversity, thereby questioning the broader socio-economic logic of the dominant system. These dynamics connect to a broader body of food sociology and political-economy scholarship on seeds as commons (Wolter and Sievers-Glotzbach, 2019), seed sovereignty as a collective right (Kloppenburg, 2005), and the role of Alternative Food Networks (AFNs) in creating market conditions that support diversity-based breeding (Goodman et al., 2012). SI in OFB can thus be read as a situated instantiation of wider struggles over who controls biological and cultural resources in food systems.

By examining 43 initiatives, we found that SI in OFB spans the entire breeding process—from priority setting and varietal development to valorisation and advocacy—and is not an external add-on but constitutive of OFB from the outset, shaping what problems are defined, which actors are engaged, and which solutions are considered legitimate. This broad and systemic engagement positions SI as a vehicle for structural change, shifting innovation from expert-led improvement to collective processes rooted in socio-cultural and agroecological contexts.

Stakeholder engagement

Inclusive, multi-stakeholder governance is one of the key features of SI initiatives in OFB. A wide array of actors—including farmers, researchers, nurseries, civil society groups, and public bodies—participate in breeding processes. These actors are not merely consulted; many cases foster co-design, shared decision-making, and mutual learning (Chiffoleau and Paturel, 2016). These dynamics can be understood as the formation of 'concerned groups', in which actors engage in the collective problematisation of breeding challenges and contribute to redefining both problems and solutions (Chiffoleau and Loconto, 2018).

Empowerment and autonomy are central to these approaches. In many analysed initiatives, especially those grounded in co-design, small-scale farmers actively define breeding goals and gain greater control over genetic resources. These participatory approaches challenge expert-dominated models and align breeding with local agroecological and cultural values (Chable et al., 2020). However, critical scholarship warns against romanticising participation. Power asymmetries often persist within collaborative platforms (Avelino et al., 2015; Pigford et al., 2018; Juarez et al., 2018). Without explicit mechanisms to address inequality, decision-making can remain concentrated in institutions or actors with greater technical or political capital, such as public research bodies (Cullen et al., 2014). This tension is visible in our data: the I cluster (Section 5.3) groups initiatives led by public research institutions that, while participatory in method, continue to adhere to conventional scientific breeding norms.

The question of ownership—of both processes and outcomes—is particularly acute in perennial crop breeding, which unfolds over long timeframes. Our findings show that without formal mechanisms to sustain engagement, collective governance may weaken over time. Long-term agreements, rotating leadership, and integration into territorial food systems or value chains can support continuity and accountability. The vulnerability of long-term governance is reflected in the concentration of SI in early breeding phases (Section 5.1); Autonomy cases such as the Italian fig conservatory show how in situ management can sustain long-term engagement through territorial rooting.

Some SI cases also involve consumers, particularly those that aim to differentiate products through the valorisation of neglected varieties or agroecological qualities. While these efforts may improve market recognition, their transformative impact is limited if consumer engagement is shaped primarily by branding, rather than by structural change in food systems (Pel et al., 2020). In short, the depth and scope of stakeholder engagement vary significantly across SI initiatives in OFB. Some foster power redistribution and co-ownership, while others risk reproducing traditional dynamics under a participatory veneer. Assessing these differences is key to understanding SI's transformative potential.

Knowledge exchange

Knowledge exchange is foundational to SI in OFB. Successful cases recognise the value of diverse expertise—scientific, experiential, technical—and establish platforms for meaningful interaction. This supports the understanding of SI as a co-constructed process rather than a linear dissemination of innovation (Moulaert et al., 2013). This reflects a pragmatist understanding of innovation in which knowledge is not transferred but collectively produced through interactions between actors, practices, and contexts (Chiffoleau and Loconto, 2018).

Our findings confirm that both farmers and breeders bring essential knowledge to OFB. Farmers benefit from understanding breeding concepts (e.g., effective population size, selection intensity), while breeders gain from farmers' field-based insights. These exchanges build on mutual respect and cross-learning, aligning with Almekinders and Hardon (2006) and Timmermann (2006), who emphasise collaborative knowledge production tailored to local needs.

Our results show that in OFB, knowledge flows are embedded within broader empowerment strategies. Collaborative initiatives often connect researchers, farmer groups, local authorities, and civil society to co-develop breeding goals, as also shown by Rossi and Bocci (2018) in the case of the wheat and bread value chain in Tuscany. Consumers may also influence selection criteria—particularly for traits like taste or storability that affect market uptake (Thiele et al., 2021). Many SI initiatives in OFB also aim to raise consumer awareness about the specificities of the sector and the value of organic fruit and biodiversity, in order to strengthen the long-term sustainability of these efforts—similar to approaches used in origin-based and biodiversity food labelling (Mariani et al., 2022).

These knowledge exchanges also shape institutional norms. In some initiatives, SI strengthens existing systems (e.g., local biodiversity governance); in others, it challenges dominant models by advocating for food sovereignty or alternative seed and food systems. Thus, knowledge exchange is not just technical—it is political and structural. It contributes to the definition and qualification of what counts as valuable knowledge, relevant traits, and legitimate breeding objectives, thereby shaping both practices and markets. This political dimension of knowledge exchange is most visible in the Empowerment model, where advocacy and institutional pressure are combined with community-based knowledge production to challenge regulatory frameworks such as DUS criteria.

Importantly, these exchanges can influence policy. Co-produced evidence and joint advocacy can shape regulatory frameworks, as seen in cases where stakeholder collaboration aims to lead to the development of new varietal standards or policy tools. This aligns with the vision of AKIS as an enabling environment for SI (EU SCAR, 2019).

Finally, knowledge exchange in OFB contributes to building social capital, as illustrated by the growing number of multi-actor knowledge platforms under development, often grounded in strong personal relationships. Trust-based collaboration reinforces collective resilience to shared challenges such as climate stress, pests, and market pressures. While some SI cases may appear marginal at first, their integration into broader systems—such as AKIS—can amplify their impact and enable scaling.

Interaction and complementarity between SI models

The interplay between different SI models emerges as a crucial factor in enabling broader transformation. Our SI conceptual matrix shows that SI in OFB operates in varied institutional and territorial contexts—ranging from highly experimental and locally grounded approaches to those more aligned with dominant markets or policy systems. Some models—centred on autonomy and empowerment—typically emerge in protected niche environments, often framed in grassroots initiatives. These are driven by actors committed to seed sovereignty, agrobiodiversity, and the ethical values of organic farming, with a disruptive character rooted in socio-political engagement and local knowledge. However, they often face challenges in scaling and long-term institutionalisation.

Other models—focused on institutionalisation or product differentiation—operate closer to the regime level, often developed or co-developed by research institutes or local institutions. These are supported by public programmes or market incentives and are oriented toward wider adoption. They may integrate and scale niche innovations through feedback loops that gradually reshape dominant systems, notably via the translation of grassroots practices into formal standards, the incorporation of participatory approaches into public research programmes, and policy support or market integration. Transformative potential depends on how SI initiatives are embedded and negotiated within institutional frameworks, as scaling can amplify impact while institutionalisation may stabilise or dilute their transformative ambitions (Rossi and Bocci, 2018). The tension between scaling and transformation is empirically visible in the L cluster (Section 5.3), where the Spanish PDO case channels biodiversity into formal quality schemes—gaining legitimacy and market recognition, but operating within rather than challenging the dominant regime. In this sense, transformation emerges as a non-linear and contested process, rather than a straightforward transition from niche to regime.

In the OFB sector, transformative change is not driven solely by grassroots initiatives, as often suggested in the literature on SI (Rossi and Bocci, 2018; Juarez et al., 2018). Rather, the complementarity between grassroots and institutional approaches enhances the transformative capacity of SI. The matrix (Section 5.3) confirms this: the absence of purely individualist initiatives and the significant central cluster suggest that SI in OFB naturally gravitates toward networked, relational configurations—which, from a TSI perspective (Avelino et al., 2019), is precisely the condition under which shifts in social relations, norms, and governance can accumulate into broader transformation (Chiffoleau and Loconto, 2018). Niche models offer radical alternatives, while regime-oriented models selectively scale and institutionalise their elements. For instance, local seed networks or community-based breeding may inspire policy reforms or certification schemes, while more formalised initiatives can provide legitimacy or market access that niche actors alone cannot achieve.

This dynamic interplay is best understood through the TSI lens mobilised in this paper. Rather than a linear diffusion from niche to regime, transformation emerges from the confrontation, negotiation, and partial alignment of heterogeneous actors co-constructing new breeding goals, norms, and governance arrangements (Avelino et al., 2019; Chiffoleau and Loconto, 2018). Concretely, three mechanisms of interaction can be identified across our cases: grassroots practices—such as community seed networks or participatory variety evaluations—generate evidence and legitimacy that can feed into policy reforms or certification schemes; formalised initiatives, in turn, provide market access, institutional recognition, and regulatory pathways that niche actors cannot achieve alone; and multi-actor AKIS platforms function as arenas where these two logics meet, enabling cross-level learning and the gradual translation of local innovations into wider practice (Rossi and Bocci, 2018; EU SCAR, 2019). Such interactions are especially critical in OFB, where overcoming fragmentation requires not a single dominant model but a coherent ecosystem of complementary SI approaches.

In conclusion, SI in OFB is not a singular or uniform process. Its transformative potential lies in the interaction of diverse initiatives, the depth of stakeholder engagement, and the quality of knowledge exchanges. When these elements converge, SI becomes a powerful driver of systemic change—reshaping not only breeding practices but also the values, institutions, and relationships that define the organic fruit sector.

Conclusion

This study demonstrates that SI plays a foundational role in redefining the OFB sector by embedding co-design, biodiversity, and locality at the heart of a new breeding paradigm. Analysing 43 SI initiatives across ten European countries, we show that SI is present across all stages of OFB—from genetic resource management to cultivar release and valorisation—and that its impact depends on three conditions that distinguish it from conventional breeding: enhancement of genetic diversity, inclusive multi-actor governance, and robust knowledge exchange networks.

To account for the empirical diversity of SI in OFB, we developed a classification matrix along two axes—governance (individual vs. collective) and socio-technical orientation (reductionist vs. holistic)—adapted from Sylvander et al. (2006) and Desclaux et al. (2009). This matrix yields four complementary SI models: (i) Empowerment, centred on collective advocacy and systemic change; (ii) Autonomy, focused on farm-level control over genetic material and local varieties; (iii) Differentiation, driven by market strategies that valorise organic fruit diversity; and (iv) Institutionalisation, supporting niche-building and policy alignment through shared standards and collective branding.

Crucially, these models are not mutually exclusive: their transformative potential lies in their interaction and complementarity. Grassroots empowerment and autonomy initiatives generate radical alternatives and nurture genetic diversity and seed sovereignty; institutionalisation and differentiation models translate these alternatives into legitimate practices, market channels, and policy frameworks. This dynamic is best understood through the lens of TSI, as established in the conceptual framework: incremental or market-oriented SI can create the enabling conditions—shifts in social relations, norms, and governance arrangements—that allow more disruptive approaches to scale and institutionalise. From the sociological lineages mobilised in this paper, transformation emerges not from a linear diffusion of alternatives, but from the confrontation, negotiation, and partial alignment of heterogeneous actors co-constructing new breeding goals and norms (Chiffoleau and Loconto, 2018). Transformation in OFB is therefore a non-linear and contested process, rooted in collective action and the reconfiguration of social relations rather than in systemic-level regime change alone.

Successful SI in OFB requires authentic stakeholder engagement, collaborative knowledge co-production, and critical attention to power asymmetries. Participatory processes must restructure decision-making—not merely consult users—and sustain long-term community involvement to avoid the risk that organic practices are absorbed into dominant agronomic paradigms without retaining their transformative ambition.

Three priority areas remain for future research: (i) better understanding the enablers and barriers of SI processes in OFB across different national and institutional contexts; (ii) exploring viable business models to sustain breeding activities outside conventional market logics; and (iii) deepening analysis of AKIS to improve its role in informing policy that supports transformative OFB. The typology and matrix proposed in this paper offer practical tools to advance this agenda and to operationalise SI across diverse agricultural innovation contexts.

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