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Heterogeneity of inter-organizational collaborations in agrifood chain sustainability-oriented innovations

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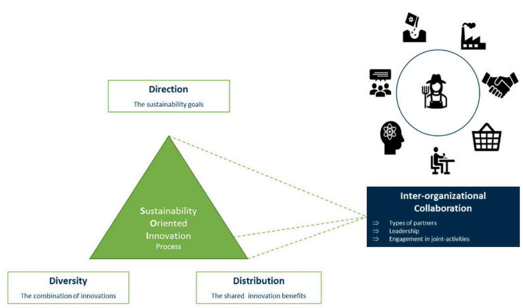
HIGHLIGHTS

- Sustainability-oriented innovation (SOI) has three dimensions: direction, diversity, and distribution
- SOI requires collaboration among multiple actors within and around the value chain
- SOI is characterised in 74 food value chains in Europe; seven clusters reveal the heterogeneity of collaboration
- The relationship between heterogeneity of collaboration and SOI dimensions provides insights for targeted innovation policy

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Sustainability-Oriented Innovation (SOI) is recognized as a way to address agrifood system sustainability challenges. Because of its complexity, SOI requires inter-organizational collaboration between actors within and around value chains. Since farming practices account for a large part of the environmental impact of food products, farmer involvement in SOI processes is key. However, there is a lack of evidence on the degree of farmer engagement in inter-organizational collaboration, as well as the diversity of partners involved. Moreover, our understanding of the heterogeneity of collaboration in relation to the sustainability dimensions of the innovation SOI processes is limited.

OBJECTIVE: The objectives of our research are twofold. First, to propose a novel conceptualization of SOI, converging the sustainability specificities of the innovation process and the characteristics of the collaboration supporting the innovation process. Second, to unpack heterogeneous forms of collaboration in SOI with attention to farmer engagement in these forms.

METHODS: We developed the SOI framework and analyzed SOI processes in the fruit and vegetable sector across Europe. A multiple correspondence statistical analysis was carried out based on data from more than one

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hundred value chains that have implemented a SOI process. A hierarchical clustering analysis was performed to reveal patterns of collaboration in SOI.
RESULTS AND CONCLUSIONS: The results show different patterns of collaborative SOI in European fruit and vegetable chains. The SOI differ as regards to three specific dimensions: the diversity, the direction, and the distribution; and they rely on various collaboration forms. Seven clusters are analyzed and discussed, with specific attention to the farmer engagement in the collaboration forms. We differentiated between 1) Intermediary-led farm & food innovation with farmer collaboration; 2) Intermediary-led short food supply chain innovation with farmer collaboration; 3) Processor-led green food product innovation without farmer collaboration; 4) Farmer-led sustainable agricultural practices innovation with a collaborative network; 5) Farmer-led coupled innovation with downstream integration; 6) value chain actor-led coupled innovation with farmer collaboration; 7) Retailer-led distribution innovation without farmer collaboration. The relationship between diverse collaboration forms and SOI dimensions is discussed.
SIGNIFICANCE: Revealing the heterogeneity of collaboration forms in SOI processes is important for developing sound policies. Given the significant role of farmers in sustainable agrifood system transitions, this paper reveals various levels of farmer engagement in collaborative SOI processes in value chains. Results have implications for mission-oriented policies since they allow a more precise and targeted approach to agrifood chains within the broader agrifood system transformation.

1. Introduction

Innovation in agrifood chains is increasingly recognized as a way to cope with grand sustainability challenges facing the agrifood sector, such as food security, climate change, biodiversity loss, and immigration (Herrero et al., 2020; Weber et al., 2020; El Bilali, 2018). Sustainability-Oriented Innovation (SOI) has received increasing attention from management scholars, to capture the intentionality of the innovation process (Adams et al., 2016; Cagliano et al., 2016; Kimpimäki et al., 2022; Urbinat et al., 2023). According to Hansen et al. (2009), the term SOI refers to the establishment of new products, processes, and/or management systems that have an overall positive effect on the capital of a company, by addressing environmental, social, and economic goals. In contrast to the traditional linear model of innovation, which follows the trajectory of basic research leading to applied research and the subsequent development of new products and processes (Von Hippel and de Jong (2010), sustainability-oriented innovation is recognized as possessing greater complexity, uncertainty, and risk. This is primarily due to its multifaceted objectives and the interconnectedness among various components of the agrifood system (Barrett et al., 2022).

One characteristic feature of SOI is that it requires more collaborative or open system approaches (Adams et al., 2016; Cagliano et al., 2016). Therefore, systemic, and open innovation, which has been considered as a factor of growth and competitiveness in the past (Chesbrough, 2003), becomes central to address the sustainability challenges in food systems (Barrett et al., 2022; Bogers et al., 2020; Medeiros et al., 2016; Wieczorek and Hekkert, 2012). The Agricultural Innovation Systems approach has shown how firms (including farmers) engage in SOI by collaborating with various stakeholders in the process of innovation (Pigford et al., 2018). Main results show the importance of inter-organizational collaboration to foster knowledge exchange between the actors of the system, and for instance stress how farmers develop knowledge networks helping them to implement sustainable farming practices (Sutherland and Labarthe, 2022) or how multi-stakeholder partnerships may foster cross-sectorial innovation (Dentoni et al.,2016). Complementary to such systemic perspective, some studies building on Sustainable Supply Chain Management (Gold et al., 2010) consider agrifood chains as pre-existing structures that link the actors of a food system in a coherent way (Ménard, 2013) and that constitute innovation spaces in the broader system (Stanco et al., 2020; Meynard et al., 2017). The need for supply chain reconfiguration is emphasized (Beske et al., 2014) as well as the multiple ways farmers can collaborate with actors of the chain, notably through joint R&D strategies, but also joint planning, and co-investments (Meynard et al., 2017).

Acquiring public support for farmers and their network in the context of SOI processes entails a comprehensive understanding of the different forms of collaboration and the contributions of the actors of the agrifood chains toward the transformation of the food system (Galli et al., 2020). Recent debates around mission-oriented agricultural innovation systems and policy further highlights the importance of understanding how the actors organize themselves to effectively pursue sustainability objectives (Kok and Klerkx, 2023).

Revealing the heterogeneity of interorganisational collaboration in agrifood chains is even more important to craft anti-competition policy in the recent CAP reform debates.[1] This notwithstanding, research on collaborative SOI is mainly conceptual, calling for further empirical studies in the agrifood sector; and several gaps exist in the literature.

First, while studies suggest that the involvement of multiple and complementary actors fosters SOI processes, the heterogeneity of collaboration forms and partners involved remains underexplored (Pigford et al., 2018; Fischer et al., 2012). Next, given the important impact of farming on the sustainability of agrifood systems and the embeddedness of farmers within agrifood chains, it is fundamental to understand how farmers are engaged in collaborative SOI. Recent research emphasized the multiple roles of farmers in innovation processes (i.e. developer, supporter or end-user) (Kernecker et al., 2021; Lacombe et al., 2018), but there is a lack of empirical evidence on their degree of engagement and the diversity of actors with whom they collaborate. While communities of practices and group of farmers peers have received lot of attention so far (Sutherland and Labarthe, 2022; Dolinska and d'Aquino, 2016), the studies of farmers engaging with other agrifood chains actors to innovate remains scarce (Cholez and Magrini, 2023; Cholez et al., 2020; Stanco et al., 2020; Bitzer and Bijman, 2015). Finally, previously mentioned studies take sustainability as a contextual starting point but fail in providing an integrated approach of collaborative SOI process. Therefore, the relationships between the inter-organizational collaboration characteristics and the SOI dimensions in terms of direction (economic, social, and environmental), diversity of innovation types (product, process, organisation) and

[1] The European Commission recently launched (January 2023) a public con sultation on how to design sustainability agreements in agricultural sector, using the novel exclusion from EU competition rules introduced during the recent reform of the common agricultural policy ('CAP'). Article 101 of the Treaty on the Functioning of the European Union ('TFEU') generally prohibits agreements between companies that restrict competition, such as those between competitors that lead to higher prices or lower quantities. However, Article 210a of Regulation 1308/2013 establishing a common organisation of the markets in agricultural products excludes certain restrictive agreements in the agricultural sector from that prohibition, when those agreements are indispensable to achieve sustainability standards. Understanding the heterogeneity of collaboration forms in the agrifood system would therefore help clarify how actors can design joint sustainability-oriented innovation initiatives in line with policy.

distribution (shared innovation benefits) need to be investigated further (STEPS Centre, 2010).

Building on these gaps, the objectives of our research are twofold. First, to propose a novel conceptualization of SOI, converging the sustainability specificities of the innovation process and the characteristics of the collaboration supporting the innovation process. Second, to unpack the heterogeneity of collaborative SOI in agrifood chains, with a specific focus on farmer engagement. The overarching research questions we seek to answer are as follows:

What is the heterogeneity of inter-organizational collaboration forms in SOI process?

How do farmers engage in these different forms of inter-organizational collaboration in SOI process?

To answer these research questions, we developed the SOI conceptual framework and applied it to the empirical setting of the fruits and vegetable (F&V) sector in Europe. The societal and governmental pressure that actors of the F&V are facing to reduce chemical inputs, plastic, and water use, while guaranteeing access to healthy food for consumers, as well as decent working conditions and revenues for farmers and agricultural workers, motivated our choice of empirical context (Liu et al., 2022). F&V value chains involve perishable products and complex domestic and international trade flows, making SOI even more challenging (Pérez-Mesa et al., 2019; Halloran et al., 2014). Recent studies pointed out the importance of collaborative innovation in F&V value chains, also calling for further analysis of collaboration forms (Boulestreau et al., 2022; Pérez-Mesa et al., 2021). Based on a survey across 118 value chains that have successfully implemented SOI, we utilize multivariate statistical analysis and hierarchical clustering analysis to reveal patterns of SOI processes, with a specific focus on their associated inter-organizational collaboration forms and the farmer engagement in these forms.

The article is organized as follows: Section 2 introduces the conceptual framework of SOI, based on a selective review of innovation systems and sustainable supply chain management literature streams. Section 3 describes the methods we used to operationalize the framework for the European F&V sector presenting the survey design and the statistical Hierarchical Clustering Analysis (HCA). Section 4 presents the results highlighting seven different SOI clusters. Section 5 provides a discussion of these SOI clusters, and Section 6 concludes, describes the limitations of the research, and presents options for further research.

2. SOI as a multidimensional inter-organizational collaborative process

While there has been an increase in scholarly interest regarding sustainability-oriented innovation (SOI) research in the management literature (Adams et al., 2016; Kimpimäki et al., 2022; Urbinat et al., 2023), there remains a gap in the conceptualization of research on the ways actors organize innovation processes for sustainability within their value chains (Kaufmann and Danner-Schröder, 2022). Section 2 proposes to address this gap by conceptualising SOI as a multidimensional innovation process that relies on inter-organizational collaboration. For doing so, we first present three specific dimensions of the SOI process, namely the direction, diversity, and distribution (sub-section 2.1.) and we then address the inter-organizational collaboration characteristics namely the type of actors, the leadership, and their engagement in joint activities (sub-section 2.2.).

2.1. The three dimensions of SOI process: Direction, diversity, and distribution

SOI can be conceptualized as regards to three dimensions, that we develop hereafter: the direction, the diversity and the distribution.

2.1.1. The direction of SOI

What differentiates SOI from other models of the innovation process is, first, that the change is targeted at sustainability improvement (Adams et al., 2016). However, sustainability is a broad concept that may cover different dimensions, including environmental, social, and economic. While Adams et al., (2016: 180) claims that "SOI involves making intentional changes to an organization's philosophy and values, as well as to its products, processes or practices to serve the specific purpose of creating and realizing social and environmental value in addition to economic returns", in reality, often not all three pillars are included the innovation outcomes. Therefore, we argue that the SOI model should make explicit which type of sustainability is achieved with the SOI. We call this the direction of the SOI.

While the term of *sustainable innovation* is more widespread in the agrifood sector literature (El Bilali, 2019), the term *sustainability-oriented* innovation better reflects the process nature of innovation. It is the innovation process that is oriented toward improvements in sustainability. Because of the interconnexion between social, economic, and environmental dimensions, SOI involves an important level of complexity (Cagliano et al., 2016). This also translates into a high uncertainty about the outcomes of the innovation process, since there are trade-offs among the different sustainability dimensions and the combined effect is difficult to predict (Fischer et al., 2012). As a result, sustainability studies mostly look at the environmental dimension of the innovation, with a focus on more efficient resource use in the agrifood sector, but overlook the socio-economic dimensions (Adams et al., 2016).

2.1.2. The diversity of SOI

Diversity refers to the combination of diverse types of innovation across the value chain, including technological, organizational, and institutional innovations. The transition toward more sustainability cannot only rely on technological changes such as new products or new production methods. SOI also involves organizational innovation, such as the development of new routines, the implementation of new management structures and the use of new communication channels (Adams et al., 2016).

Social sciences research on SOI in the agrifood sector has long focused on sustainable agricultural practices and technologies such as precision and smart farming, regenerative agriculture, agroecological practices, agroforestry, biodiversity conservation-oriented agriculture (Kernecker et al., 2021; Vermunt et al., 2020); while socio-economic studies on novel foods products and processes remain limited (Meynard et al., 2017). Moreover, studies encompassing both types of innovations are scarce, even though academics have stressed the need for coupled innovation (Boulestreau et al., 2022; Meynard et al., 2017) or co-innovation (Bitzer and Bijman, 2015). More recently, organizational innovation has also received attention from scholars, including research on short food supply chains (Chiffoleau and Dourian, 2020), contractual arrangements (Cholez et al., 2020) or sustainability certification schemes (Loconto and Hatanaka, 2018). These innovations are located at different steps of the value chain.

2.1.3. The distribution of SOI

The direction and diversity of SOI influences the nature of the outcomes of the innovation process: economic, social, and environmental benefits. These innovation benefits are distributed (shared) among the actors participating in the innovation process. In addition, positive externalities may benefit external stakeholders. For instance, including grain legumes in crop rotation leads to a reduction in the use of chemical fertilizers in the succeeding crop, translating into costs saving for the farmers, as well as environmental benefits for the society (Magrini et al., 2016). However, innovation benefits are not necessarily distributed equally across the participating actors and depends on the governance rules established for the collaboration.

The issue of fair value sharing in the value chain is particularly present in the sustainability debate, given that most markets are characterised by atomization on the side of the farmers and oligopoly on the side of food processors and retailers side (Deconinck, 2021). Furthermore, the introduction of digitalization in agri-food presents the risk of exacerbating power imbalances between farmers and other actors of the value chain (Giagnocavo et al., 2017).

From a normative point of view, SOI should enable a fair innovation benefit sharing among the value chain actors (Cagliano at el., 2016). Therefore, from an analytical perspective, taking into consideration the distribution of SOI (i.e. how innovation benefits are shared) is key (Cagliano et al., 2016).

The chosen direction of the innovation process, the diversity of the innovations implemented, and the distribution of the innovation benefits are all related to the form of collaboration among the value chain actors involved in the innovation process.

2.2. Inter-organizational collaboration in the SOI process

The SOI process starts with incremental changes being initiated by a firm as a response to external stimuli (e.g., legislation or market demand) and progressively evolves with more radical and pro-active changes beyond the boundaries of the firm (Klewitz and Hansen, 2014). While inter-organizational collaboration plays a key role in these system changes, literature reflects the existence of various collaborative structures in SOI processes, with several ways of categorizing the actors and their activities (Wieczorek and Hekkert, 2012). While the differentiation of actors as regards to their roles (i.e., user, producer, supporter) has long prevailed in innovation studies, recent literature shows that these roles are interwoven (Hermans et al., 2013). In a case study on smart farming technologies, Kernecker et al. (2021) show that farmers could successively take the role of developer, supporter, and end-user, and that these roles evolve throughout the innovation process. As a result, Wieczorek and Hekkert (2012) suggested categorizing the actors with respect to their role in economic activity: companies, civil society organizations (CSO), non-governmental organizations (NGO), research institutes, knowledge brokers and consultants.

Traditional studies on collaboration value chains have focussed on improving efficiency, logistics, quality control and information exchange (Hernandez et al., 2020). Innovation-oriented collaboration also referred as open-innovation practices specifically targeted improved food products, for which several actors in the chain had to change their operations to respond to consumer demand (Medeiros et al., 2016). But broader perspective on collaboration has also gained a renewed interest, including not only the partners in the value chain but also other public and private stakeholders of the agrifood system that can contribute to making farming processes and food products more sustainable (Adams et al., 2016). Agricultural Knowledge and Innovation System (AKIS) literature takes this broader perspective, exploring how farmer decision-making is facilitated not only by knowledge content, but also by the (quality of the) knowledge flows across diverse organizations. The complex challenges involved in making agrifood chains more sustainable have made the traditional agents of knowledge transmission and innovation, such as extension services and applied research institutes, less influential. Current agricultural innovation models therefore emphasize co-creation, co-design, open innovation, and peer learning with the involvement of many actors, from value chain partners to financial service providers, non-governmental organizations, civil society, and public authorities (EU SCAR AKIS, 2019). Pigford et al. (2018) go even beyond AKIS in their call for adopting an Agricultural Innovation Eco-System (AIES) perspective emphasizing the importance of cross-sector and cross-disciplinary collaboration through multi-stakeholder partnerships (Barzola Iza et al., 2020; Dentoni et al., 2016; Dentoni and Bitzer, 2015), and innovation intermediaries acting as a bridge between farmers and societal stakeholders (Kivimaa et al., 2019; Klerkx and Leeuwis, 2009).

While the collaboration between farmers and societal stakeholders is important for steering SOI, the partnerships between farmers and traditional actors of the value chain remain of high relevance in tackling the wicked problem of sustainability (Magrini, 2023; Brun et al., 2021; Meynard et al., 2017). Beyond traditional sales transactions, agrifood chain actors also collaborate to reach sustainability goals through innovation both in long and short supply chains (Chiffoleau and Dourian, 2020; Tepic et al., 2013). Our scholarly understanding of SOI-processes would therefore benefit from a more systematic analysis encompassing all the types of partners in and around the value chain, to highlight different collaboration forms for SOI.

The type of actor taking the lead (referred as leadership in this article) influences the subsequent SOI-process. Some studies suggest that a farmer-led collaborative SOI-process is more likely to respond to farmer needs and expectations and to provide a fair benefit sharing (Ensor and de Bruin, 2022; el Bilali, 2019). Other studies show the transformative potential of consumer-led collaboration (Chiffoleau and Dourian, 2020). Yet, our knowledge on the impact of distinct types of leadership in SOI remains scattered, calling for a more systematic analysis of the leadership in SOI in value chains.

The engagement level of the partners in the collaboration in SOI process varies, also justifying the existence of diverse governance structures (Ménard, 2013). While exchange of knowledge and R&D are the focus of the innovation system literature, the partners can be involved in other (joint) activities, encompassing decision-making and planification on production and marketing, as well as common investment in (material and immaterial) resources (Cholez et al., 2020; Stanco et al., 2020; Meynard et al., 2017). The pooling of decision and resources results from the actors' acknowledgement of the technological interdependencies and complementarities, as well as the expected benefits in the form of reduced transaction costs, reduced risk, and improved bargaining power (Ménard, 2013; Barratt, 2004).

Finally, existing studies use sustainability as a starting point and take the sustainability elements for granted, but they fail in providing an integrated approach in linking the collaboration characteristics (types of partners, leadership, and engagement) with the dimensions of SOI as described in section 2.1. (direction, diversity, distribution). Moreover, while farmers are considered as key agents of changes in the sustainability transition, their position and engagement in inter-organizational collaboration in SOI-processes need to be further explored.

Our empirical study enables us to explore collaborative SOI process, and to progress on an analytical framework linking the nature of inter-organizational collaboration to the three dimensions of SOI (Fig. 1).

3. Material and methods

We have analyzed SOI processes in 74 fruit and vegetables (F&V) value chains, inventoried in the H2020 CO-FRESH project.[2] The heterogeneity of SOI processes in agrifood chains is analyzed, as regards to its three dimensions (direction, diversity, distribution) and its inter-organizational collaboration characteristics, with an attention given to the farmer engagement in the collaboration. Data collection (further developed in sub-section 3.1.) relied on an innovation tracking participatory method, and a survey addressed fruit and vegetable value chains in Europe. Data analysis (further developed in sub-section 3.2.) consisted of statistical analysis of qualitative data, namely a Multiple Correspondence Analysis, followed by a Hierarchical Clustering Analysis (HCA). The choice of the HCA method fits our ambition to illustrate the diversity of SOI processes and to highlight patterns.

3.1. Data collection

The European F&V sector is characterised by a high diversity of farming systems (open field, greenhouses, permaculture), the co-existence of domestic and export markets as well as short and long

[2] CO-creating sustainable and competitive FRuits and vEgetableS' value cHains in Europe More information at: https://co-fresh.eu/

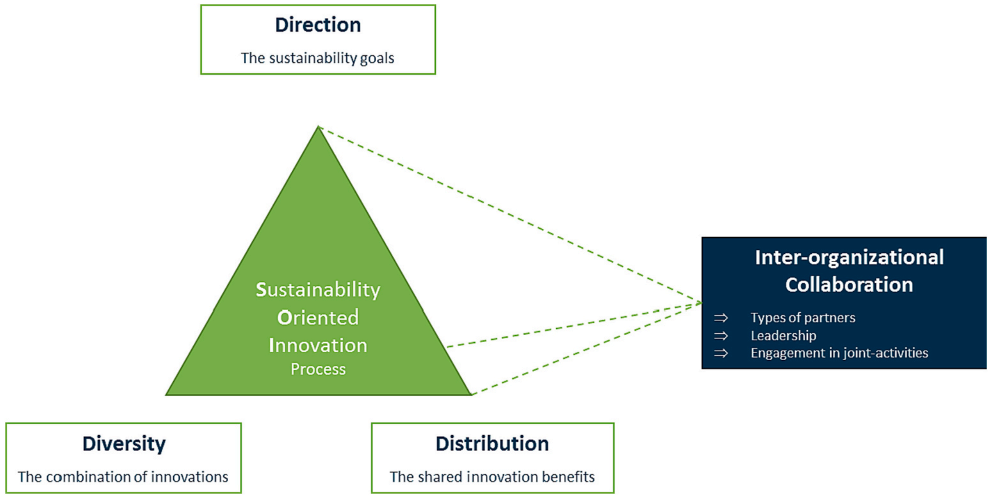

Fig. 1. Inter-organizational Collaboration in the Sustainability-Oriented Innovation process.

value chains (Pérez-Mesa et al., 2019). The F&V sector is facing sustainability challenges related to water use, climate change, energy use and pesticide use (Liu et al., 2022). The reduction of food loss and waste is also key, as F&V are perishable products and give rise to more food waste compared to grain crops (Halloran et al., 2014). While the literature on sustainability in the F&V sector emphasizes the environmental dimension (García-Granero et al., 2020), socio-economic challenges related to working conditions and living wages are also a high priority.

To identify and inventory a diversity of SOI in the F&V sector, we used the innovation tracking approach. According to Salembier et al. (2021: 61), innovation tracking refers to "an active process leading to the discovery of innovations (in contrast with encountering them 'by chance'); […] an investigative process driven by intentions, involving data collection and analysis and the production of outputs and outcomes". The innovation tracking approach is a non-random selection approach that aims at intentionally discovering some innovations in a delineated system/population, without considering the relative share of these innovations in the system/population under study. This method was originally developed for innovations on farming practices such as "basic technique (e.g. an intercrop), equipment, or an agricultural system (e.g. cropping system, livestock system, couples of equipment, and cropping systems)" (Salembier et al., 2021:61). The approach was afterward extended to encompass a broader set of innovations and the processes underlying their emergence in agrifood chains (Boulestreau et al., 2022; Salembier et al., 2021). Following this approach, our data collection was carried out in two steps: (1) an inventory of cases of collaborative SOI in value chains; and (2) a survey among the leading organizations of the SOI to collect data on the SOI dimensions (direction, diversity, distribution) and the characteristics of the collaboration (actor types, leadership, and farmer involvement).

The innovation tracking followed a participatory approach involving the 26 partners of the CO-FRESH project, under the lead of the authors. The authors defined minimum requirements and selection criteria to guide the partners in their search for SOI in fruits and vegetables value chains in Europe (all species included) Table 1 summarizes the operationalisation of the concepts and the selection criteria.

Table 1
Selection criteria for guiding the tracking of Sustainability-Oriented Innovation.

Criteria	Inclusion rule
Collaboration	At least two organizations of the value chain are involved
Direction	At least two of the three pillars of sustainability (economic, social, environmental) are targeted
Diversity	At least two types of innovations (technological, organizational) are implemented
Distribution	At least two organizations of the value chain benefit from the innovation

Selection criteria were reported to the CO-FRESH partners at the end of April 2021 through emails, and during a workshop on 20th of May 2021. The identification of the value chain complying with the criteria remained the responsibility of each of the 26 CO-FRESH partners under the general coordination of the authors. A template was created by the authors to collect basic information on the value chain such as the type of crop, the final product, and its type (fresh or processed); the description of the activities and organizations involved in the value chain; and the geographical scope of the chain.

The innovation tracking phase resulted in an inventory of 118 value chains where SOI had been implemented. Annex A presents the list of innovations inventoried, and the related dataset is available in open-access on Zenodo.[3] For each value chain, the focal organisation (i.e., the organisation that has been leading the SOI process) was identified.

After the value chain identification, a survey was designed to deepen our understanding of collaboration for SOI. The objective of the survey was to triangulate the data collected by the partners during the innovation tracking and to collect additional information on the SOI dimensions and its collaboration characteristics. The survey, designed in English and translated in eight languages, was implemented on-line in July 2021, and was addressed to the focal organisation that has led the SOI process ($n = 118$). From the 118 focal organizations to which we sent the survey, we received 74 usable responses (see Annex B for characteristics of the sample).[4]

3.2. Multiple correspondence analysis and hierarchical cluster analysis

To analyse our data ($n = 74$) and identify patterns of SOI, we conducted a Multiple Correspondence Analysis (MCA) followed by a Hierarchical Cluster Analysis (HCA), using R software with the package FactoMineR (Lê et al., 2008). All variables in our survey are qualitative categorical variables, most of them relying on Likert Scale. Due to the respondent's subjectivism in their perception of the categories of the ordinal scales, it was not appropriate to use statistical tools for continuous variables, and we chose to work with the traditional set of statistical tools appropriate for multivariate nominal and categorical variables analysis (relying on Chi-square distance). Also, while the Chi-square test enables to measure the association between a pair of variables, revealing whether two variables are dependent or not, the

[3] https://zenodo.org/record/6566021

[4] The interview guide and final dataset ($n = 74$) are available upon request.

advantage of the MCA is that it enables us to explore simultaneously the relationships between variables, with analysis being done at the level of the modalities. For these reasons, MCA was determined to be the best factor analysis method for our data and was used as pre-treatment of our data before doing the HCA (on the principal components). Table 2 presents the list of 17 variables we used for the MCA, and the distribution of their modalities (in total 55). The variables address the dimensions of SOI (direction, diversity, distribution) and the characteristics of the collaboration (actor types, leadership, farmers involvement).

The HCA was done based on the MCA object score and enabled us to identify clusters of SOI that have similar patterns. In other words, the HCA gathers the SOI cases into the same cluster when they have the same specific combination of dimensions. We based our HCA on the Euclidian matrix distance and Ward's criterion aggregation method. The choice of the appropriate number of clusters was guided by the Calinski-Harabasz pseudo-F index score (Caliñski and Harabasz, 1974).

A Chi-square test enabled us to analyse which variables are discriminating the clusters the most. In addition, the interpretation of the clusters was based on the over- or under-representation of modalities in each cluster compared to others. For identifying the modalities characterising the cluster, we performed a hypergeometric test on the number of cases in Cluster 1, comparing the proportion of the modalities of a variable x to its proportion in the global population; a similar test was done for each cluster and each modality of the set of variables (Lê et al., 2008).

4. Results

Based on the methodology described in Section 3, we derived seven clusters. The first 10 dimensions of the Multiple Correspondence Analysis explains around 60% of the variance of our data (Annex D). We used the coordinates of the 74 respondents on these dimensions to run the HCA. Based on the calculation of Calinski-Harabasz pseudo-F index score (see Annex C), we chose a classification in seven clusters, as illustrated in the following dendrogram (Fig. 2).

4.1. Cluster characterization

Based on Chi-square test, Annex E presents the sorting of the variables from the more discriminating (lowest *p*-value) to the lowest (highest p-value). Below we discuss the results of the HCA for each cluster. We present the modalities that are overrepresented in a cluster compared to the total number of observations ($n = 74$). We only discuss the modalities for which the p-value is equal to or lower than 0.05 (see Annex F for the details per cluster).

Table 3 summarizes the modalities that are discriminant for each cluster. For conciseness, we gathered the variables that refer to a similar aspect of collaboration namely farmer engagement in joint-activities and the types of partners in the collaboration. Therefore, the row "farmer engagement in joint activities" refers to the significant modalities of the following variables: Kn_farmer; Rd_farmer; Pl_farmer; In_farmer. The row "importance of collaboration with diverse actor types" refers to the significant modalities of the following variables: Collabimp_insup; Collabimp_proc; Collabimp_trad; Collabimp_ret; Collabimp_cons; Collabimp_pri; Collabimp_psp; Collabimp_ngo.

Cluster 1 is composed of 9 observations (accounting for 12% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: As regards to the diversity, innovation concerns both farming practices and food product or process. Innovation is led by intermediaries which include input suppliers, research institutes, innovation brokers. Farmers take part in joint R&D activities but there is no joint-investment or pooling of resources. Collaboration with processors is important or very import for the implementation of the innovation as well as with inputs suppliers, consumers research institutes, and innovation brokers. The direction and the distribution of innovation benefits

Table 2
Variables used for the MCA and their modalities distribution.

Variable name	Description	Modalities	N*
Direction, diversity, and distribution			
Dirinnov	Combination of the two most important sustainability objectives of the SOI (With Eco = economical; Soc = social; and Env = environmental)	1 = EcoEnv	16
		2 = EcoSoc	15
		3 = SocEnv	11
		4 = SocEco	9
		5 = EnvEco	11
		6 = EnvSoc	12
Diversinnov	Combination of innovations (With Farm = new farming practices; Food = new food products or processes; Distri = new way of distributing the final product to the consumers)	1 = Farm	8
		2 = Food	10
		3 = Distri	6
		4 = FarmFood	16
		5 = FarmDistri	6
		6 = FoodDistri	6
		7 = FarmFoodDistri	22
Internorg	Organizational changes within the leading organisation of the SOI process	2 = No	18
		1 = Yes	56
Farmrev	Enhancement of farmers revenue resulting from the SOI	1 = No impact	10
		2 = Minor/Moderate impact	25
		3 = Strong/Extreme impact	39
Inter-Organizational Collaboration characteristics			
Leader	Which actor leads the SOI process	1 = Farmer or farmers organisation	34
		2 = Processing company	20
		3 = Trader or wholesaler	6
		4 = Retailer	7
		5 = Intermediaries incl. Inputs suppliers, research institutes, innovation brokers	7
Kn_farmer	The collaboration involves exchange of knowledge and ideas with farmers	2 = No	33
		1 = Yes	41
Rd_farmer	The collaboration involves joint research and development activities with farmers	2 = No	53
		1 = Yes	21
Pl_farmer	The collaboration involves joint planification with farmers (on production or marketing)	2 = No	46
		1 = Yes	28
In_farmer	The collaboration involves joint investment and pooling of resources with farmers (for production or marketing)	2 = No	53
		1 = Yes	21
Collabimp_insup	Importance of collaborating with an inputs supplier for the SOI implementation	1 = Not at all important	23
		2 = Slightly/Moderately important	16
		3-Important/Very important	35
Collabimp_proc	Importance of collaborating with a processor for the SOI implementation	1 = Not at all important	24
		2 = Slightly/Moderately important	28
		3 = Important/Very important	22
Collabimp_trad	Importance of collaborating with a trader for the SOI implementation	1 = Not at all important	23
		2 = Slightly/Moderately important	15
		3 = Important/Very important	36
Collabimp_ret	Importance of collaborating with a retailer for the SOI implementation	1 = Not at all important	26
		2 = Slightly/Moderately important	19
		3 = Important/Very important	29
Collabimp_cons	Importance of collaborating with consumers for the SOI implementation	1 = Not at all important	10
		2 = Slightly/Moderately important	15

(*continued on next page*)

Table 2 (*continued*)

Variable name	Description	Modalities	N*
		3 = Important/Very important	49
Collabimp_pri	Importance of collaborating with a public research institute or governmental agencies for the SOI implementation	1 = Not at all important	13
		2 = Slightly/Moderately important	22
		3 = Important/Very important	39
Collabimp_psp	Importance of collaborating with a private services provider for the SOI implementation	1 = Not at all important	15
		2 = Slightly/Moderately important	26
		3 = Important/Very important	33
Collabimp_ngo	Importance of collaborating with a Non-Governmental Organisation for the SOI implementation	1 = Not at all important	29
		2 = Slightly/Moderately important	23
		3 = Important/Very important	22

* Occurrence of the modality i.e. number of observations of the modality over the total population ($n = 74$).

(here, benefits on farmers revenue) are not significantly different than in the global population.

Cluster 2 is composed of 11 observations (14.86% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: The direction of the SOI is first social improvement and second, economic improvement, the environmental last. As regards to the diversity, the innovation concerns farming practices in combination with the way the final products are distributed from farmers to consumers. As regards to the distribution, the impact on enhancing farmers revenue is (very) important. Innovation is led by intermediaries. Collaboration with a processor is not considered at all important, while collaboration with an NGO is viewed to be (very) important. Farmers are involved in the SOI collaboration particularly for knowledge exchange.

Cluster 3 is composed of 12 observations (16.22% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: The direction of the innovation is first environmental, and second, economic improvement. As regards to the diversity, the innovation concerns only food product or food process. As regards to the distribution, there is no impact noted at all on enhancing farmer revenue. The leader of innovation is a processing company. There is no knowledge exchange with farmers, nor R&D activities with farmers, and no joint-investment. Collaboration with NGOs is considered not important.

Cluster 4 is composed of 13 observations (17.57% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: As regards to the diversity, the innovation concerns only farming practices. The leaders of the innovation process are farmers. Collaboration with other value chain actors is considered slightly to moderately important. These other actors include consumers, retailers, processors, traders, and inputs suppliers.

Cluster 5 is composed of 12 observations (16.22% of the sample). The modalities that are significantly overrepresented in that cluster are as follows: As regards to the diversity, the innovation concerns a combination of farming practices, food product or process, and the way the product is distributed from farmers to consumers. As regards to the distribution, the impact on enhancing farmers revenue is not significantly different than in other clusters. The innovation is led by farmers. Collaboration is considered not important at all for the success of the innovation.

Cluster 6 is composed of 13 observations (17.57% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: The direction of innovation targets first economic, second social, and finally, environmental improvement. As regards to the diversity, the innovation concerns a combination of farming practices, food product or process, and the way the products are distributed from farmers to consumers. As regards to the distribution, there is a minor to moderate impact of the innovation on farmer revenues. Farmers are involved in joint-investment and pooling of resources, joint planning of production and marketing, joint R&D, as well as knowledge exchange. The collaboration with traders is (very) important for SOI implementation.

Cluster 7 is composed of 4 observations (5.41% of the sample). The modalities that are significantly overrepresented in this cluster are as follows: The direction of the innovation is first social, second environmental, and last economic. As regards to the diversity, the innovation only concerns the way the product is distributed from farmers to

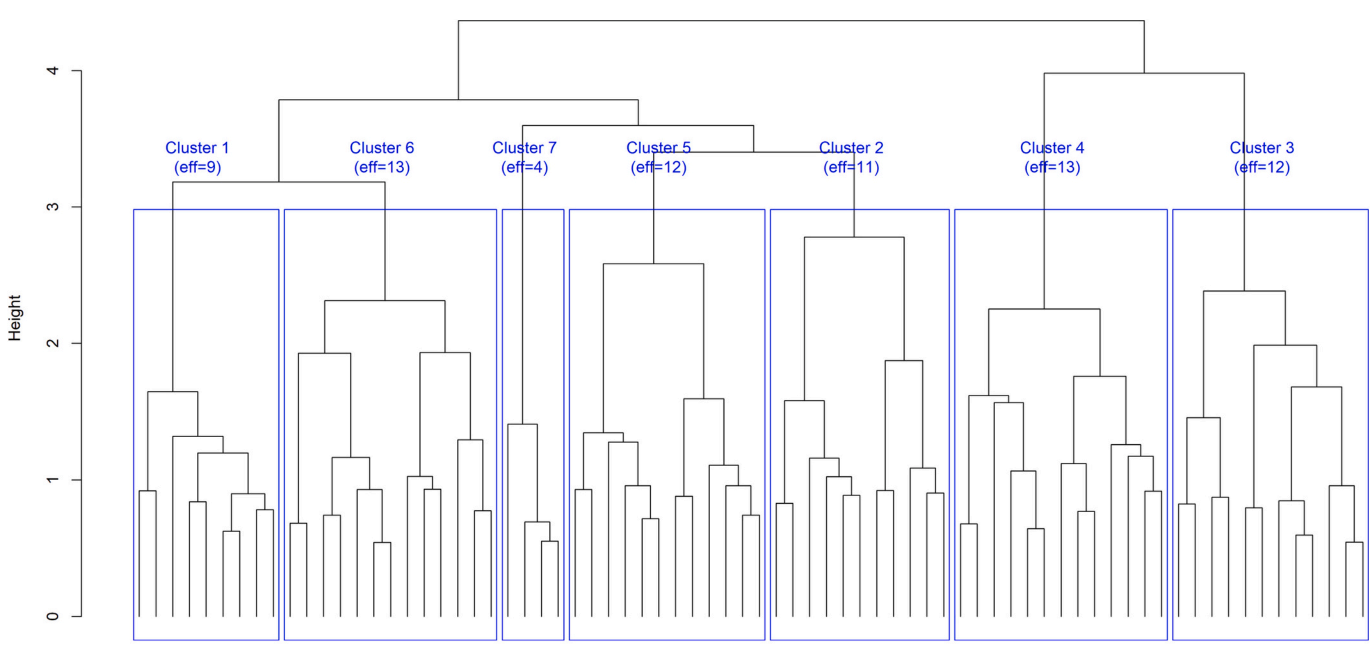

Fig. 2. Hierarchical Cluster Analysis Dendrogram ($n = 74$).

Table 3
Clusters characterization.

SOI dimension	Cluster 1 ($n = 9$)	Cluster 2 ($n = 11$)	Cluster 3 ($n = 12$)	Cluster 4 ($n = 13$)	Cluster 5 (n = 12)	Cluster 6 (n = 13)	Cluster 7 ($n = 4$)
Label	*Intermediary-led farm &food innovation with farmer collaboration*	*Intermediary-led SFSC innovation, with farmer collaboration*	*Processor-led green food product innovation, without farmer collaboration*	*Farmer-led SAP innovation with a collaborative network*	*Farmer-led coupled innovation with downstream integration*	*Agrifood chain actor led-coupled innovation with farmer collaboration*	*Retailer-led distribution innovation without farmer collaboration*
Direction, diversity, distribution							
Dirinnov	NS	SocEco**	EnvEco*	NS	NS	EcoSoc**	SocEnv*
Diversinnov	FarmFood*	FarmDistri**	**Food*** **	**Farm*** **	**FarmFoodDistri*** **	FarmFoodDistri**	**Distri*** **
Farmrev	NS	Strong extreme**	**No impact*** **	NS	NS	**Minor/ Moderate*** **	NS
Inter-Organizational Collaboration characteristics							
Leader	Intermediary*	Intermediary**	**Processor*** **	Farmers *	Farmers**	NS	**Retailers*** **
Farmer engagement in joint-activities	**R&D*** **	Kn*	**No Kn*** ** No R&D* No In*	NS	NS	Kn* R&D* Pl** **In*** **	**No Kn*** ** No R&D* No In*
Importance of collaboration with diverse actor types	**(very) important processors*** **, inputs suppliers**, consumers*, public research institutes*, private service providers*	(very) important with NGO* not important at all with processors*	not important at all with NGO*	**(slightly)moderately important with consumers*** **, **retailers*** **, processors**, traders**, inputs suppliers**, public research institutes*	**not important at all with NGO*** **, public research institutes**, traders**, consumers**, private service providers*, processor*	(very) important with traders**	not important at all with NGO*

Note: *** indicates p-value <0,001, ** indicates *p*-value<0,01, * indicates p-value<0,05 and "N.S." stands for non-significant indicating that the p-value is >0,05. SFSC: Short Food Supply Chain; SAP: Sustainable Agriculture Practice; NGO: Non-Governmental Organisation.

consumers. The leader of the innovation process is a retailer. There is no knowledge exchange with farmers, nor R&D activities with farmers, and no joint-investment. Collaboration with NGOs is considered not important.

4.2. Cross-cutting description

The seven clusters present similarities and differences enabling us to highlight different degrees of (i) farmers engagement (or not) in the collaboration (ii) and patterns of SOI dimensions.

(i) Farmers engagement in the collaboration in SOI process.

We found SOI processes that do not include farmers, and others that do involve farmers, either as leaders or as participants. In our sample, the SOI processes led by processors (Cluster 3), or retailers (Cluster 7) have significantly less farmer engagement than the global population (of SOI processes under study), meaning that farmers are not engaged in knowledge exchange and R&D nor in joint-investment regarding the production or marketing. Opposite to these SOI where farmers are absent, other SOI processes rely on inter-organizational collaboration involving farmers. Findings enable us to differentiate between SOI in which farmers are leaders (Clusters 4 and 5) and SOI in which farmers are participants while it is led by an intermediary (Clusters 1 and 2) or any other actor in the value chain (Cluster 6). In the farmer-led SOI processes, we found that collaboration with multiple stakeholders including value chain actors and actors of the AKIS such as public research institutes can be important (Cluster 4) or not important at all (Cluster 5). While Cluster 4 may refer to an SOI process in which farmers are part of a knowledge or R&D collaborative network, Cluster 5 reveals a process of empowering farmers that does not necessarily rely on strong network collaboration. Finally, findings show that in intermediary-led collaboration, farmers engagement concerns knowledge exchange and R&D (respectively Clusters 2 and 1), and that the collaboration involves a limited set of actors (such as in Cluster 2 in which the collaboration rely strongly on NGO but not at all on processors), or a broad range of actors (such as cluster 1 in which the collaboration includes processors, input suppliers, consumers, public research institutes and private service providers). Compared to these intermediary-led collaborations, Cluster 6, in which the collaboration is led by any value chain actor, presents more farmer engagement, including not only knowledge exchange and R&D, but also planification of production, marketing, and joint investment.

(ii) SOI diversity, direction, distribution.

Next to the collaboration forms in SOI process, we also explored the diversity, direction, and distribution of benefits of the innovation process. Commencing our cross-cutting analysis with the diversity of SOI, we found a distinction between single innovation and combined (or coupled) innovations. The single innovation process focused on the core technological step/activity of the innovation leader. Examples are new farming practices for the farmer-led SOI (Cluster 4), new product development for the processor-led SOI (Cluster 3), and new distribution channels for the retailer-led SOI (Cluster 7). In all the other clusters, the innovation process is based on a combination of innovations across the various stages of the value chain, such as new farming practices and new food product development (Cluster 1); farming and food distribution (Cluster 2); and farming with new food product and distribution (Clusters 5 and 6).

Continuing the cross-cutting analysis as regards to the direction of SOI, even though SOI is theoretically targeting the three dimensions of sustainability, the results show which dimension the value chain actors prioritize to orientate the innovation process. In the overall sample, the economic dimension is therefore a priority direction for 42%, the environment a priority direction for 31%, and the social a priority for 27%. Cluster 6 prioritizes significantly more the economic dimension, while Cluster 4 and 5 also prioritize economic dimension but following the tendency of the global sample population). We found that the environmental dimension of sustainability is a significant priority direction only for the processor-led innovation on food product (Cluster 3). The social dimension of sustainability is a priority orientation for the retailer-led innovation on food products distribution (Cluster 7). As cluster 7 is not characterised by strong collaboration with farmers, the social orientation of this innovation is a concern of consumers. The social dimension is also considered a priority direction for the intermediary-led SOI targeting new ways of distributing products in combination with new sustainable farming practices (Cluster 2). The SOI of this cluster are characterised by the non-importance of collaborating with the processors, suggesting that the products distribution innovation aims at shortening supply chains, subsequently enhancing social links between consumers and farmers.

Finally, results provide insights on the distribution of SOI, and more specifically, on the enhancement of farmers revenues. Regarding the distribution of benefits in the overall sample, the impact of SOI on farmers revenue is considered strong/extreme for 53%, minor-moderate for 34% and null for 13%. There are no significant differences regarding this variable repartition in four of the clusters (Clusters 1, 4, 5 and 7), indicating that this variable does not differentiate substantially in the clusters. For the three remaining clusters, we found that Cluster 2 is significantly characterised by a positive impact on farmer revenues, Cluster 6 by a significant minor/moderate impact on farmer revenues, and Cluster 3 by a significant null impact on farmer revenues.

5. Discussion

Our results enable us to discuss and challenge several assumptions on innovation processes toward sustainability currently found in the literature. We discuss the degree of openness of the innovation process in agrifood value chains in relation to other dimensions of SOI (diversity, distribution, and direction). Openness of the innovation process in value chains is qualitatively assessed according to the characteristics of the collaboration (types of partners, leadership, and farmer engagement in joint activities). Here we highlight the controversies which were found in our results.

5.1. Controversy 1: the degree of openness of the innovation process and the diversity of the innovation

Literature on SOI-processes tends to emphasize the need for a diversity of innovations (both technological and non-technological) along the value chain (Barrett et al., 2022) and suggests that the required combination of innovations can be fostered by collaboration between various actors, that is, by open innovation (Riccaboni et al., 2021; Kimpimäki et al., 2022). Because of the interdependencies among the distinct stages of the value chain, co-creation of coupled innovations would have a stronger transformative impact on sustainability, compared to non-collaborative innovations in one stage (Meynard et al., 2017; Bitzer and Bijman, 2015). However, our results show that, in the SOI processes observed in the F&V sector, the relationship between the diversity of SOI and the degree of openness of the SOI-process is not straightforward, as illustrated by the comparison of two farmer-led innovation processes (Clusters 4 and 5). Cluster 5 represents a coupled innovation process combining new farming practices with new food processes and new forms of distribution, yet the innovation relies on limited collaboration. On the contrary, cluster 4 represents an open-innovation process that is focused on the farm level (sustainable agricultural practices), while involving farmers and a broad range of partners such as food processors, retailers, consumers, and research institutes. One interpretation is that cluster 5 results from a farmer strategy of diversification into food processing and retail. While diversification of the farm has already received attention since the 1960's, as a value capturing strategy for farmers (McElwee and Bosworth, 2010), value chain innovation and downstream integration strategies are enjoying renewed interest in the context of SFSC. Examples of such SOI in our dataset include the in-house valorisation of pumpkin seeds in innovative healthy snacks, sold through a farmer-owned e-shop, and the creation of an on-farm restaurant valorizing fruits and vegetables into healthy smoothies. These in-house innovation strategies are of limited scale and are developed within family-farm businesses (Chiffoleau and Dourian, 2020). In contrast, cluster 4 reflects a strategy in which farmers innovate only on agricultural practices but seek the support of a broad network of actors, as emphasized in AKIS studies (Sutherland and Labarthe, 2022).

5.2. Controversy 2: the degree of openness of the innovation process, farmer engagement, and the distribution of benefits

The challenges of fair benefit sharing (referred as distribution in this article) have been a long-standing research topic in innovation literature, also known as the 'paradox of openness' in which the actors contributing the most to the innovation process are not always the ones that benefit the most (Teece, 1986; Chesbrough, 2003). At the same time, the literature on SOI stresses the importance of fair benefit sharing among the actors of an innovation process (Cagliano et al., 2016) and suggests that involving more actors in the innovation process can prevent that value is captured by only one actor (Rialti et al., 2022; Rauter et al., 2017). The agricultural innovation systems literature suggests that the inclusion of farmers in the innovation process would ensure not only their contribution to value creation, but also their capturing of part of the value generated (Barrett et al., 2022). Our results allow us to discuss this assumption. Cluster 3, although an example of successful SOI, supports the assumption by showing that SOI, as a closed innovation process with no collaboration nor farmer engagement, does not generate farmer benefit. Contrary to this, Cluster 6 shows a high engagement of farmers (notably collaboration with a trader), resulting in a positive impact on farmer benefit. Therefore, the degree of farmer engagement in collaboration remains key to explain the innovation benefit sharing (i.e. the distribution of SOI) along the value chain, as also illustrated by the comparison between Cluster 7 and 2. In both clusters, the innovation on product distribution aims at shortening the value chain, avoiding intermediaries appropriating a share of the value. However, Cluster 7 does not show improved farmer benefit, which could be explained by the fact that farmers are not taking part in the collaboration directly, even though the way of distributing products is considered innovative since it reduces intermediaries. Contrary to Cluster 7, in Cluster 2 farmers are included to some extent for knowledge exchange. The fact that the leader of the innovation process is not a value chain actor and that the collaboration with an NGO is important also suggests that the interests of farmers are better represented, compared to the retailer-led short food supply chain.

Nonetheless, while both Clusters 1 and 2 represent SOI-processes led by intermediary organizations that include farmers and other value chain actors, only Cluster 2 provides benefit to farmers in terms of revenue enhancement. It is noticeable that the innovation process in the value chain is less open in Cluster 2 since it does not include processors. This observation is in line with the literature on market power in value chains and the economic rationale behind SFSCs, suggesting that reducing the number of intermediaries between consumers and producers can economically benefit farmers (Chiffoleau and Dourian, 2020). Finally, these insights suggest that the type of actors matter more than the degree of openness of the innovation process itself for explaining benefit sharing (i.e. the distribution of the SOI).

5.3. Controversy 3: the degree of openness of the innovation process, farmer engagement, and the direction of innovation

Literature on SOI suggests that open-innovation strategies can increase the environmental and social sustainability performance of organizations (Rauter et al., 2017). Our study did not aim to measure the

SOI sustainability performance per se but to inform about the direction of the SOI, that is, the sustainability orientation and the goals of the innovation process, and more specifically, an assessment of the relative importance of the economic, social, and environmental objectives. Results of the SOI clustering do not show a straightforward relationship between the degree of openness of the innovation process and the chosen direction of the SOI. Clusters 3 and 7 are characterised by closed innovation processes that do not engage farmers but prioritize environmental and social objectives. For the processor-led SOI (Cluster 3), the fact that the SOI aims at environmental improvement and that farmers are not involved is consistent with the green innovation literature that mostly describes cases of food companies innovating in-house or sometimes collaborating with technology providers but not with farmers (Sarkar and Costa, 2008). For the retailer-led SOI (Cluster 7), the innovation mostly refers to opening new cooperative supermarkets. Contrary to schemes of community-supported agriculture, these food cooperatives do not pool resources or share decisions with farmers. If the governance and decision-making in these food cooperatives do involve social and environmental objectives related to on-farm production, consumer groups often do not take part in farm production activities nor in knowledge exchange with farmers (Mehrabi et al., 2022; Miralles et al., 2017). Therefore, the social orientation of cluster 7 refers to fostering community-based relationships and social ties between consumers that is known to be a key objective of SFSC initiatives (Duncan and Pascucci, 2017). Opposite to Cluster 3 and Cluster 7, Cluster 6 represents a more open innovation process with seriously engaging farmers but prioritizing the economic dimension of sustainability.

6. Conclusions

The objective of the study was to analyse various SOI processes and their inter-organizational collaboration characteristics in the F&V sector. We addressed two research questions. First, w*hat is the heterogeneity of inter-organizational collaboration forms in SOI processes?* Second, *how do farmers engage in these different forms of inter-organizational collaboration*? In response to a lack of conceptual clarity in the literature, this article proposed a novel conceptualisation of SOI, converging the specificities of the sustainability innovation process (direction, diversity, and distribution) and the characteristics of the collaboration supporting the innovation process.

Based on a survey across 118 value chains in the F&V sector and multivariate statistical analysis, the study revealed seven clusters of SOI and unpacked heterogenous forms of inter-organizational collaboration supporting the SOI. Contrary to studies proposing ideal types of inter-organizational innovation processes that might exist (e.g., Fieldsend et al., 2022), we reveal real patterns of collaboration supporting SOI processes in agrifood value chains. The SOI processes go from a closed innovation process led by traditional value chain actors (processors, retailers) to open innovation strategies involving multiple actors. We differentiated between 1) Intermediary-led farm & food innovation with farmer collaboration; 2) Intermediary-led SFSC innovation with farmer collaboration; 3) Processor-led green food product innovation without farmer collaboration; 4) Farmer-led SAP innovation with a collaborative network; 5) Farmer-led coupled innovation with downstream integration; 6) value chain actor-led coupled innovation with farmer collaboration; 7) Retailer-led distribution innovation without farmer collaboration. About the role of farmers in the SOI-process, we observed that farmers involved in collaboration in SOI processes not only engage in R&D activities and knowledge exchange but also engage in joint planification and investment for production and marketing activities.

Results show that the inter-organizational characteristics and the degree of openness of the innovation processes are not directly associated with a particular SOI profile (as regards to diversity, direction, and distribution), thus opening new research avenues. First, innovation in farming practices can rely on collaborative strategies involving a broad range of actors in and outside the value chain. This supports the traditional AKIS position, in which farmer participation is key next to support from non-value chain actors. Conversely, farmer-led innovation addressing at the same time farming practices, transformation, and distribution, without external collaboration, could also be found. This finding reflects a downstream integration strategy by farmers but raises the question of availability of internal resources needed to implement such SOI-process. Including the type of farms, their organizational structure, and their capabilities in our analytical framework could provide additional explanation. Second, the distribution of SOI benefits seems more strongly associated with the type of actors involved in the collaboration than the degree of openness of SOI. Regarding farmer revenues, SOI processes that present a moderate to strong benefit were also relying on the engagement of farmers, but collaboration relying on a broader network of actors was not necessarily associated with a significant positive impact on farmer revenues.

These results corroborate the 'opening paradox' according to which not all partners of an innovation process benefit from it in economic terms. This observation suggests that a closer look at the governance structures of the collaboration forms is required to understand the innovation benefit-sharing rules. The value farmers capture from open collaborative SOI is not necessarily in economic terms but may lead to more legitimacy and better social embeddedness. Our clustering shows no relationship between the direction and the openness of the SOI process. While literature on SOI assumed that collaboration is a precondition for pursuing social and environmental sustainability goals, our results show that closed innovation can still prioritize these sustainability dimensions. Also, open innovation in value chains may only focus on the economic dimension.

Our study contributes to the debate on which form of inter-organizational collaboration is required for innovation toward more sustainability (Rauter et al., 2017). This calls for a more sophisticated view of SOI and for further research to disentangle the relations between collaboration characteristics and the three dimensions of SOI. Results provide empirical insights that can guide public policies and agrifood chain actors. Following Cagliano et al. (2016), our results suggest that there is not a one-size-fits-all form of collaboration to support SOI. Alternative forms of inter-organizational collaboration exist and are suitable for different sustainability goals, also echoing the co-existence of values within agricultural systems (Plumecocq et al., 2018). Policy makers and innovation agents should be aware of which dimensions of SOI they are most concerned with. Our study suggests that if policies aim at improving sustainability in the whole value chain, farmer engagement is necessary.

In line with Kernecker et al. (2021), our results call for a better differentiation of SOI types to target innovation support and open innovation strategies in the agrifood sector. While not directly challenging the existing consensus according to which sustainability transformative paths require interactions between all actors in the system, as well as their long-term commitment, our study calls for a better characterization of the actors involved and the level of farmer engagement beyond knowledge exchange. While multistakeholder R&D projects are currently a popular tool among EU and national policy makers to support SOI in the agrifood sector (Cronin et al., 2022), our study emphasizes the importance of support for other forms of inter-organizational collaboration for SOI (Fieldsend et al., 2022).

Our approach of diversity, direction and distribution in SOI may help to develop and implement policies that aim to support transitions toward more sustainable food systems. Gaitán-Cremaschi et al. (2019) have argued that policy makers need to acknowledge the diversity of food systems and thereby the opportunities different food systems hold for sustainability transitions. Our clustering of SOI-configurations may provide a further operationalisation of the framework presented by Gaitán-Cremaschi et al. (2019, 2020) to characterise different collaborative innovation strategies as entry points for food system transformation. Our results also link to the work with Kok and Klerkx (2023), who provide an inspirational discussion on mission-oriented agricultural innovation systems (MAIS), particularly on the politics involved in setting-up and implementing these innovation systems. Getting MAIS established requires insights in the diversity, direction and distribution of SOI in particular value chain and food system configurations. While our analysis of SOI sets aside the power dynamics underpinning the direction of innovation within the global food system, it constitutes a useful framework to describe and assess the existing organizational configurations both within the niches and the incumbent regimes. Our approach can therefore support a more detailed micro and meso-analysis of the various outcomes (and thus the feasibility) of MAIS targeted at food system transformation.

Our study has limitations. First, our sampling strategy aimed at identifying the diversity of SOI in F&V value chains was based on judgmental sampling. As a result, the clusters do not inform about the relative importance of these phenomena in agrifood systems but inform about their presence and diversity. Second, our analysis is based on variables that are qualitative assessed, based on the perception of the respondents. For instance, the innovation benefit of enhanced farmer revenue is measured by the perception of the innovation leader, which was not always a farmer or a farmer organisation. Further studies could collect the perception of the various collaborating partners to triangulate the data, or directly measure farmer revenues prior and after the SOI implementation. Moreover, while we chose to operationalize the framework with a limited number of variables, our survey data provided us more insights on the distribution of the SOI benefits, with information collected on various economic (e.g., reducing transaction costs in the value chain), social (e.g., healthy diet), and environmental benefits (e.g. reduction of the use of plastics) that could be used in future studies. Third, our analysis based on the HCA enabled us to identify patterns of alignment between collaboration characteristics and SOI dimensions, but it did not assess linear correlation and causality between the variables. Future studies using panel data would enable to econometrically test the relationship between the variables.

Finally, our research design did not allow a longitudinal perspective of the innovation process. Differentiation of the phases along the lifespan of the innovation process, as it was done in other studies (Kernecker et al., 2021), could provide insights on the complexity of the innovation process and on the stability of the collaboration over time. While the external environment (public policies and market demand) and the management of the collaboration (selection of partners, degree of formalisation; frequency of interactions, and internal capabilities) are acknowledged as determinants of a successful collaboration in SOI, our results also show that the relative importance of these factors vary according to the types of collaboration in SOI. Subsequent studies, using the results and discussion herein, could analyse the importance of other success factors as regards to the diversity of SOI patterns.

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

Data will be made available on request.

Acknowledgment

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Annex A: List of the innovations inventoried in the +100 fruit and vegetable value chains

Innovation in farming system
Integrated crop management including use of biological plant protection products, improved propagation material, new grafting technique
Crop diversification with new species
Genetic selection for tolerant varieties
Smart farming practices including use of new decision support system and precision farming
Biodiversity conservation practices
Innovation in food system
Healthy products for e.g. reduction of sugar content in fruit juices
New super food ingredients
Fermented food products
Optimization of food processing lines to save energy
Packaging alternatives to plastic
Packaging deposit systems
Packaging Augmented reality system
Innovation in agrifood chain and system
Use of by-products, valorisation of imperfect fruit and vegetables
New standards and certifications on working conditions
Community-supported agriculture
Digital platform
Fully automated physical supermarkets
Food cooperative

Annex B: Characteristics of the sample (n = 74 value chains)

Characteristics	N*
Country of the leading organisation	
ES	14
IT	13

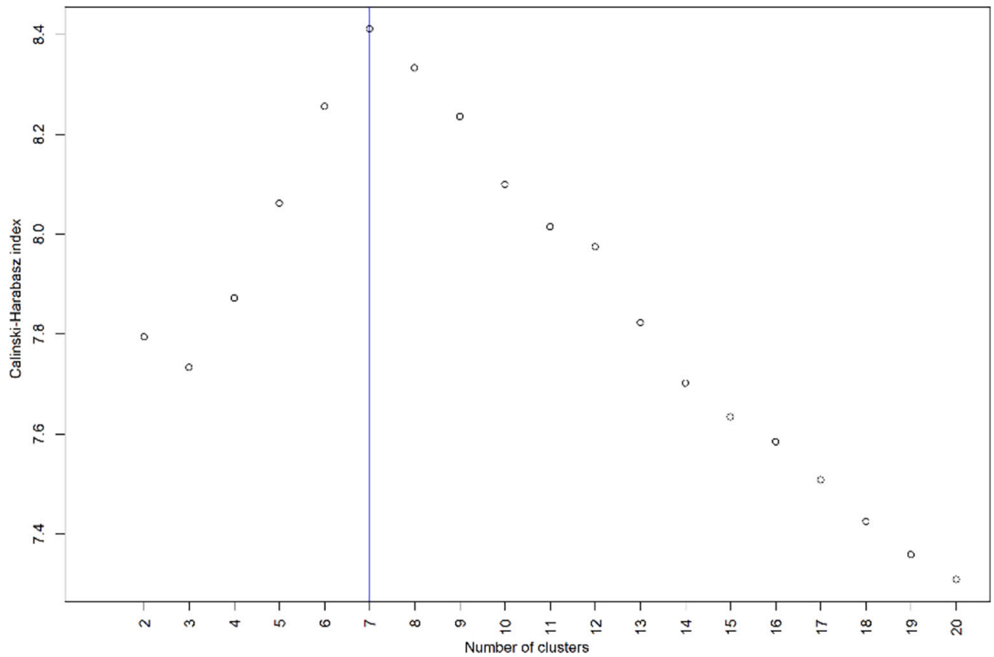
(continued on next page)

(*continued*)

Characteristics	N*
FR	10
HU	8
BE	7
SK	5
GE	4
PL	4
GR	3
NL	3
BG	1
CY	1
DK	1
Type of organisation	
Farmer or farmers organisation	34
Other actors of the agrifood chain (including processors, retailers, wholesalers)	33
Actors external to the agrifood chain (i.e. intermediaries)	7
Years in the industry	
<5	21
5 to 10	8
>10	37
n.a.	8
Species for which SOI has been implemented	
F&V mix	33
grape	5
olive	3
tomato	3
acorn	2
apple	2
berries	2
orange	2
pumpkin	2
spiruline	2
strawberry	2
almond	1
asparagus	1
broccoli	1
celery	1
cherry	1
chickpea	1
kiwi	1
lemon	1
persimmon	1
prickly pear	1
quince	1
rosehip	1
sea buckthorn	1
seaweed	1
soya	1
zucchini	1

[*] F&V mix indicates that the value chain and SOI that has been implemented is not targeted to one species but to a mix of Fruit & Vegetables species.

Annex C: Calinski-Harabasz index depending on the numbers of HCA clusters



Annex D: Percentage of variance explained by the 10 first dimensions of MCA

Axe	Eigenvalue	Percentage of variance	Cumulative percentage of variance
dim 1	0,2236	10	10
dim 2	0,1844	8,25	18,25
dim 3	0,1635	7,32	25,57
dim 4	0,1567	7,01	32,58
dim 5	0,1247	5,58	38,16
dim 6	0,1115	4,99	43,15
dim 7	0,1005	4,5	47,64
dim 8	0,0913	4,09	51,73
dim 9	0,084	3,76	55,49
dim 10	0,0784	3,51	58,99

Annex E: Chi-Square test between each variable and HCA

Variables	*P* value	df
Diversinnov	1,1005E-15	36
Leader	1,332E-13	24
Collabimp_cons	1,2834E-06	12
In_farmer	3,4786E-06	6
Farmrev	9,0115E-06	12
Rd_farmer	7,2392E-05	6
Dirinnov	8,7715E-05	30
Kn_farmer	0,00010489	6
Collabimp_trad	0,00015627	12
Collabimp_proc	0,00019927	12
Collabimp_ngo	0,00029551	12
Collabimp_ret	0,00154276	12
Collabimp_insup	0,00590413	12
Pl_farmer	0,00725825	6
Collabimp_psp	0,04613096	12
Collabimp_pri	0,06708579	12
Internorg	0,1372293	6

Interpretation: Based on p-value <0,05 criteria, only the variable Collabimp_pri (i.e., importance of collaboration with private research institute) and the variable Internorg (i.e., organisation of routines within the organisation) are not significantly discriminating the clusters.

Annex F: Results presentation of the hypergeometric test for each cluster

Interpretation: The following tables present for each cluster the over-represented modalities (Highlighted in green) and the under-represented modalities (highlighted in red). The modalities that are not significantly different from the global population (based on a *p*-value >0,05) are not presented in these tables. In these tables «Mod »refers to the modality of the variable; «Cla/Mod »': Out of all the individuals in the total population who have the modality, percentage of those who are in the cluster; « Mod/Cla »: Percentage of the individuals in the cluster who have the modality; «Global »: Percentage of the individuals in the total population who have the modality; p.value: *p*-value of the test of comparison between the share of the modality in the cluster(Mod/Cla) and the share of the modality in the total population (Global); v.test: value of the test of comparison between the share of the modality in the cluster (Mod/Cla) and the share of the modality in the total population A positive value indicates an over-representation of the modality in the cluster i.e. Mod/Cla > Global, while a negative value indicates an under-representation of the modality in the cluster i.e. Mod/Cla < Global.

Hypergeometric test - Cluster 1 ($n = 9$)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Collabimp_proc	3	36,36%	88,89%	29,73%	0,00015945	3,7759
Rd_farmer	1	33,33%	77,78%	28,38%	0,00165024	3,1469
Collabimp_insup	3	22,86%	88,89%	47,30%	0,00958263	2,5905
Collabimp_cons	3	18,37%	100,00%	66,22%	0,0185883	2,3537
Diversinnov	4	31,25%	55,56%	21,62%	0,02159472	2,2974
Collabimp_pri	3	20,51%	88,89%	52,70%	0,02331763	2,2682
Leader	5	42,86%	33,33%	9,46%	0,0380166	2,0747
In_farmer	2	16,98%	100,00%	71,62%	0,04009634	2,0528
Collabimp_psp	3	21,21%	77,78%	44,59%	0,04269397	2,0267
Under-represented modalities						
In_farmer	1	0,00%	0,00%	28,38%	0,04009634	−2,053
Collabimp_trad	1	0,00%	0,00%	31,08%	0,02752622	−2,204
Collabimp_insup	1	0,00%	0,00%	31,08%	0,02752622	−2,204
Collabimp_proc	1	0,00%	0,00%	32,43%	0,02266865	−2,279
Rd_farmer	2	3,77%	22,22%	71,62%	0,00165024	−3,147

Hypergeometric test - Cluster 2 (n = 11)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Dirinnov	4	66,67%	54,55%	12,16%	0,00017785	3,7486
Diversinnov	5	66,67%	36,36%	8,11%	0,00379823	2,8944
Farmrev	3	25,64%	90,91%	52,70%	0,00612543	2,741
Leader	5	57,14%	36,36%	9,46%	0,00831754	2,6389
Kn_farmer	1	24,39%	90,91%	55,41%	0,01036293	2,5635
Collabimp_ngo	3	31,82%	63,64%	29,73%	0,01475952	2,4382
Collabimp_proc	1	29,17%	63,64%	32,43%	0,02678169	2,2147
Under-represented modalities						
Dirinnov	1	0,00%	0,00%	21,62%	0,05447415	−1,923
Collabimp_ret	2	0,00%	0,00%	25,68%	0,02862647	−2,189
Kn_farmer	2	3,03%	9,09%	44,59%	0,01036293	−2,564

Hypergeometric test - Cluster 3 (n = 12)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Leader	2	60,00%	100,00%	27,03%	5,7405E-09	5,8241
Diversinnov	2	80,00%	66,67%	13,51%	1,3411E-06	4,8336
Kn_farmer	2	36,36%	100,00%	44,59%	1,6169E-05	4,3121
Farmrev	1	70,00%	58,33%	13,51%	4,4338E-05	4,0836
In_farmer	2	22,64%	100,00%	71,62%	0,01215742	2,5075
Rd_farmer	2	22,64%	100,00%	71,62%	0,01215742	2,5075
Dirinnov	5	45,45%	41,67%	14,86%	0,01472985	2,439
Collabimp_ngo	1	27,59%	66,67%	39,19%	0,04404885	2,0136
Under-represented modalities						
Collabimp_ret	2	0,00%	0,00%	25,68%	0,01999309	−2,327
In_farmer	1	0,00%	0,00%	28,38%	0,01215742	−2,508
Rd_farmer	1	0,00%	0,00%	28,38%	0,01215742	−2,508
Farmrev	3	5,13%	16,67%	52,70%	0,00775813	−2,662
Leader	1	0,00%	0,00%	45,95%	0,0002546	−3,658
Kn_farmer	1	0,00%	0,00%	55,41%	1,6169E-05	−4,312

Hypergeometric test - Cluster 4 (n = 13)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Collabimp_cons	2	66,67%	76,92%	20,27%	9,7796E-07	4,896
Diversinnov	1	75,00%	46,15%	10,81%	0,00022242	3,6921

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(*continued*)

Hypergeometric test - Cluster 4 (n = 13)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Collabimp_ret	2	47,37%	69,23%	25,68%	0,00034955	3,5755
Collabimp_proc	2	35,71%	76,92%	37,84%	0,00235565	3,0413
Collabimp_trad	2	46,67%	53,85%	20,27%	0,00343154	2,9262
Collabimp_insup	2	43,75%	53,85%	21,62%	0,00564895	2,7675
Leader	1	29,41%	76,92%	45,95%	0,01708051	2,385
Under-represented modalities						
Collabimp_trad	3	8,33%	23,08%	48,65%	0,04870488	−1,971
Collabimp_insup	1	4,35%	7,69%	31,08%	0,04399016	−2,014
Collabimp_psp	1	0,00%	0,00%	20,27%	0,03867302	−2,068
Collabimp_ret	3	3,45%	7,69%	39,19%	0,00936449	−2,599
Collabimp_proc	3	0,00%	0,00%	29,73%	0,00606761	−2,744
Diversinnov	7	0,00%	0,00%	29,73%	0,00606761	−2,744
Collabimp_cons	3	6,12%	23,08%	66,22%	0,00068058	−3,397

Hypergeometric test - Cluster 5 (n = 12)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Collabimp_ngo	1	37,93%	91,67%	39,19%	7,5677E-05	3,9577
Collabimp_pri	1	46,15%	50,00%	17,57%	0,00533606	2,786
Leader	1	29,41%	83,33%	45,95%	0,00575392	2,7615
Collabimp_trad	1	34,78%	66,67%	31,08%	0,0072741	2,684
Collabimp_cons	1	50,00%	41,67%	13,51%	0,0086549	2,6254
Collabimp_psp	1	40,00%	50,00%	20,27%	0,01349514	2,4704
Diversinnov	7	31,82%	58,33%	29,73%	0,02917199	2,1812
Under-represented modalities						
Collabimp_psp	2	3,85%	8,33%	35,14%	0,03312113	−2,131
Collabimp_proc	2	3,57%	8,33%	37,84%	0,0205688	−2,316
Leader	2	0,00%	0,00%	27,03%	0,01563096	−2,417
Collabimp_ngo	3	0,00%	0,00%	29,73%	0,00940479	−2,597
Collabimp_trad	3	2,78%	8,33%	48,65%	0,00222085	−3,059

Hypergeometric test - Cluster 6 (n = 13)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
In_farmer	1	57,14%	92,31%	28,38%	1,5274E-07	5,2492
Farmrev	2	40,00%	76,92%	33,78%	0,00068058	3,3973
Diversinnov	7	40,91%	69,23%	29,73%	0,00157836	3,1599
Pl_farmer	1	35,71%	76,92%	37,84%	0,00235565	3,0413
Collabimp_trad	3	30,56%	84,62%	48,65%	0,00498886	2,8078
Rd_farmer	1	38,10%	61,54%	28,38%	0,00739202	2,6786
Kn_farmer	1	26,83%	84,62%	55,41%	0,02125765	2,3034
Dirinnov	2	40,00%	46,15%	20,27%	0,02251685	2,2815
Under-represented modalities						
Collabimp_trad	2	0,00%	0,00%	20,27%	0,03867302	−2,068
Dirinnov	1	0,00%	0,00%	21,62%	0,03015185	−2,168
Collabimp_insup	2	0,00%	0,00%	21,62%	0,03015185	−2,168
Farmrev	3	7,69%	23,08%	52,70%	0,02258918	−2,28
Kn_farmer	2	6,06%	15,38%	44,59%	0,02125765	−2,303
Rd_farmer	2	9,43%	38,46%	71,62%	0,00739202	−2,679
Pl_farmer	2	6,52%	23,08%	62,16%	0,00235565	−3,041
In_farmer	2	1,89%	7,69%	71,62%	1,5274E-07	−5,249

Hypergeometric test - Cluster 7 (n = 4)

Variables	Mod	Cla/Mod	Mod/Cla	Global	p.value	v.test
Over-represented modalities						
Diversinnov	3	66,67%	100,00%	8,11%	1,3036E-05	4,36
Leader	4	57,14%	100,00%	9,46%	3,0418E-05	4,17
Dirinnov	3	27,27%	75,00%	14,86%	0,00960781	2,59
Under-represented modalities						
There is no significantly underrepresented modality in cluster 7.						

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