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Barriers to the adoption of open-pollinated varieties in the organic farming sector: a case study of small-scale vegetable production in France

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Seeds are a critical, influential element of agricultural production and sustainability. The European organic farming sector has specific standards and targets regarding its seed supply. Ideally, seeds should be grown organically, participate in the conservation of biodiversity, contribute to the autonomy of farmers, and be bred into reproducible cultivars. Inbred lines and open-pollinated varieties, along with organic heterogeneous material, fit with this criterion. In a case study of small-scale vegetable production in the South-East of France, we analyze the gap between the organic sector's seed standards regarding reproducibility and their actual implementation when farmers buy seeds. The data were collected through a focus group and interviews of 15 farmers and seven other actors of the organic vegetable value chain. While all farmers of the sample consider open-pollinated varieties more aligned with the principles of organic agriculture and peasant farming, their perception of the operational relevance of the OP varieties currently available in seed companies' catalogues varies and leads to contrasted varietal choices. Perceived advantages of OP varieties over hybrids include ethical and hedonic aspects along with context-specific technical advantages. On the other hand, the listed advantages of hybrid varieties are mostly about productivity, disease resistance and access to technical recommendations. This paper discusses how the technical, economic, educational, and social contexts influence farmers' seed choices of hybrids versus open-pollinated varieties. We highlight 11 barriers to the adoption and use of open-pollinated varieties. These barriers are present in the seed market, at the farm level, as well as in the education and extension sectors. Our findings suggest that activating various levers is needed to make it more feasible for organic farmers to choose open-pollinated varieties. These findings call for further assessment of the conditions required for the adoption of reproducible varieties in a wider range of organic farming contexts across Europe.

KEYWORDS

organic agriculture, vegetables, seed system, crop biodiversity, hybrids, lock-in, plant breeding, agroecology

1 Introduction

1.1 Seeds supply and types of cultivars in the European farming systems

Seeds are the starting point of seasonal agricultural production. As FAO stated, « Seed is one of the most crucial elements in the livelihoods of agricultural communities. It is the repository of the genetic potential of crop species and their varieties resulting from the

continuous improvement and selection over time » (FAO, 2022). Farmers obtain seeds either by buying seeds from seed suppliers (« formal seed systems ») or by producing seeds on the farm or exchanging seeds with other farmers (« informal seed system » also sometimes called « farmers' seed system ») (Bocci and Chable, 2009; Lammerts van Bueren et al., 2018; Louwaars, 2007). Seed systems are described as « *complex and made up of different actors with contrasting behaviors and acting at the same time in the formal or the informal system* » (Bocci et al., 2019).

In Europe, the formal seed system is largely dominant, although on-farm production and direct seed exchanges are also present at a smaller scale (Bocci et al., 2019; Demeulenaere and Piersante, 2020; Lammerts van Bueren et al., 2018; Mazé et al., 2021). In the formal seed system, the official European *catalogue of varieties* lists all the varieties authorized for marketing throughout the territory of the European Union. To be included in the catalogue, a variety must be assessed as « distinct, stable and sufficiently uniform » and be « of satisfactory value for cultivation and use » (European Commission, 2002). In terms of vegetable species, the European Catalogue currently includes more than 22,000 varieties (European Commission, 2024). Registered varieties can be obtained through contrasted breeding and production methods, leading to various types of varieties (according to their breeding process): hybrids (mostly F1 hybrids, or F2, F3, F4), open-pollinated (OP) varieties, or inbred lines. Hybrids are obtained from the combination of two inbred lines, which renders them very homogeneous, highly heterozygous. Hybrids are generally improved by the heterosis effect but cannot be reproduced without a decline in performance. Inbred lines are developed for self-pollinating species as highly homogeneous and homozygous cultivars. Open-pollinated varieties are obtained through mass selection, pairwise crosses and recurrent selection, traditionally from cross-pollinated plant species, and are genetically diversified (Messmer et al., 2015). Within the European Catalogue, about 55% of currently registered vegetable varieties are hybrids. The share of hybrids varies depending on species: it reaches 58% of carrot varieties, 73% of cauliflower varieties, 77% of tomato varieties, and 89% of cucumber varieties (Table 1) (European Commission, 2024). Since January 2022, the marketing of organic heterogeneous genetic material, such as composite cross populations, is also allowed independently from official catalogues under certain conditions (European Commission, 2021). This new legislation allows the entrance of a more diverse set of genetic material in the formal seed system for the organic sector. The new regulation might provoke changes in the organisation of the organic seed market in the future, since heterogeneous material relies on low cost evolutionary breeding methods, is not subject to intellectual property and call for a decentralised production in the bioregions where they are used to best rely on plants' adaptation capacities.

1.2 Specific objectives of seed supply for the organic sector

The European umbrella organisation for organic food and farming (IFOAM) has adopted standards for organic seed production and proposed standards for organic plant breeding in collaboration with the European Consortium for Organic Plant Breeding (2012), IFOAM (2017), and Lammerts van Bueren (2010). According to these standards, organic breeding and seed production should maintain the

TABLE 1 Number of hybrid and non-hybrid varieties in the European Catalogue of varieties, for some major vegetable species.

Species	Species name and code	Total number of varieties in the Catalogue [1]	Number of hybrid varieties[2]	Share of hybrid (%)	Number of non-hybrid varieties [2]	Share	Type of variety unknown [2]	Share
All vegetable species		22,939	12,718	55%	8,479	37%	1742	8%
Carrot	*Daucus Carota* L.	489	285	58%	167	34%	37	8%
Cauliflower	*Brassica oleracea* L.	1990	1,447	73%	414	21%	129	6%
Cucumber	*Cucumis Sativus*	1,333	1,192	89%	100	8%	41	3%
Fresh beans	*Phaseolus vulgaris* L.; *Phaseolus coccineus* L.	1,293	18	1%	167	13%	1,108	86%
Fresh peas	*Pisum sativum* L.	1,093	1	0%	115	11%	977	89%
Lettuce	*Daucus carota* L.	2,448	4	0%	2,232	91%	212	9%
Onions	*Allium cepa* L.	999	573	57%	34	3%	392	39%
Tomato	*Solanum Lycopersicum* L.	4,530	3,491	77%	660	15%	379	8%

Tomatoes, onions, fresh peas, carrots, fresh beans, and lettuces are the most grown vegetables in Europe in terms of acreage according to Eurostat (2020); Cauliflower and cucumber are provided as additional examples; Fresh peas correspond to Eurostat category V5100; Fresh beans correspond to Eurostat category V5200. Data source: EU Plant variety database (https://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/search//public/index.cfm?event=searchForm&ctl_type=H&active_tab=v); data retrieved on 13/06/2024.

[1]Only currently registered varieties.

[2]Retrieved with data search criteria: "hybrid" (Yes / No / All).

ability of plants to reproduce. This way, they should allow for varieties to be « *reproduced as farm-saved seed* ». Plants reproducibility is consistent with the principle of availability of genetic resources to all farmers and breeders (IFOAM, 2017) and is critical for the possibility of adapting plants to local conditions, which contributes to maintain and develop genetic biodiversity (Chable et al., 2008). Inbred lines and open-pollinated cultivars fit with this criterion. Although reproducible varieties are identified as the most consistent with the principles of organic farming, their use is not compulsory under the organic farming regulation.

1.3 State of the data and literature available on seed supply and varietal preferences in the EU organic sector

Over the past decade, several European research projects have been funded to assess the production and use of seed in the organic sector. These projects include Diversifood (2015–2019), Liveseed (2017–2021), and Liveseeding (2022–2026), which have collected data on the organic seed sector, investigated opportunities of technical developments, studied related socio-economic aspects, and provided conceptual frameworks. In this body of work, the assessment of seed supply has been focused on organic seeds as a whole, without a distinction of the types of cultivars (such as reproducible cultivars or hybrid varieties). One mention is found of OP varieties in Orsini et al. (2020). In this survey, the use of open pollinated varieties was ranked by farmers as the third most important action to boost organic seed use (after an improvement of the availability of organic seed for locally adapted varieties and an increase of the efforts in breeding for organic farming). To the best of our knowledge, there is no comprehensive data on the types of cultivars currently used in the European organic sector.

Besides the deliverables produced by the EU-funded projects, there is a scarcity of academic research addressing the varietal preferences and actual utilization of organic seeds in Europe, as already highlighted by Orsini et al. (2020). To verify available data and analysis, the scientific literature database Scopus was screened with combinations of keywords including organic; organic farming; organic agriculture; seed; variety; cultivar; open-pollinated; hybrid; hybrids; Europe. No scientific papers were found regarding the share of hybrid/OP varieties being grown in Europe, nor on farmers' preference for those types of cultivars. Additionally, no analysis of the barriers to the use of open-pollinated varieties in the European organic sector was identified.

1.4 Scope of the research

In this paper, we look at farmers' varietal choices when buying seeds and seedlings for organic vegetable production. Through this research, we aim to map which criteria are used by farmers and other actors to make up varietal choice and seed (or seedlings) purchase decisions. We show how these criteria intersect with the type of cultivars (hybrid (H) or open-pollinated (OP) varieties), and which contextual elements weight in actors' choices towards hybrid or OP varieties. The research was rolled out through a Case Study approach, with a focus on small-scale organic production in Southern France (*Alpes-Maritimes*). The research provides a methodological approach to assess farmers' preferences and constraints with regard to hybrid/OP varieties.

2 Theoretical framework

Our analysis framework is based on the concept of lock-ins, which refers to dominant routines that hinder other pathways of development at both the individual and collective levels. Initially identified by Cowan and Gunby (1996), this concept aligns with the vision of transition proposed by Geels (2004). The lock-in framework is based on a comprehensive approach to innovation, considering organizational, technical, financial, cultural, and knowledge-related elements (De Herde et al., 2019). It is based on identifying interactions within a system, considering diverse actors and contrasted visions.

Lock-in analysis have been rolled out to study transition pathways and challenges in various European production sectors including the dairy, wheat and pulses sectors (De Herde et al., 2020; Magrini et al., 2016, 2018; Vanloqueren and Baret, 2008). Only few lock-in studies are available in the organic sector (Stassart and Jamar, 2008; Vidal et al., 2022) and specifically in the organic vegetable sector (Rohe et al., 2022). The lock-in framework is generally applied to medium or large-scale analysis of systems (De Greef and Casabianca, 2009; Kuokkanen et al., 2017; Vanloqueren and Baret, 2009). However, it has been more rarely applied to farmer agency (De Herde et al., 2019; De Snoo et al., 2013). To our knowledge, this concept has never been applied to the context of variety choice from a farmer's perspective.

Focusing on the adoption of open-pollinated varieties by farmers, this analysis provides insights at the farming stage of value chains. This is complementary to the following two studies that, respectively, looked at breeding systems (upstream of farmers) and marketing (downstream of farmers). The analysis of agricultural research systems by Vanloqueren and Baret (2009) highlights the development of genetic engineering vs. agroecological innovations, and indicates a lock-in effect that hinder the adoption of agroecological practices (Rohe et al., 2022) analyses the challenges faced for the diffusion of organically bred vegetable varieties within the food market.

3 Methodology

3.1 Data collection

3.1.1 Context of the case study

The Case Study is located in the *Alpes-Maritimes* region, in the South-East of France. France has experienced significant and steady growth in its organic production and market (IFOAM, 2021). Like Europe in general, France's seed sector is highly regulated and formalized (Bocci and Chable, 2009; SEMAE, 2024), which implies that a large share of seeds is purchased from seed companies.

In that area, the production of fresh vegetables under the framework of organic agriculture involves about 130 farmers on a total area of 112 ha (Observatoire Régional de l'Agriculture Biologique PACA, 2021). The region is convenient as a Case Study because all types of actors of the vegetables value chain are represented. The vegetable sector includes numerous regional actors operating at the downstream stage (processing, distribution, food catering), upstream

stage (seed companies, vegetable seedling nurseries), and as extension services and education (farming advisory, agricultural education, associations). These stages of the value chain and actors are interconnected through material flows of seeds, seedlings, fresh vegetables and processed products as well as information flows (Figure 1).

The region is also relevant as a Case Study since there is an interest of actors to learn and discuss topics related to seed systems. Various national and international programs aimed at supporting cultivated biodiversity have been rolled out in South-East France (e.g., Biodiversité étoilée under Interreg AlcoTRA, Intervabio, and DiversiGO). A specific interest was expressed by the local association *Maison des Semences Paysannes Maralpine* (MSPM) to gain insights on the barriers to the adoption of OP varieties. Founded in 2018, the MSPM association is a « peasant seed house » (Gevers et al., 2019) aiming at safeguarding and promoting heirloom varieties, and fostering knowledge and skills related to their production and breeding in a farmers' network. The MSPM association currently has around 50 members including farmers, seed producers, gardeners, chefs, retailers, CSA members, etc. Members pay a yearly membership fee and commit to respect the principles described in the association's charter. The activities of the association encompass: the collection of heirloom varieties; support to farmers for the conservation, breeding, production and sales of seeds; the promotion of agrobiodiversity; the study of the obstacles to the adoption of heirloom varieties; in-situ conservation and seed multiplication; and dissemination of relevant information and resources. This context offers the possibility to study criteria and factors that influence varietal choices beyond the preliminary problems of awareness about, and interest in, OP varieties.

3.1.2 Data collection contents

The data collection focused on three topics. The first topic is the criteria used by actors to assess and choose varieties. It was addressed through questions on the definition of these criteria and their relative importance at the time of the data collection as well as in the past. The second topic was centered on actors' knowledge and perception of OP/hybrid variety types. It was approached through questions on how actors understand these types of varieties and think of them as well as questions on concrete choices of one or the other type of varieties. The third topic covered the factors that influence the choice of varieties, and the barriers and levers to the adoption of open-pollinated varieties. This topic was investigated thanks to questions on sources of information, interactions between actors, and needs and opportunities to improve varietal portfolios and seed supply. Additionally, descriptive questions were asked to collect data on the characteristics of the sample. These included questions on technical and economic characteristics of farms and organisations and their history.

3.1.3 Data collection process

Data was collected through a three-step multi-actor data collection. At first step, a focus group was organised with the intention to collect data regarding opinions, consensus, and divergence between

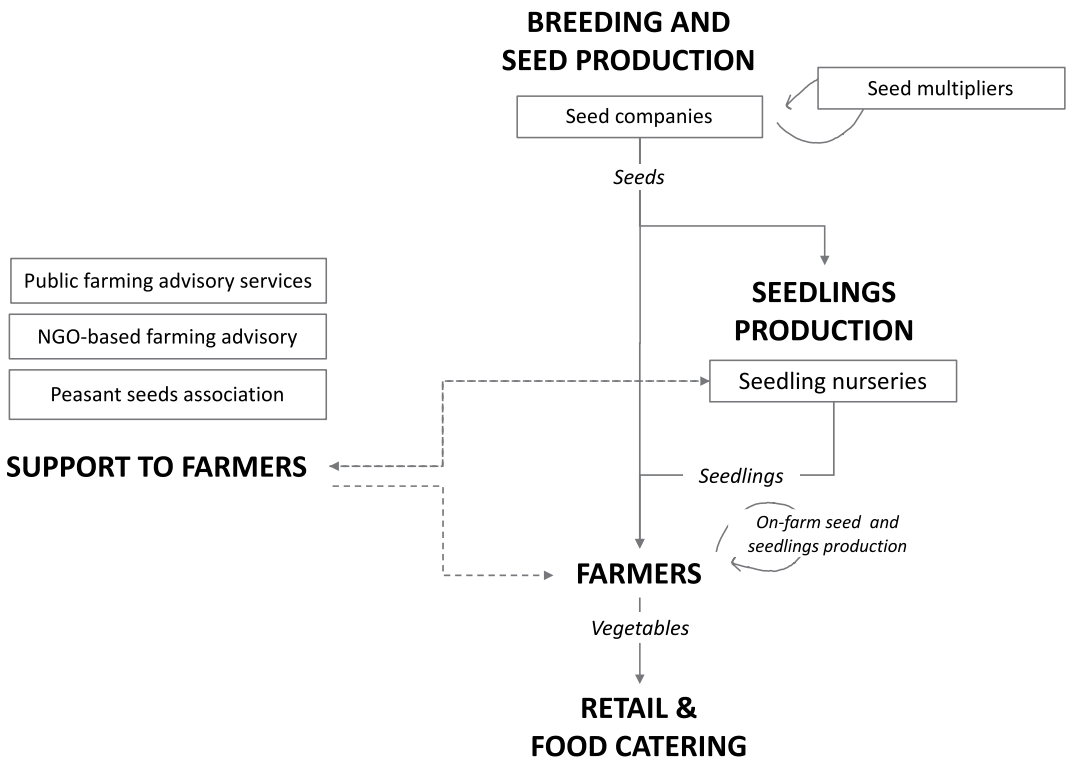

FIGURE 1
Mapping of the actors and flows of the Maralpine fresh vegetable sector, from seeds to food. Solid line arrows: flow of seeds, seedlings and fresh vegetables. Dotted line arrows: formal flow of information relating to varietal choices. In addition, informal information flows were identified through the research (see Results section). Source: A preliminary version of this mapping was prepared before the data collection. It was then updated based on actors' interviews.

farmers regarding varietal choices (topic 1 and 2). The focus group took place in September 2019 with 15 voluntary farmers who are members of the *Maison des Semences Paysannes Maralpine* peasant seed house. In the second step, six individual interviews were rolled out in January 2020 with voluntary farmers who had previously participated in the focus group. These interviews were rolled out to collect specific data on farms' history, technical, economic and organizational characteristics as well as their embeddedness in the actors' network in order to investigate contextual aspects behind varietal choices (topics 3 and 4). In the third step, seven individual interviews were conducted in March 2021 with the other types of actors involved in the value chain of the small-scale organic vegetable sector. Other actors interviewed include extension agents providing farming advisory services (2), vegetable seedling nurseries (2), retail and food catering actors (3) with whom the interviewed farmers are directly interacting with as suppliers or clients. The actors were chosen based on the first set of interviews rolled out with farmers, who were asked which actors they interact with. This last round of interviews aimed at understanding the range of knowledge and opinions other actors have about varietal choices, and how it may influence farmers' choices (topic 2 and 3). Questions used to guide the focus group and the individual interviews are provided in Supplementary data.

3.1.4 Characteristics of actors interviewed

Farms included in the data collection work under small-scale organic vegetable production systems (Table 2). Farms have a diversified production, with 10–40 species of vegetables. Their marketing channels can be classified as *short food supply chains* (Kneafsey, 2012; Praly et al., 2014). All farmers buy part or all their seeds from seed companies. Eleven producers out of the 15 also produce some seeds on their farm for their use or in the context of participatory seed production. The share of OP and hybrid varieties in farms varies widely. In 10 farms out of 15, OP varieties dominate with only a few hybrid varieties present. In contrast, 2 farms primarily plant hybrid varieties. The remaining 3 farms represent intermediate situations with a balanced mix of both types.

The actors from the farming advisory services included one representative of the public extension services and one from a NGO-based farming advisory services. Both are in charge of providing technical and strategic advice to farmers in the area. The public extension services provide basic advice to any farmer for free while further advice is based on paid membership. The NGO-based farming advisory services works based on paid membership. The two vegetable seedling nurseries include one small-scale seedling producer located in the mountainous area and one medium-scale seedling producer located in the plain. Retail and catering actors included one smaller and one medium-size organic groceries shops as well as one fresh groceries urban shop, all sourcing directly from the farmers interviewed.

3.2 Data analysis

Data from the individual interviews and the focus group were treated using the NVivo software. The coding per topic allowed for classifying information collected on: 1. the criteria used by actors for assessing varieties; 2. elements of opinions and knowledge regarding hybrid/OP types of varieties; and 3. barriers and levers to the adoption of OP varieties.

First, the criteria used by farmers and other actors for choosing varieties were listed in the interviews and focus group transcripts. The listed criteria were compared and aggregated when similar to establish a comprehensive yet non-repetitive list of criteria at the group level. A definition was elaborated for each criterion based on the transcripts. Second, actors' opinions and knowledge regarding hybrid/OP types of varieties were listed across interviews and focus groups transcripts. This allowed us to analyze how actors' background on hybrid and OP varieties intersect with the criteria used for varietal choice. Third, the factors (barriers) behind these perceptions and operational choices were listed and classified according to the actors they apply to.

In addition, a coding per actor was done to facilitate comparisons of the positions taken by actors. The actors verbatim quoted below are coded with the following letters: A for advisory services, N for seedling nurseries, D for the actors involved in the distribution of food, i.e., retail and food catering, and M for vegetable farmers (*maraîchers* in French). Actors' verbatim were anonymized with a number (e.g., D1, D2, etc.).

The results were presented to actors having participated in the data collection on occasion of the General Assembly of the MSPM. It has also been used since then in an education module in agricultural education schools in the region.

4 Results

The results section first highlights the criteria used by actors for varietal choices. Second, we review the perceptions of hybrid and open-pollinated varieties, differentiated between farmers and other actors. Finally, we describe 11 barriers to the adoption of open-pollinated varieties.

4.1 Transversal analysis of varietal choice

Throughout the data collection, we identified twelve criteria utilized by farmers and other stakeholders in the organic vegetable value chain to assess varieties and make decisions about varietal choices. The list of criteria includes: one criterion related to the conditions of production and origin of seeds; one criterion about the degree of availability of seeds; five criteria related to the characteristics of the varieties as plants, at the farming stage; and five criteria related to the characteristics of the varieties' products, at the downstream and marketing stages.

The ethical criterion illustrates farmers' preference for seed supply channels and seed types that increase their autonomy and are consistent with the principles of organic farming. The second criterion is about the availability of seeds or seedlings of the preferred variety, either in seed companies' catalogues, seedlings from nurseries, or as farm-saved seeds. The price of seeds was mentioned during interviews but was not described as a criterion for varietal preference.

Five criteria were identified at the farming stage: productivity; vigor; disease resistance; adaptation to specific farming conditions; ease of harvest; and availability of technical information. The technical information farmers seek includes the conditions of cultivation, the recommended period for sowing and harvesting, and the average

TABLE 2 List of farmers having participated in the data collection (focus group and individual interviews).

Farmer	Years of work as a farmer	Origin of the farm	Financial situation	Climate conditions and duration of the production season in month	Crops	Area for vegetables (ha)	Number of vegetable varieties grown	Share of OP varieties[1]	Marketing channels
M1	> 20	Created the farm	already repaid	Plains and low mountains (9 months)	Diverse fresh vegetables	2.9	20–40	>90%	Markets (100%)
M2	<5	Bought an existing farm	no loan	High mountains (4 months)	Diverse fresh vegetables	1.8	40	<50% <20%	Markets (80%) Grocery shops (15%) Restaurants (5%)
M3	> 20	Created the farm	already repaid	Mountain (6 months)	Diverse fresh vegetables	1.7	40	50–90%	Markets (80%) Grocery shops (15%) Farmers shop (5%)
M4	5–20	Farm inherited from family	no loan	Plains (10 months)	Zucchinis Peas Cabbage Fava Fruit trees	0.8	<10	>90%	Grocery shops (100%)
M5	<5	Created the farm	ongoing loan repayment	Plains (10 months)	Diverse fresh vegetables	0.7	30	<50%	Direct selling Grocery shops
M6	<5	Created the farm	No loan	Higher mountain (4 months)	Med crops, wild crops	<0.1	<5	>90%	Direct selling
M7	<15	Created the farm	No loan	Mountain	Vegetables, cereals, others	1.8	30	50–90%	Direct selling
M8	5–20	Created the farm	No loan	Mountain	Vegetables, engrais verts	1.0	30	100%	Direct selling
M9	5–20	Created the farm	No loan	Mountain	Vegetables	<1.0	10	>90%	Market
M10	5–20	Created the farm	No loan	Lower mountains	Vegetables, crops, others	<1.0	>30	100%	Direct selling
M11	<5	Farm inherited from family	No loan	Lower mountains	Veg	<1.0	30	50%	Direct selling
M12	5–20	Farm inherited from family	No loan	Lower mountains	Vegetables, others	0.2	30	100%	Self-consumption, direct selling
M13	<5	Created the farm	Loan	Lower mountains	Veg	<1.0	30	50–60%	Direct selling
M14	<5	Farm inherited from family	Loan	Plain	Vegetables, flowers	0.3	>30	>90%	Restaurant
M15	5–20	Created the farm	Loan repaid	Mountain	Vegetables, flowers	<1.0	>30	50–90%	Direct selling

[1]As a percentage of the acreage dedicated to the production of vegetables, as declared by farmers.

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productivity. Farmers and other actors assess this « productivity » through indicators such as the volume of vegetables produced per unit of surface or plant. Plant vigor describes the capacity of the plants to strive and develop in the given agronomic conditions. Disease resistance refers to a plant's ability to resist infection by a disease or to maintain desired vegetable production even when affected by a disease. Adaptation to agronomic conditions refers to the capacity of plants to grow and produce in specific agronomic and climatic conditions (in terms of fertilization, climate, soil characteristics, duration of the productive season, etc.). Practicality characterizes the ease of cultivation and harvesting, e.g., depending on the number of fruits per plant, the regularity and duration of vegetables' ripeness period (which can be preferred short or spread over a longer period, depending on farms' working organization and marketing channels opportunities). Farmers and actors look at these aspects in absolute terms but also in comparison with other varieties of the same species to which they have access. They also consider the reliability of varieties regarding these aspects, i.e., the degree of reproducibility of satisfying results from 1 year to the other or in comparison to the description provided in the catalog.

Finally, five criteria are identified that are related to the characteristics of products derived from the variety, and relevant at the downstream and marketing stages. The degree of homogeneity (or heterogeneity) of the vegetables in terms of shape, weight, and quality, influences the conditions for marketing the vegetables, both in terms of pricing (price per unit vs. price per kg, etc.) and consumers' targets (depending on whether they value or not the heterogeneous character of products). The second criterion at the marketing stage is originality. Originality can respond to consumers' desire to see more diversity in their baskets and plates and, as such, be seen by farmers as an advantage to differentiate their offer on the stalls. Alternatively, originality can be a limiting factor, if the distance from consumers' habits limits marketing opportunities. The two mentioned quality features are taste (organoleptic quality) and visual aspect (aesthetics). Finally, the fit with culinary use is an advantage when aligned with consumers' habits and food culture, e.g., large artichokes are easier to prepare than very small ones, round zucchini are used for making « petits farcis », a local recipe of the region of Nice; some tomato varieties are preferred for salads while others are considered best for cooking.

The next section illustrates how these 12 criteria intersect with whether varieties are hybrid or open-pollinated varieties when farmers and other stakeholders in the organic vegetable value chain assess and choose varieties. How is the type of cultivars (hybrid or open-pollinated) considered in actors' seeds and seedlings purchase and advice decisions?

4.2 Perception of hybrid and open-pollinated varieties by other actors

All the interviewed farmers knew the terms "open-pollinated" and "hybrid" varieties. Although none of them precisely track the number of OP or hybrid varieties they grow, they were able to provide an approximate range of the share of OP/hybrid varieties present in their fields. Arguments provided by farmers and by other actors concerning hybrid or OP varieties are listed with regard to each of the varietal choice criteria in Table 3.

Regarding the ethical criteria, farmers provided arguments only in favor of the OP varieties. Being reproducible, OP varieties preserve the possibility of being independent from an external seed provider. This is a concern for farmers both from an ethical perspective and as a practical search for resilience. One farmer said: « *One of my basic goals is to be resilient. […] If you base your whole agricultural system on purchased hybrid seeds and external fertilizers, then your system might completely collapse in case of a big supply problem* ». Farmers also perceive OP varieties as a better option with regard to contributing to agrobiodiversity.

Concerning the availability of seeds (or seedlings), the perceived advantages of OP and hybrids are contrasted. Farmers mentioned not always finding OP varieties with the desired characters in the seed companies' catalogues, while a large range of hybrid varieties is available.

The availability of technical information is an influential criterion for farmers, especially for those who started only recently as professional farmers. These technical references are useful to plan their production and to make good decisions for crop management. Technical information is usually obtained either from seed companies' catalogues and internal advisory services or from public or private extension services. The technical references provided by public extension services at the regional level are mostly about hybrid varieties' characteristics and production methods. Technical references regarding the OP varieties are only available in some of the seed companies' catalogues. Additionally, farmers consider them to not be fully reliable or complete. One farmer stated: « *This seed company's catalogue is well done: you can read about the taste, the yield, and the operations needed. It's easy. […] We see how much [the plant] produces per m². Farmers rely on that a lot, but in fact, it does not necessarily correspond to real productivity level in our fields* »; another farmer added: «*The average yield of each variety is not provided in catalogues; only a yield range is provided by species* ».

Regarding plant varietal characteristics, the productivity, vigor, and disease resistance are perceived as generally high in hybrids while these aspects are less consistent across OP varieties currently available in seed companies' catalogues: « *In general, hybrids work well; while OP varieties' success is more variable* » said a farmer. For some species, farmers declared not finding any reliable, productive OP variety in the seed companies' catalogues. Since good varieties of these species were available in the past (according to the same farmers), questions were raised about the conservation or breeding process operated by seed producers. There are contrasted views about the current and potential productivity of OP varieties, which can be related to the fact that the current level of performance of OP varieties varies depending on species, cultivars, and sources. Despite this variability, some farmers consider that « *there are OP varieties that are productive enough* » for their business model. Some OP varieties are perceived as highly productive and attractive on all criteria. Locally, this is the case of farmers-bred varieties over 20–60 years. « *A neighbor farmer [who presented her variety of zucchini, which she had bred herself] has perfectly proven that OP varieties can work out, in terms of yield, and even better than hybrids* » *underlined a farmer.*

OP varieties have a series of advantages related to their reproducible character. For example, they offer the possibility to undertake an on-farm or regional breeding process, to orientate the variety evolution towards specific, desirable criteria, such as a longer period of ripening, a higher number of fruits per unit of surface, etc.

TABLE 3 Features of OP varieties and hybrid varieties according to interviewed farmers, for each varietal choice criteria.

Criteria	Listed features of the OP varieties	Listed features of the hybrid varieties
Ethics	• Farmers' autonomy • Consistency with the value and goals of organic farming and peasant farming (important for farmers themselves as well as for customers)	
Accessibility to seed or seedlings (purchase or production)	• For some species, lack of varietal options in the catalogues • Option to reproduce seeds on the farm (useful for local breeding, saving money, farm autonomy and resilience)	• Common in seed companies' catalogues, with reliable quality
Availability of technical information	• Technical information is rare • Existing technical information is not always reliable	• Technical advice provided in catalogues and through seed companies extension services • Knowing the productivity of the variety in advance is useful for farmers to reliably plan their production
Productivity	• Some OP varieties are enough productive for farmers' business model • For certain species, the productivity should be increased to make varieties more attractive	• Generally, highly productive, when farming conditions are average to good. • Preferred by farmers when launching their activity
Disease resistance	• Disease resistance is strong in some specific cases (thanks to breeding effort and local adaptation).	• Disease resistance is scientifically assessed and strong for specific diseases (in consistency with breeding strategy).
Adaptation to agronomic conditions	• OP varieties can adapt to diverse, harsh and variable conditions.	• More relevant in favorable agronomic conditions.
Practicality	• Certain vegetables shapes, size and ripening period are preferred.	• Certain vegetables shapes, size and ripening period are preferred.
Homogeneity [e]	• Heterogeneity is preferred in some cases, e.g., to extend the harvesting period • Certain OP varieties, which have been through an extensive breeding process, showcases a very high level of homogeneity	• The homogeneity of vegetables/fruits makes it easier to harvest and store products • Homogeneity is also a positive feature in specific marketing channels (grocery shops)
Originality [f]	• Varieties that are less common, different from mainstream production are considered interesting for marketing a	• Consumers are commonly used to Hybrid varieties
Aesthetic	• Wide range of aesthetic characteristics	• Fit with mainstream food habits.
Taste	• More diverse and interesting organoleptic quality.	• Fit with mainstream food habits.
Fit with culinary use	• Fit with local culinary habits	• Fit with mainstream food habits.

OP varieties are also considered by some farmers the most relevant in case of specific farming conditions, e.g., low input systems or mountain climate, while hybrids are bred in and for optimal, controlled agronomic conditions. « *OP varieties adapt very well to having no fertilizer at all, or just a little, whereas if I put a hybrid in there I will have even less yield* » assessed a farmer working in a low inputs system.

In terms of practicality, farmers' preferences vary depending on farms' working organization and marketing channel opportunities. Some farmers prefer to have an extended ripening period, while others prefer a short, simultaneous ripening. « *With hybrid varieties, having 200 cauliflowers ripe in the same day, that's nonsense for us. While with the populations, maturation happens throughout a period, so we can sell them progressively* » said one farmer. Another provided a contrasting comment: « *The OP variety of peppers grows late, its shape varies… while hybrid peppers are of very uniform shape and color. To be efficient with harvesting, and to sell the vegetables to shops, we need to have homogeneous products and regular and sufficient production* ».

Finally, regarding the characteristics of products derived from the variety, OP varieties are valued for their originality, especially when they are less common than hybrid varieties. This uniqueness allows farmers to differentiate their products from mainstream production. This aspect is also appreciated by farmers themselves, to diversify the crops and colors in their fields. OP varieties are generally also appreciated for their organoleptic and cultural qualities. In several cases, farmers described hybrid varieties as less attractive in terms of taste but there were exceptions.

In summary, perceived advantages of OP varieties over hybrids include ethical and hedonic aspects along with context-specific technical advantages. On the other hand, the listed advantages of hybrid varieties are mostly about productivity, disease resistance and access to technical recommendations. While all farmers of the sample consider OP varieties more aligned with the principles of organic agriculture and peasant farming, their perception of the operational relevance of the OP varieties currently available in seed companies' catalogues varies and leads to contrasted varietal choices.

Criteria are applied in a differentiated way depending on the species. For species that make up a major share of the income (in the region of this case study, tomatoes and zucchinis), technical and economic criteria tend to have more weight. On the other hand, for species that are secondary in income or cultivation acreage, the

originality and hedonistic criteria are stronger. Depending on the species, the market offering varies in terms of the number of varieties available in the catalogues and in how much it addresses the selection criteria identified. There is no consensus among farmers regarding the best varieties available for each species. Finally, for some species, there are no (or few or unreliable) OP varieties available in seed companies' catalogues. Farmers then rely almost systematically on hybrids. This is, for example, the case for CMS hybrid cabbages varieties.

4.3 Perception of hybrid varieties and open-pollinated varieties by other actors

We also analyse the arguments about OP and hybrid varieties mentioned by extension services, seedlings producers, retailers and restaurant managers.

The ethical argument was mentioned only by retailers and restaurants while it was absent in extension services' interviews. For the retailers, the local character of OP varieties is a valuable asset for sales pitches. One retailer mentioned: « *Above each sale box, we write down the name of the vegetable species and the geographical origin […] We experimented indicating "peasant seeds" and "local variety" on the boards. It worked very well, despite the high price* ». Another retailer added that « *a reflection [has been started] on the possibility of creating a brand that would emphasize vegetables' seeds as obtained from 'peasant seeds'* ». These elements suggest that there is, in this specific context, a marketing opportunity that could be encouraging for OP varieties.

The availability of seeds or seedlings was not a direct concern for the interviewed actors.

Regarding technical information, public extension services consider the information available in catalogues insufficient for farmers to make informed decisions in their local conditions. They set trials to verify and complement the information available in seed catalogues. Most technical experiments are rolled out with hybrid varieties. Extension services then publish their varietal recommendations based on their own trials, other regional experiments, on-farm field observations, and open discussions with seedlings suppliers.

Arguments relating to the productivity and vigor of varieties were cited by the public extension services representative and the seedling suppliers. For the farming adviser, the issue of (agronomic) productivity is strongly linked to that of (economic) profitability via the turnover that can be generated by production volumes. This issue is seen as crucial in the small-scale vegetable sector since farms profitability remains on average fragile and remuneration is low despite a high workload. Productivity is mentioned both quantitatively (quantity per square meter) and in terms of regularity and reproducibility (in the sense of reliability). The two seedling suppliers showcase contrasted choices in their portfolio, one preferring hybrid varieties for their productivity and reliability while the other one produces seedlings of OP varieties together with some hybrid varieties. The weight of this criterion is, however, considered to vary depending on the importance of the crop for the farm's economic viability. For crops that provide a large share of turnover (tomatoes, peppers, etc.).

The issue of disease resistance was mentioned only by the representatives of the agricultural extension services and seedling providers. Disease resistance is seen by agricultural advisers and seedling providers as an important criterion for varietal choice: « *Part of our job is to assess resistance to diseases and pests* ». While resistances are clearly identified in hybrid varieties—since they are described in the varietal characteristics—disease resistances of population varieties are less often evaluated. Moreover, the resistance of a population variety is related not only to the individual plant but also to the composition of the population, hence some variability. Again, disease resistance is perceived as particularly critical for varieties that represent a large share of the economic benefits.

Adaptation to specific farming conditions is currently not a focus of the trials done by the agricultural advisory services. In contrast, retailers mentioned organic farming and absence of pesticides or synthetic inputs as commercially valuable aspects.

Varieties' practicality for cultivation, distribution and sale was mentioned both by the extension services representative and the retailers. Practicality relates for example to the ease of harvesting, or to shapes that facilitate storing and putting vegetables in boxes for selling them.

The criterion of homogeneity was mentioned by the retailers and restaurant owner. At the distribution level (here in organic grocery stores and medium-sized stores), heterogeneity does not appear to be an obstacle. However, in direct sales, some farmers cited it as a problem, for example for sales by the unit.

Varietal originality is seen as a commercial asset by retailers. Among the retailers interviewed, varietal originality can be very well valued, if vegetables are of high quality. This positive view of varietal originality can be linked to the fact that sales are made in niche markets, to consumers who are interested in local products. « *As far as local products are concerned, consumers are happy. I do not see any obstacle related to originality* »; « *The* variety *name could be emphasized even more. We do it for example on zucchini, but not on all vegetables, but it would be interesting to talk about it more* ».

Organoleptic quality was mentioned by the seedlings provider as a criterion that matters for farmers, even if in second place compared to productivity: « *Farmers tell me that in terms of taste, a population variety is much better, but that the reliability to have sufficient productivity is not always there* ». The extension services representative also takes taste as a criterion for comparing varieties. From the point of view of retailers, there is a remarkable link between breeding and taste quality: « *It is obvious that when farmers work well at the seed level, the results on the taste are incomparable. There are some farmers who really manage to make up quality by breeding their local variety* ».

The aesthetic criterion was explicitly mentioned by retailers. This criterion is considered as a major factor for a good commercial value of vegetables: « *When you have a local variety with high quality, like the beautiful zucchini bred by *, you sell everything, people ask for it. So we see that there is something to do in terms of varieties* »; « *The beauty of the product is valuable: tomatoes can sell for up to € 8 /kg* ».

Finally, the fit with culinary use was not mentioned by the actors, whereas it had been by the farmers.

4.4 Barriers to the adoption of open-pollinated varieties

Within this sample, nine out of the 11 farmers declared using OP varieties on more than 50% of the farm acreage. However, none of them use only OP varieties. Based on the data collected, we uncover

TABLE 4 List of the barriers to the adoption and use of OP varieties in the small-scale organic vegetable production sector, sorted by level of the agri-food chain where they exert an influence.

Actors	Barriers description
Breeding sector	1. Fewer OP varieties with high performance (in terms of productivity and resistance) available
Seed market	2. Contrasted commercial arguments used to promote high-performance Hybrid varieties (in terms of productivity and resistance to specific diseases) vs. OP varieties (ethical argument of "peasant varieties," "for the pleasure of diversity," etc.).
	3. Incomplete information in seed companies' catalogues about OP varieties—such as productivity, advice for cultivation, reproducibility—is not systematically communicated.
Extension services	4. Position favorable to hybrids / against OP at the institutional level. 5. Limited resources available for the extension and R&D services at the regional level, limiting the capacity for assessing alternative varieties. 6. Omnipresence of productivity criteria (with a preference for high productivity) and reproducibility across years, leading to testing and dissemination of information mostly on F1.
Farmers	7. Strong financial pressure to reach profitability of farming activity (caused by the high investments made for land, infrastructures and tools, and the related loans or conditional subsidies, compared to limited benefits from the sales of vegetables). 8. Lack of time and skills to assess and implement innovations (e.g., to test new varieties or participate in a participatory breeding project). 9. No widespread nor comprehensive awareness about organic breeding and types of cultivars. 10. No training/educational modules on varietal choices and related organizational and technical skills (until recently). 11. Use of Hybrid varieties as a « risk insurance », further emphasized by a general opinion disseminated to and by farmers in favor of F1.

Sources: 2020 and 2021 data collection.

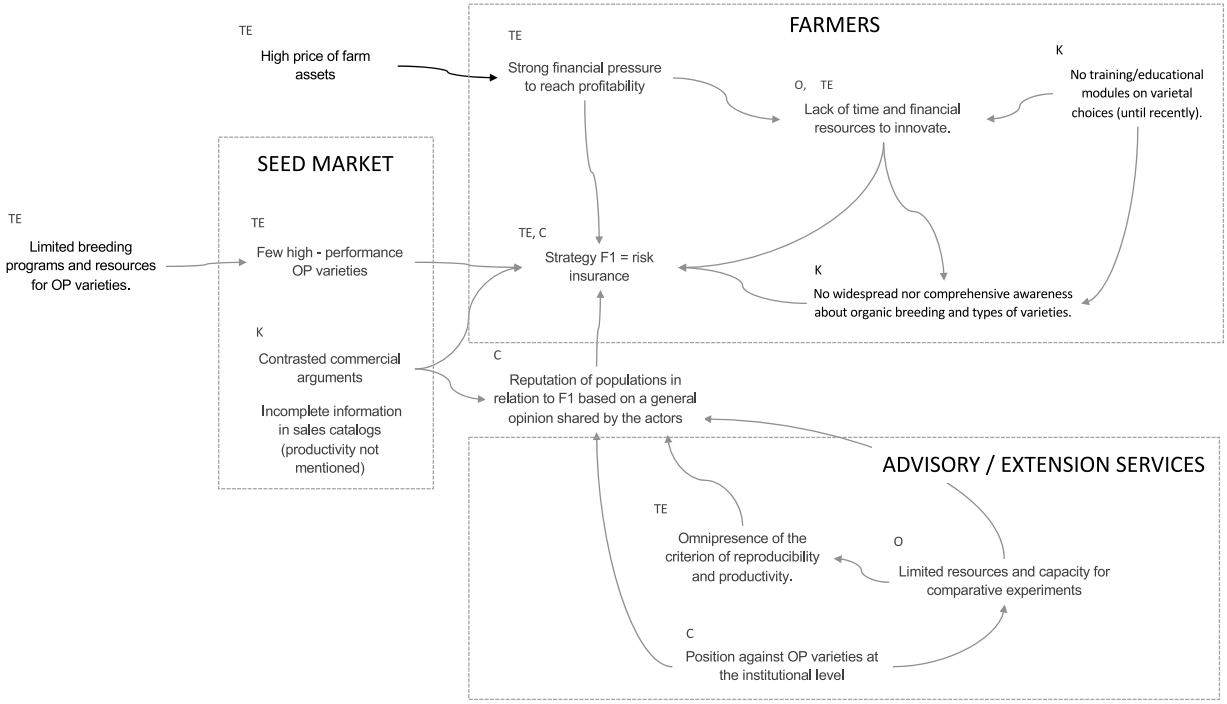

FIGURE 2
Factors that operate as barriers to the adoption and use of OP varieties in the small-scale organic vegetable sector, with a representation of how they are intertwined. Eleven factors have been identified that hinder the adoption and use of OP varieties: three factors in the seed market, five factors at the farming stage, and three factors in the extension services. Three additional factors have been identified that operate beyond the scope of these actors. Notes: O stands for Organizational barriers, T for technical barriers, E for economic barriers, K for knowledge-related barriers, C for cognitive barriers.

11 factors impeding the wider adoption of OP varieties in the small-scale organic vegetable sector. These factors operate as technical, economic, organizational, cognitive and knowledge-related barriers that are strongly intertwined (Table 4, Figure 2). Five factors are identified at the farming stage, three factors are found within the context of extension services, and three factors are identified at the seed market level. In this Case Study, no barriers were identified at the downstream level. Rather, downstream actors offer opportunities to market vegetables from OP varieties. This can be related to the specificities of the local market that includes consumers with high revenues and/or high interest in local, high-quality varieties (cf. *supra*).

When looking at the seed market, the first and central factor identified is the lower number of OP varieties available within the seeds catalogues that have a sufficient level of performance. On the

contrary, there are multiple hybrid varieties available in catalogues that have high levels of performance. When they buy seeds in catalogues, farmers may compare varieties and tend to select varieties that offer higher level of performance and predictability in terms of productivity, vigor, and disease resistance. A farmer said: « *The hybrid varieties that we plant today are very satisfactory from many points of view: productivity, taste […] And for a non-hybrid variety to reach the same levels of performance, there is a lot of work to be done* ». The choice of hybrids can also be an alternative, if no reliable OP varieties are found. A farmer said: « *We increased the share of hybrids because we had major tomato production problems. We had to choose varieties that are more resistant to diseases, to Fusarium wilt for example. With hybrid varieties, there was better resistance to Fusarium wilt* » (M3). The problem of low availability of OP varieties is a topic not only in catalogues (as seeds) but also at nurseries (as seedlings). In some cases, only seedlings of hybrid varieties are available from plant nurseries. In these cases, growing OP varieties requires farmers to produce their own seedlings, which is more time-consuming and resource-intensive compared to the convenience of purchasing seedlings from plant nurseries.

In addition, two factors are identified at the seed market level that make up an imbalance of information between OP and hybrid varieties. First, technical information for the cultivation of OP varieties in seed companies' catalogs is not always sufficient. Farmers emphasized a lack of technical data regarding the performance of OP varieties—such as productivity, advice for cultivation, resistance to diseases—both in commercial catalogues and in technical documentation. A farmer explicitly said: « *there is no proof about [OP varieties'] productivity* » (M2). Another added a specific example: « *The cucumber mosaic virus is present in the area, so we prefer planting resistant varieties. Among OP seeds, I do not think there is any resistance. Well, maybe there are but not really demonstrated* ». The breeding and conservation process behind each variety is also not indicated in catalogues. Therefore, there is no specification nor verification of the breeding process behind an OP variety. Second, in seed catalogues, the sales argument of high-performance hybrid varieties (mostly focused on productivity and resistance to specific diseases) coexists with the marketing of OP varieties sold with other commercial arguments (ethical argument of "peasant varieties," "for the pleasure of diversity," etc.). This further pushes the idea that OP varieties are a secondary option.

At the farming stage, a central reason for farmers to choose hybrid varieties is that they consider it a « risk insurance ». This is related to the reputational and technical factors identified above at the seed market level. When farmers consider predictability and productivity as the main criteria for choosing varieties, hybrid varieties benefit from an intense breeding history and a positive reputation. The choice of hybrid varieties as a « risk insurance » is especially visible for species that make up for a large share of the farm revenues. A farmer said: « *For tomatoes and zucchini, we plant hybrids because we know that we will make a lot of money with them. And then we have a little fun in the open fields with other varieties* ». The advisory agent said: « *we prefer to give recommendation of hybrids, because we know well what their productivity potential is. It's easier [to recommend them] because they are well characterized* » (A1).

Behind these preferences of farmers, a key factor is the high level of financial pressure to reach profitability, in order to make sure they get a salary out of farm activity. Within the sample, the preference for hybrid varieties is the highest when farmers face a high level of financial pressure (due to a high loan repayment, or to extremely short productive season and difficult biophysical farming conditions). This is further emphasized in the context of starting a new farm: « *When you start a farm, you cannot afford a failure in production. At first, I only used hybrid* varieties, *to be sure to produce a lot! It was purely an economic choice. Today, after a few years of activity, we can try other varieties* ». Another farmer added: « *We did not give much thought [to the choice of seeds] because there were so many other things to do and learn… for example, preparing the soil adequately, knowing how to plant correctly, how to support plants health without chemical inputs […] When you start [a new farm] there are a lot of things to learn* ». The first years of a farm enterprise are recognized as a period during which new farmers face numerous challenges and learning processes (Curley, 2020; European Commission et al., 2016). Within the sample, farmers using OP varieties the most are either settled for a long time with an already established economic success and having gained significant skills for varietal selection over time, or younger farmers who benefit from family assets or/and have a side-job that ensures their revenues. Farmers using OP varieties the most also have average to best agronomic and climatic production conditions.

The preference for varieties with measured characters and predictability of production is accentuated by the lack of time and skills farmers have for implementing, assessing and scaling up innovations. Varietal choices are embedded in farm history, and, as such, are subject to the phenomena of path dependency. As a farmer progressively organizes their yearly activities, choosing seeds (seedlings) from the same variety and sourcing channels from 1 year to the next can be an efficient default choice. On the other hand, testing new varieties or species or other sourcing channels is more time demanding. The scarcity of time for making up new varietal choices seems to be especially critical in farms that have a high degree of vegetables diversity or multiple distribution channels. Consequently, early choices of Hybrid varieties tend to be continued throughout the farm's history. In farms in which the production is focused on a smaller number of vegetables and marketing is done through one or two channels, there seems to be more time and attention available for varietal innovation.

Finally, there is low awareness about organic breeding and types of cultivars. Without specific knowledge in this regard, farmers (as well as other actors) may either not consider the type of variety (hybrid/OP) as a criterion or may rely on subjective or incomplete hearsay. « *Many farmers produce without being really interested in the varietal choice: they order a type of phenotype from their nurseryman or seed companies catalogues, without necessarily asking for a specific variety; […] Even if they have chosen a specific variety at the time of ordering, they may forget during the season which variety they had ordered* » (A1).

The lack of awareness and skills about organic breeding and types of cultivars is due to a deficit of training/educational modules on varietal choices. Until 2 years ago, there were no training modules on the topics of varietal choices and possibilities of on-farm/regional breeding strategies available in the region. When they started their farming activity, most interviewed farmers had no skills and knowledge regarding breeding and seed types (M1, M2, M3, M4, M5). A farmer said: « *We started [the farm twenty-eight years ago] with hybrid tomato varieties. At first, we did not know at all [what that meant]. We bought plants [from nurseries]. We did this because we were*

told to do so. We knew absolutely nothing at the start; afterward, gradually, I had the chance to wander around and learn about techniques and plants » (M5). Another farmer added: « *When I settled down [four years ago], to make my first choice of seeds, I hastily made it from a main [seed company's] catalogue* » (M4).

Three factors are identified in the context of extension services. Advisors who make varietal recommendations mostly encourage farmers to choose hybrids. Farmers mentioned having received recommendations from the public farming advisory services in favor of Hybrid varieties or warnings against OP varieties (M3, M4, M5). « *A person from the advisory service told me to be careful, that OP seeds are more susceptible to disease; so, they can catch the disease faster and pass it on to other plants* ». Some farmers' organizations hold a similar position: « *in the ADEAR*[1] *network I used to belong to, on peasant seeds network, we are very cautious about advising young farmers to use OP seeds. There is no reliable proof that it is possible today [to build up a successful farm with OP varieties]. When we look at the data that is available at the ARDEAR,*[2] *we see that the diversified vegetable farmers in small areas who are successful—while maintaining affordable prices—work more with hybrids; I will say with 80% hybrids* » (M3). This position against OP at the institutional level (both from public advisory services and from farmer-based advisory services), comes together with an omnipresence of productivity criteria from public advisory services (while other criteria such as the resilience to extreme climate events are not taken into consideration). The comparisons of varieties made by the advisory services are designed with productivity as one of the major criteria. The advisor also mentions they prefer to recommend varieties that showcase high and consistent productivity across years. Disease resistance is also presented as one of the most important criteria. Advisors tend to rely on hybrids also as a source of simplification of their own work, in a context of resources scarcity. « *The work of comparing varieties takes me 15 to 20 days of work—depending on the species. It would have to be repeated over several years, so it's a big job. We do it less and less because we lack resources. To do it rigorously scientifically takes a lot of time, so producers cannot do all this work either* » (A1). While there rarely is information available about the performance of OP varieties, F1 mostly are characterized by companies and by national or regional extension services, which makes it more straight forward for advisors to recommend them to farmers.

5 Discussion

5.1 Insights on the factors for the adoption of open-pollinated varieties in the organic vegetable sector

This paper looks at the adoption of hybrid and open-pollinated varieties by organic farmers. In contrast to the cereal sector, there are only few studies on the current state of the varietal portfolio of vegetables species for organic production. With an in-depth view into the example of small-scale organic vegetable production in South-East France, we propose undertaking a reality-check on the capacity of current seed systems to provide organic farmers with OP varieties in consistency with the recommendations from the organic agriculture standards. This analysis contributes to mapping the current state of seed systems in the perspective of supporting strategic choices for the organic sector.

The research lays out important insights regarding the making of varietal choices. The data collected reveals that numerous criteria are looked at when making up varietal choices. Farmers and other actors show contrasted levels of interest in each criterion, which can be related to specific characteristics of farms and value chains. The presence of an ethical criterion is not surprising given that organic farming is based on certain ethical values and the values integrity approach (Verhoog et al., 2007). A study rolled out in the same region has shown that organic vegetable farmers are concerned with social and moral aspects (Mzoughi, 2011). However, the analysis shows that farmers do not choose their varieties independently of the context in which they work. Although the varietal choice is made at the farm level, it is strongly linked to what happens upstream and downstream. This is consistent with findings from other studies (Lammerts van Bueren et al., 2018; Vanloqueren and Baret, 2008; Winter et al., 2021, 2023). Through this research, 11 barriers have been identified that hinder the adoption of OP varieties by small-scale organic vegetable producers. Beyond farmers' preferences, material aspects such as financial pressure for farms' economic viability and the actual portfolio of varieties available in the seed market play a key role. Immaterial aspects such as educational context and interpersonal and institutional communication are also influential factors. The analysis highlights how those cognitive, technical and economic barriers are intertwined. This is consistent with other lock-in studies characterized by a complex system of barriers which are inter related, of various types, and that occur simultaneously along value chains. These observations invite the sector to design relevant strategies at multiple levels with a coordinated approach.

This paper highlights three essential dimensions for the development of organic agriculture: integration of the value chain, coexistence of models and risk management. The integration of the web of stakeholders' expectations is crucial to align the needs of farmers, value chains, and consumers to encourage the adoption of open-pollinated varieties. Varietal choices are influenced by midstream and downstream actors whose expectations for more standardized and homogeneous products favour hybrid varieties. On the other hand, more consumer attention to local adaptation and autonomy of farmers will favour OP varieties. These two options are not fully incompatible, and as shown in the interviews, may differ across species. They may also coexist. The coexistence of agricultural and consumption models is a real challenge as, in many cases, the logic of commercial competition is dominant (Lamine et al., 2014). The evolution and development of organic agriculture models requires considering different breeding and production strategies and the organization of their coexistence to meet the diverse needs of both the market and producers. This coexistence has to be organized at the territorial level (Gasselin et al., 2020). The coexistence challenges of the organic sector are not only the competition against the conventional sector but also risks of internal competition between different visions of the organic sector development. The choice of seeds and varieties is a key element of this debate. The existence of

1 ADEAR stands for *association pour le développement de l'emploi agricole et rural*, i.e., association for the development of agricultural and rural employment.

2 The ARDEAR is a federation of the local ADEAR organizations.

different options within the seed systems that supply the organic sector will favour a coexistence process (Lammerts van Bueren et al., 2018).

The challenges faced by organic agriculture in Europe regarding its seed supply are multiple (Lammerts van Bueren et al., 2011; Le Doaré, 2017; Luttikholt, 2021; Orsini et al., 2019, 2020; Padel et al., 2021; Rey et al., 2014; Solfanelli et al., 2020). As stated by Brzezina et al. (2016) « Organic farming has some potential to bring resilience to the European food system, but it has to be carefully designed and implemented to overcome the contradictions between the dominant socio-economic organization of food production and the ability to enact all organic farming's principles—health, ecology, fairness and care—on a broader scale ». The research results presented in this paper brings light on a concrete aspect of farming systems—the varietal choices and upstream breeding process and seeds supply—which needs to be addressed for organic agriculture to fulfill its objectives of sustainability. In this case, addressing barriers and supporting the adoption of OP varieties would contribute to a better alignment of organic production systems with the organic agriculture standards. One of the major barriers to adopting open-pollinated varieties is the perceived risks and performance levels, which are linked to market factors, breeding history, and biological and environmental conditions including climate change and plant diseases. The opportunity for the organic sector is to breed OP varieties towards increased productivity while maintaining the advantages of resilience they offer both at the field level and at the seed system level. While an important body of research is available on the informal seed system (on participatory breeding, farmers' networks, etc.) and on the breeding and performance of hybrid varieties in the formal seed system regarding, there is a lack of research on OP varieties in the context of the formal seed sector. This paper offers to look at this gap from farmers' perspective, and indicates both shortcomings and opportunities for the organic sector to improve its supply from the formal seed system. Next steps for the development of organic seed systems may be based on a co-innovation approach among different stakeholders, to strengthen interactions within agri-food chains and develop collaborative approaches to offer practical solutions over the medium term.

5.2 Study limitations

The data collection was rolled out with voluntary small-scale farmers. Fifteen farmers were interviewed, which covers 10% of the farmers producing fresh vegetables under organic conditions in that region.

The data highlights the complex nature of varietal choices and preference for hybrid/OP types of varieties. This complexity causes numerous challenges in the interpretation of data. In many cases, farmers' ideal choice of a variety differs from their actual choices. It was thus necessary to question them about the gap between their current varietal portfolio and their interest in other varieties.

The data also revealed that farmers rarely have access to, nor undertake by themselves, scientific comparison of the technical and economic features of varieties. Their assessment is mostly qualitative. Regarding hybrid/OP types of varieties, farmers have a general opinion but may as well cite counterexamples. Therefore, it was not possible to take one farmer's opinion as a fixed fact, but rather as some insight into a wider, more complex picture that the actors themselves are not necessarily able to describe comprehensively.

Additionally, the vegetable sector has an inherent complexity due to the large number of species it includes. For the analysis and interpretation of the data, it was necessary to carefully distinguish between generic aspects that applied to the vegetables seed supply in general, versus aspects that are specific to one or several species. The variability of OP varieties characteristics is increased by the fact that they may be produced by various seed producers with diverse seed production methods. Consequently, the varietal offering in the seed companies' catalogues may contain varieties with various levels of actual breeding and selection. This increases the difficulty of generalizing observations.

The data was collected in 2019–2021. The data presented was possibly affected by the effect of the pandemic on the farming and food sector. The data was collected before the addition of organic heterogeneous material in the legal European framework.

5.3 Recommendations for further research

This research reviewed criteria and provided insights about farmers' seed and varietal preferences in the context of small-scale organic vegetable production, and the systemic barriers to the adoption of OP varieties. Beyond this scope, complementary questions could be further research, both by extending the scope of the study and by undertaking a conceptual analysis.

The methodology used for this study could be rolled out in a diverse set of European vegetable production settings, including larger scale farms and specialized production systems. This recommendation is based on the findings of the hereby study, that shows that the challenges related to varietal choices are embedded into farms' technical, social and economic conditions, and that the market offerings significantly vary across species, implying that diverse strategies or timelines may be necessary to overcome breeding and adoption challenges for major versus minor species. Such complementary assessments will be useful to design relevant seed supply strategies at the EU level. In addition, rolling out a parallel study at the market level with genetic resources specialists, plant breeders, and seed retailers, would be a valuable add-on to continue mapping how these actors shape and constrain the adoption of different types of cultivars.

In this article, we highlighted the seed supply and varietal choices focusing on hybrid versus open-pollinated varieties in the current situation. To build on this analysis, an opportunity is to consider possible future scenarios showcasing contrasted evolution. For such prospective analysis, it will be important to go beyond the assessment of varieties available in farms and on the market, considering not only the current performances of varieties but also their potential for improvement when further bred and adapted. Prospective studies could discuss the potential contribution of formal and informal seed systems, assess potential competition and lock-in phenomena between these systems (Vanloqueren and Baret, 2009).

Organic agriculture aims at a sustainable production of food with farming methods that do not hinder natural resources. Within this framework, organic farming recognizes the integrity of plants as an essential aspect of organic crop production. In this regard, the organic seed systems have a major role to play, by providing varieties that are in line with the ethical principles of organic agriculture and that can strive in the agronomic and economic conditions of organic farming.

Data availability statement

The datasets presented in this article are not readily available because agreements from the participants were obtained in the context of this present study. Requests to access the datasets should be directed to clementine.antier@uclouvain.be.

Ethics statement

Ethical approval was not required for the studies involving humans because Participants in this study were fully informed about the objectives of the research and the conditions under which their responses would be used. They provided oral consent to participate in the study. Furthermore, their anonymity was guaranteed throughout the process, ensuring that all data was handled confidentially and securely. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

CA: Conceptualization, Investigation, Methodology, Writing – original draft. PB: Conceptualization, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

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

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