Journal of Cleaner Production 279 (2021) 123654

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Adopt to adapt? Farmers' varietal innovation adoption in a context of climate change. The case of sunflower hybrids in France

Mikaël Akimowicz [a, b, *], Jean-Pierre Del Corso [b], Nicola Gallai [b], Charilaos Képhaliacos [b]

[a] LEREPS, Université Toulouse III - Paul Sabatier, Route de Narbonne, 31330, Toulouse, France
[b] LEREPS, Ecole Nationale Supérieure de Formation de L'Enseignement Agricole, 2 Route de Narbonne, 31320, Castanet-Tolosan, France

ARTICLE INFO

Article history:
Received 30 January 2020
Received in revised form
23 June 2020
Accepted 5 August 2020
Available online 14 August 2020

Handling editor: Zhifu Mi

Keywords:
Varietal innovation
Sunflower seeds
Adoption decision
Climate change
Institutional environment

ABSTRACT

In a context of adaptation to climate changes, the recent development of hybrids with environmental traits, such as drought-tolerance, rejuvenates the question of farmers' adoption of varietal innovation. In this article, due to the limitations of econometric models to investigate farmers' adoption of varietal innovation from an institutionalist perspective, we implement a qualitative design based on semi-structured interviews. The purposive sample of stakeholders involved in several links of the sunflower supply chain is selected in Nouvelle Aquitaine and Occitanie. the two regions leading the French sunflower production. Results show the embeddedness of farmers' decisions in economic, social, and environmental constraints. Moreover, perceptions and concerns diverge between farmers, distributors, and seed companies. Particularly, seed companies' optimistic vision about the future of sunflower production is not shared by farmers and distributors. On the one hand, farmers expect genetics to remedy their technical issues, while distributors are concerned by their economic viability. On the other hand, seed companies focus on the Central and Eastern European markets and capitalize on the quality of the French environment for research and development.

1. Introduction

The scientific consensus on climate change highlights a modification of crop growing conditions (IPCC, 2018). Both the frequency and intensity of extreme adverse climatic events, such as droughts and floods, are likely to increase (Canfin and Staime, 2015). In France, forecasts for a 1 °C temperature increase scenario indicate that thermic stress may be exacerbated by rare summer precipitations, harvests may take place earlier, lighter rainfalls may both facilitate late field work and open windows for winter crops, while nitrogen soil fluxes may be modified (Brisson and Levrault, 2010).

Farm adaptation to these changing crop growing conditions can rely on the introduction of hardy crops, such as sunflower, which have the convenience of better resisting abiotic stressors. Sunflower is indeed a break crop with advantageous characteristics such as a short agricultural cycle, low nitrogen needs, and a taproot that can access deeper soil moisture. However, concerns about an increasing variability of interannual sunflower yields have emerged; they could push farmers to irrigate early on in the season, utilize complements during early crop stages, and seed early varieties (Op. cit.). Since farmers' adoption of hardy crops can foster farm adaptation to climate changes, the identification of factors affecting farmers' varietal adoption is therefore a timely and urgent challenge.

In France, the food insecurity context of the post-World War II period resulted in the consolidation of agro-industrial supply chains (Temple et al., 2011). The sunflower supply chain was no exception (Galliano et al., 2018). Within agro-industrial supply chains, material (e.g., production factors, goods) and immaterial (e.g., financial, knowledge) fluxes that connect farmers with each other, as well as with upstream stakeholders-e.g., agri-supply industries-and with downstream stakeholders-e.g., collectors -create interdependencies among stakeholders (Malassis and Ghersi, 1996). Moreover, the globalization of economic activities has resulted in a geographical separation of production, transformation, and consumption operations, which requires adopting supranational perspectives to analyze the articulation of agro-industrial supply chains (Rastoin and Ghersi, 2010).

* Corresponding author. LEREPS, Université Toulouse III - Paul Sabatier, Route de Narbonne, 31330, Toulouse, France.
E-mail addresses: mikael.akimowicz@iut-tlse3.fr (M. Akimowicz), jean-pierre.del-corso@ensfea.fr (J.-P. Del Corso), nicola.gallai@ensfea.fr (N. Gallai), charilaos.kephaliacos@ensfea.fr (C. Képhaliacos).

https://doi.org/10.1016/j.jclepro.2020.123654
0959-6526/

This industrial consolidation contributed to the structuration of the seed sector, which transitioned from a public lead in the 1930s to a private lead in the 1950s (Bonneuil and Thomas, 2009, 2012). The emergence of hybrids, the regulation of the seed market, and the enforcement of intellectual property rights have transformed the farmer-seed relationship (Pimbert, 2017). Three cornerstone changes in the French legal framework have contributed to these transformations. In 1932, an Official Catalog that inventories available varieties was introduced to clarify varietal offer (JORF, 1932). In 1949, a decree banned the utilization for commercial purposes of varieties that are not registered on the Official Catalog (JORF, 1949). In 1960, another decree enabled the exclusion of varieties that do not meet new registration criteria (JORF, 1960).

In France, the registration of new sunflower varieties on the Official Catalog relies on two series of tests,[1] which are conducted by the Variety and Seed Study and Control Group[2] (GEVES) in open fields over two years. While the first test determines whether varieties satisfy the criteria of homogeneity and stability based on morphological, physiological, and biochemical characteristics, the second test evaluates varieties' agronomic, technological and environmental value. Particularly, the latter must demonstrate varietal improvements in regard to varietal references. However, criteria vary from one European country to another and France is the only country where environmental criteria are enforced.

In these conditions, most open-pollinated varieties (OPV)-i.e., varieties whose seeds produce plants that are roughly similar to their parents-are not registered on the Official Catalog. Their exclusion is primarily due to their lack of homogeneity and stability as well as difficulties to demonstrate improvements in research stations where soil and climate conditions may be significantly different from their original terroir. OPV, which had adapted to local growing conditions after centuries of co-evolution with territories, have been replaced by hybrids almost entirely (Rosset and Altieri, 2017). Additionally, in France, the cultivation of genetically modified (GM) crops is prevented by a moratorium, except for the MON810 maize. As a result, hybrids dominate the French seed landscape. Farmers, who used to store a share of their harvest as seeds for the following growing season, now tend to acquire hybrids every year due to both a weakening of hybrids' traits of interest after the first year of cultivation (i.e., weakening of the heterosis effect) and the implementation of varietal property rights. Over time, the offer of hybrids has diversified: in addition to yield and pest-resistance traits, characteristics such as drought-tolerance are sought to respond to the current stake of environmental preservation.

This article aims to shed light on the factors influencing farmers' adoption of varietal innovation (VI) in France using the case of the sunflower production sector. Following the above-mentioned elements, we make the hypothesis that farmers adopt VI based on their technical needs, which are evolving to facilitate adoption to climate changes, while public policies and the organization of the supply chain also drive their choices. We adopt a farmer-centered approach that critically complements Galliano et al.'s (2018) agro-industrial perspective. We conducted semi-structured interviews with stakeholders from the sunflower supply chain-i.e., representatives from seed companies and collectors, farmers, and researchers, which enable an in-depth analysis and a comprehensive understanding of stakeholders' complex decisions. The purposive sample was composed of stakeholders from the Nouvelle Aquitaine and Occitanie regions, the two leaders of sunflower production in France. The results of the thematic analysis shows the embeddedness of farmers' VI adoption decisions within economic, social, and environmental considerations. In particular, they highlight the existence of a discrepancy between farmers' needs and seed companies' priorities while distributors focus on their own economic viability.

This investigation of farmers' VI adoption applied to the French sunflower sector contributes to filling gaps in the economic literature. The focus on sunflower, which has valuable environmental benefits due to its lower input needs, its ability to diversify crop rotations, and its capacity to face climate change (Brisson and Levrault, 2010; Lecomte and Nolot, 2011), departs from previous studies' focus on staple food, such as maize and rice, which was driven by an emphasis on food security. The selection of a research field comprised of the two French regions that concentrate most of the French sunflower production brings an original perspective that differs from previous analyses that investigated the adoption factors of VI adoption in the Global South, where OPV, hybrids, and GM crops coexist (Singh et al., 2019). Moreover, the diversification of hybrid traits, such as drought tolerance, rejuvenates the interest of an analysis of farmers' VI adoption in the French context of a decreasing planted area of sunflower (Palleau and Motard, 2015). Last but not least, an institutional lens based on Vatn (2005, 2017) adds a layer of complexity for the understanding of farmers' VI adoption dynamics, which valuably adds to previous econometric results that compose the economic literature. In the following section, the review of the literature highlights the limitations of econometric results and sets the ground for a discussion of the methodological choices made for this research. The method used and the data collected for the analysis are detailed in the third section. The fourth section presents the results, which are then discussed in the fifth section.

2. A review of factors affecting farmers' adoption of varietal innovation

This literature review aims to present a synthetic analysis of the results presented in the economic literature on farmers' adoption of varietal innovation. It is restricted to the analysis of the adoption factors of low-tech varieties since they do not raise issues of societal acceptability as much as GM crops. Indeed, while GM crops result from high-tech modifications of the plant DNA, OPV and hybrids stem from low-tech development (Altieri, 2001). Our meta-analysis highlights the role of nine factors influencing farmers' VI adoption. These factors are especially meaningful for understanding adoption dynamics in family farms where the overlap of farm business activities with the farm household organization results in complex relationships (McNamara and Weiss, 2005; Bosc et al., 2018). This analysis leads to the conclusion that there is a need for a more comprehensive approach that could enable a clear understanding of the articulation of factors affecting farmers' VI adoption decision-making.

Unlike Akimowicz et al. (2013), who classically used a micro-economic lens to classify farm decision-making factors into farm structure, farm household, and regional factors, we differentiate technical (that explain observed preferences), contextual (that create contingencies), and institutional (that drive behaviors) factors. We base this categorization on Vatn's (2017) institutionalist perspective that conventions and norms contribute to the formation of beliefs that drive actors' preferences. This classification is thus a tentative institutionalist interpretation of the factors classically used in econometric analyses. Although other factors such as soil and climate conditions or public policies are likely to have an influence on farmers' VI adoption (Waldman et al., 2017), only statistically significant factors highlighted in the reviewed

[1] https://www.gnis-pedagogie.org/inscription-varietes-catalogue-officiel/.

[2] Since 1989, GEVES is a public interest body comprised of the French Ministry of Agriculture, the French Institute for Agronomic Research (INRA), and the French Interprofessional Organization for Seeds and Plants (GNIS).

econometric models as affecting farmers' adoption are discussed below.

2.1. Technical factors: Introducing new crops

Hybrids appear to be central elements of farmers' strategies that rely on an intensive use of capital assets. The size of the area under cultivation is a critical factor for VI adoption. On the one hand, farmers facing land shortages (Smale et al., 1995; Fisher and Kandiwa, 2014) along with tenants under crop sharing agreement (Mariano et al., 2012; Zeng et al., 2018) tend to rely on VI more intensively to boost production and generate a surplus. On the other hand, farmers with larger landholdings also tend to be more likely to adopt VI (Matuschke et al., 2007; Beshir and Wegary, 2014; Fisher et al., 2015; Shah et al., 2016; Zeng et al., 2018). Moreover, ownership of complementary equipment such as tractors (Smale et al., 1995; Mariano et al., 2012) and cultivation of irrigated land (Smale et al., 1995) both increase the likelihood of adopting VI.

The exploitation of VI's yield potential often requires the utilization of complementary inputs such as fertilizers and pesticides, which induce cash expenditures at the beginning of the growing season. As a result, there is a consensus that farmers' access to credit and bank loans is a favorable factor for the adoption of VI (Matuschke et al., 2007; Mariano et al., 2012; Boahene et al., 1999; Smale and Heisey, 1993; Smale et al., 1995). Organizations such as credit clubs also enable farmers to access courtesies such as the free delivery of inputs to their villages (Smale et al., 1995).

In line with these findings, labor availability has a positive impact on the adoption of VI (Fisher and Kandiwa, 2014). Boahene et al. (1999) suggest that while rural population ageing resulting from rural youth out-migration has decreased farmers' reliance on family labor, the high cost of hired labor prevents smallholders from hiring labor; instead, smallholders tend to rely on cooperative labor when such arrangements exist.

2.2. Contextual factors: Managing an uncertain world

Farm and plot managers' age both appear to be a consensual factor that negatively affects the decision to adopt VI (Boahene et al., 1999; Beshir and Wegary, 2014; Fisher and Kandiwa, 2014; Fisher et al., 2015). The shorter time horizon of older managers is commonly advanced to explain their lower likelihood to adopt VI. Based on the premises that risky returns on investment of financial resources immobilized for and learning time devoted to mastering new agricultural practices are not worth the effort, older managers are not expected to adopt VI as much as younger managers.

Time and context also contribute to shaping farmers' attitude and risk aversion towards the uncertain outcomes of VI (Derwisch et al., 2016). The adoption of a new variety generates costs resulting from the search of information, experimentation within farmers' local environment, and overall induces a transition period during which farm incomes may decrease. Risk aversion is identified as a factor of VI adoption by both Fisher and Kandiwa (2014) and Shah et al. (2016). Risk aversion can stem from households' needs for subsistence food, which imply growing more local varieties that are culturally appropriated for food consumption (Smale and Heisey, 1993; Smale et al., 1995; Mariano et al., 2012; Shah et al., 2014, 2016). In this regard, adverse events, such as droughts, that affected crop yields during previous cultivation years have been shown to reduce the share of land cultivated with VI (Adesina and Baidu-Forson, 1995; Mariano et al., 2012; Fisher and Kandiwa, 2014). Attitudes towards VI such as valued traits sought by farmers (Adesina and Baidu-Forson, 1995; Fisher et al., 2015), perception of land goodness that can incentivize farmers to invest in learning new practices (Fisher and Kandiwa, 2014), as well as favorable biophysical conditions and social institutions (Matuschke et al., 2007; Mariano et al., 2012; Fisher et al., 2015) are also factors that can significantly influence VI adoption.

2.3. Institutional factors: Making complex decisions

While the factors below can be interpreted as an attempt to take into account institutional factors shaping farmers' VI adoption, the utilization of rather simple dichotomous variables appears to prevent a comprehensive understanding of the complex social constructions that shape farmers' decision-making. The influence of such factors is overall more prone to controversies, which is highlighted by the often contradictory effects of independent variables on dependent variables.

In line with Fisher and Carr (2015), who identified that men and women do not have equal opportunities to adopt hybrids based on differences in access to land, information, and credit, Duong and Thanh (2019) found that male heads are more likely to adopt VI while Fisher and Kandiwa (2014) highlighted that both female household heads and wives in male-headed households are less likely to grow hybrids. However, gender variables had no significant effect in several other studies (Mariano et al., 2012; Fisher et al., 2015; Ricker-Gilbert and Jones, 2015; Zeng et al., 2018). This lack of consensus could stem from the complexity of gender relationships structuring farm households. Gebre et al. (2019) showed that power relationships shaping the positionality of men and women within the household influence decision-making about the intensity of VI adoption. Household headship gender appears to be a weak indicator that needs to be completed by plot-level analyses, which can capture the complexity and heterogeneity of family farm decision-making (Doss and Morris, 2001; Smale, 2011).

The role of information is critical for the adoption of VI (Matuschke et al., 2007). Part of a learning process, information that is shared within farmers' networks is the bedrock of collective learning (Adesina and Baidu-Forson, 1995; Boahene et al., 1999; Mariano et al., 2012; Derwisch et al., 2016; Shah et al., 2014, 2016; Duong and Thanh, 2019). These authors highlighted several streams of information that are commonly used by farmers to gather information: interactions with extension personnel and dealers, farmer-to-farmer exchanges, and attendance at training sessions. Although formal information exchanges with extension personnel are often considered as complementary to informal information exchanges with other farmers, Boahene et al. (1999) showed instead that farmers tend to substitute these two sources of information due to a lack of resources to invest in both the search for information and the internalization of information into knowledge. These attempts to take into account information do not consider two critical parameters characterizing information exchanges: neither the quality of the information shared nor the trustworthiness of the sources are considered (Shikuku, 2019).

Learning is often approximated by variables such as education and experience. The literature is relatively consistent with the idea that more educated managers are more likely to adopt VI (Mariano et al., 2012; Beshir and Wegary, 2014; Fisher and Kandiwa, 2014; Fisher et al., 2015; Shah et al., 2014, 2016). Boahene et al. (1999) further noted that more educated managers are more likely to be selected by extension services for programs aiming to foster the adoption of VI while Mason and Ricker-Gilbert (2013) highlighted that they are more likely to receive subsidies incentivizing the purchase of VI. Indeed, more educated managers are perceived as more able and more effective at processing information and mobilizing new knowledge about agricultural technologies. More experienced farmers also seem to be more likely to adopt VI. In addition to formal education, farmers also learn by doing, for instance when they experiment with new varieties on small plots

Table 1
Effects of significant variables identified in the literature on farmers' VI adoption.

Factors	Variables	Effect	Critical assessment
Technical	Intensive system	+	
	Access to credit	+	
	Labor availability	+	
Contextual	Age	-	
	Positive attitude	+	
	Risk aversion	-	
Institutional	Gender	+/−	Depends on the household organization
	Information	+	Does not consider information quality nor the trustworthiness of informants
	Learning	+	Poor differentiation of education and experience

before eventually increasing the share of the experimented variety if satisfying results are observed (Smale and Heisey, 1993; Smale et al., 1995; Duong and Thanh, 2019). Despite their convenience for econometric modeling, both education and experience do not capture well individuals' learning heuristics (Gars and Ward, 2019). Learning is indeed a dynamic process that is hardly approximated by static variables such as education and experience. Additionally, these indicators also hardly capture the social processes at stake during information exchanges surrounding technological adoption decisions (Barham et al., 2018).

2.4. Literature review findings

In summary, most research studies investigate farmers' VI adoption in Global South countries-in Africa (75%) and in Asia (25%)-where hybrids compete with OPV and GM crops (Bellon and Brush, 1994; Zerbe, 2001; Singh et al., 2019). The food security perspective adopted in these studies highlights a dominating interest for staple food-such as maize (63%) and rice (25%) as shown in (Appendix 1). In this regard, the current investigation of sunflower VI adoption, which can foster environmental benefits, in France, a Global North country, contributes to filling a gap in the literature. Last but not least, since econometric modeling hardly goes beyond the observation of statistical significance (Table 1), this review also demonstrates the relevance to conduct in-depth comprehensive qualitative analyses of farmers' VI adoption.

Due to both an individualistic perspective on farmers' decision-making and challenges to capture the complexity of institutional environments (e.g., public policies, power relationships), econometric correlations hardly enable inferences about farmers' VI adoption that meaningfully comprehend adoption processes. This result aligns well with Boahene et al. (1999), who emphasized the limitations of siloed approaches that hardly make sense of complex multidimensional processes, as well as with Smale and Heisey (1993), who demonstrated the importance of the institutional context. Consequently, our method departs from econometric modeling and, instead, relies on a qualitative approach about farmers' adoption of sunflower hybrids, which enables a comprehensive analysis that gives meaning to facts based on a "holistic, systemic, and evolutionary" stance (Wilber and Harrison, 1978: 71).

3. Method and data

We conducted semi-structured interviews to test our hypotheses about French farmers' sunflower VI adoption dynamics with an institutionalist lens. We adopted a mesoeconomic stance focusing on interactions between farms, distributors (most often cooperatives), seed companies, and research institutions. In this section, we present the survey tool, the structure of the French sunflower sector, and the main characteristics of the sample.

3.1. The survey tool

We conducted semi-structured interviews, which let the researcher guide the discussion while offering the respondent an opportunity to add information when deemed relevant, enable an assessment of the topics that are of most interest for the respondent. Five topics that cover the current issues of sunflower cultivation in the French context were selected: the strengths and weaknesses of sunflower, the genetic traits sought by farmers, the diffusion of VI, the impacts and perceptions of public policies, as well as the impacts and perceptions of climate changes. Four themes were then selected for a thematic analysis with closed coding: farmers' technical needs, the organization of the supply chain, the role and perception of public policies, and the impact of climate changes. These themes facilitate a confrontation of stakeholders' strategies regarding VI. In the present case, the focus is on farmers, distributors, and seed companies, whose strategies appear to interact without necessarily aligning well.

3.2. The well-structured French sunflower production sector

Two thirds of French farmers are member of a cooperative,[3] which usually supplies input, delivers extension services, and collects harvests. Cooperatives and wholesalers are part of central purchasing organizations that facilitate price negotiations with seed companies due to a strengthened bargaining power. Fig. 1 below highlights a simplified visualization of the French sunflower supply chain, whose stakeholders' names and functions are then detailed in Appendix 2.

In 2019, 604,000 ha of sunflower, which yielded 1,300,000 tons, were cultivated in France (France Agrimer, 2019). Sunflower crushing facilities are located relatively close to production areas while enabling easy access to international transportation infrastructure (Fig. 2). The Cargill facility in St Nazaire can crush 500,000 tons per year while the Saipol facilities in Bassens and Lézoux can crush 700,000 and 180,000 tons per year respectively. A crushing facility located in Sète, which can crush both rape seed and sunflower, is currently crushing rape seed only for economic reasons.

However, none of these facilities could shell sunflower seeds to increase protein content before 2013. Compared to other countries, France produces a relatively high share of oleic sunflower (approximately 60%) due to its capacity to isolate oleic from linoleic products and avoid contamination all over the supply chain.[4]

3.3. The sample

The semi-structured interviews were conducted in two French regions, namely the Occitanie region and the Nouvelle Aquitaine

[3] https://www.lacooperationagricole.coop/fr/nos-actualites-coop-de-france.
[4] https://www.ocl-journal.org/articles/ocl/full_html/2018/02/ocl180015s/F2.html.

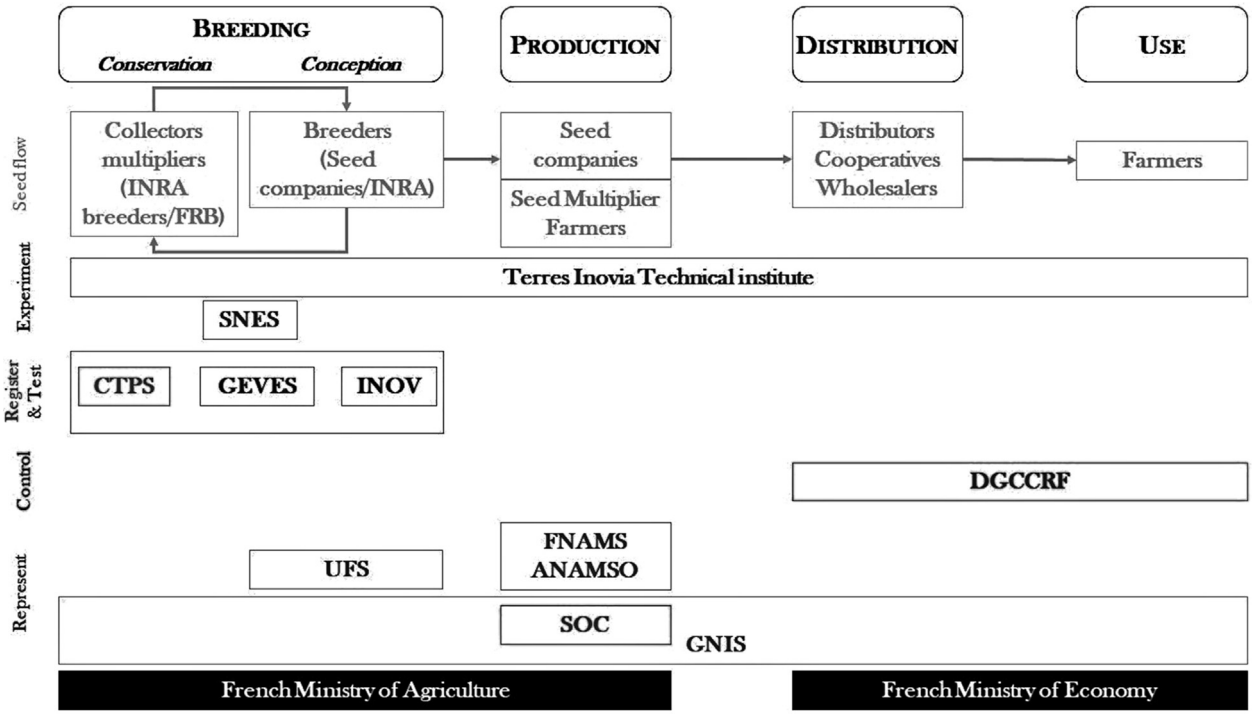

Fig. 1. Organization of the French sunflower seed supply chain.

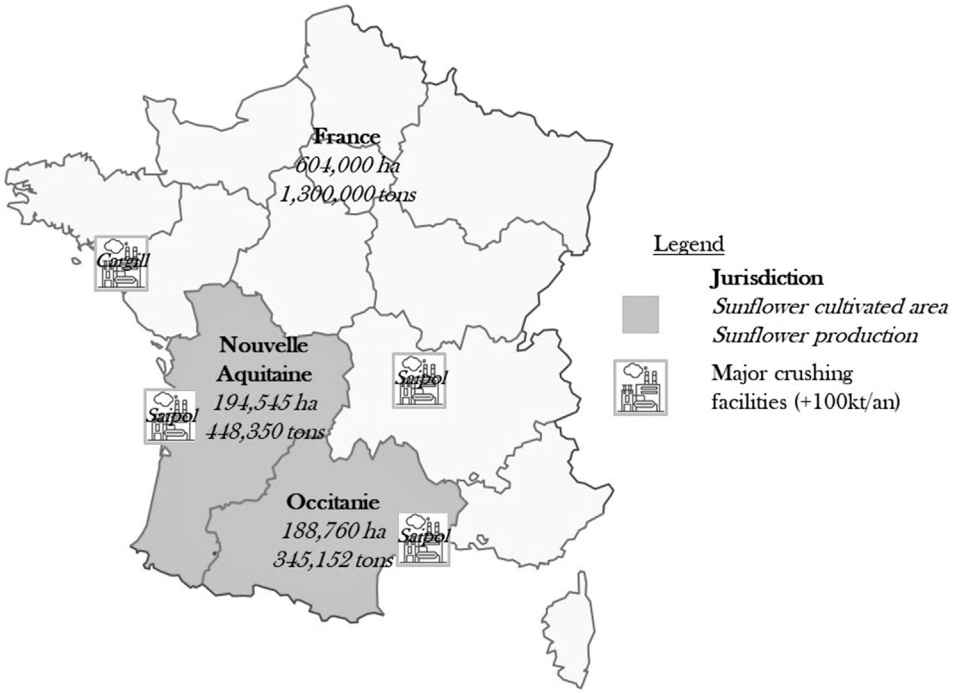

Fig. 2. Two research fields in regions leading sunflower production.

region, where 31% and 32% of French sunflower cultivated areas were respectively located in 2019, for a combined production of 794,000 tons (France Agrimer, 2019). A comprehensive and meaningful vision of the sunflower supply chain is granted by interviews with stakeholders operating at different links. We selected eighteen farmers (eight from Nouvelle Aquitaine—X—and ten from Occitanie—Y), six representatives from seed companies (S), four from research institutes (R), four from technical institutes (T), and five distributors (D).

The representatives of seed companies had several years of experience within the company and were either technical, research, or development managers, therefore representing seed companies' three areas of activity. The distribution representatives were also experienced personnel, with strong technical expertise in

sunflower agriculture. Farmers were between 40 and 70 years old and, on average, had 25 years of experience. Their farms were typical French cash-crop farms with an average size of 179ha (55/420ha) and an average sunflower-planted area of 51ha (3.5/150ha).

4. Results

This section builds from the farm level and gradually investigates broader perspectives involving other stakeholders of the supply chain. A discussion on the on-farm utilization of genetics for crop management is followed by a presentation of the challenges to conduct extension services. Then, seed companies' research perspectives are presented before an investigation of their international strategies.

4.1. Leveraging genetics to respond to farm-level crop management issues

All participating farmers recognized the genetic improvement of sunflower varieties regarding yield potential and pest resistance. While yield potential strongly influences varietal choices, pest resistance traits are also considered, especially those against mildew. Overall, participants commonly use two to three varieties simultaneously, as an insurance mechanism, over four to five years. For instance, Y2 shared: "Mildew started to develop, so I am trying to get M7 … maxi resistance!" Three other directions for genetic improvement emerged during the interviews: the management of adventitious flora, the control of plant bugs, and the adaptation to soil and climate conditions.

All Midi-Pyrénées farmers considered adventitious flora as a major cause of yield losses. Interviewed farmers generally respond with integrated solutions combining genetic and chemical approaches. Herbicide-resistant varieties enable participants to simplify work by extending the range of adventitious flora controlled, reducing the number of treatments, and enabling operation in most weather conditions. In turn, distributor representatives shared concerns about the utilization of herbicide-resistant varieties due to a risk of resistance to treatments (e.g., for Wild Sunflower); however, they also acknowledged the utilization of chemical treatments can remedy to a lack of alternative solutions (e.g., against Orobanche).

> For us, either Clearfield really adds value to agronomic practices or we wait. (…) We [distributors] have to counterbalance their [seed companies'] power. D1

For 14 farmers, plant bugs, especially birds, were a major concern since they predate sown seeds and seeds at the filling stage. No clear explanation was advanced by interviewed researchers. Both farmers and distributor representatives had their own assumptions: increasing bird population due to decreasing hunting activities, proliferation of birds such as pigeons due to urban sprawl, or even the sedentarization of winter birds. There is currently no effective solution. The prohibition of neonicotinoids and the ban on seed coating prevent the utilization of chemical solutions. In turn, mechanical alternatives, such as bird bangers, induce the concentration of sunflower planted areas on large plots to facilitate crop watching. On the one hand, farmers expected genetic solutions focusing on crop vigor and seed appetence. On the other hand, seed company representatives doubted that genetics could durably fix the problem, while admitting that fast germination could reduce damages. In the meantime, Occitanie farmers have reduced the share of sunflower in their crop mix while Nouvelle Aquitaine farmers, that have kept growing sunflower, acknowledged a lack of credible alternatives due to poor market opportunities.

> Sunflower, when there is no bird, it works well. X4

In both regions, both higher frequency and intensity of adverse climate events, resulting from climate change, as well as the impoverishment of soils, stemming from years of undiversified agricultural systems, complicate crop management. Although interviewed farmers acknowledged the relatively good resistance of sunflower to hydric and thermic stressors, they also expressed interest in genetic improvements for varieties more adapted to local climate and soil conditions in order to mitigate a perceived strong interannual yield variability. They further mentioned early varieties, drought resistance, and plant hardiness as traits of interest. In this context, most participants expressed the need to access data about local experimentations, which they currently satisfy with results from post-registration tests and GEDA tests. Although approximately half of the participating farmers conduct their own on-farm experimentations, they overall find it difficult to assess the territorial value of new varieties due to the quick seed turnover.

> I re-test the varieties at home and then I see what it is worth. Soils and climate conditions are not all the same. X3

4.2. The challenges of extension services

All participating distributor representatives shared rather pessimistic discourses due to decreasing planted area, stagnating or even decreasing yields, and farmers' deception. For instance, D4 admitted that "It is a crop with problems (…) it is becoming very, very difficult!" Nevertheless, cooperatives keep engaging in extension activities to support farmers despite the lack of credible alternatives resulting from both technical constraints and the absence of local partners to market crops. Participating farmers' choice of a distributor is based on historical relationships and human factors rather than on technological considerations. Sales representatives' on-farm visits result in bonds and mutual understanding. Additionally, the geographical proximity of grain elevators tends to strengthen farmers' distributor choices.

> It's primarily men stories, I get along well with the guys from my coop and they are good at what they do. So I don't want to change, and geographically speaking it is convenient. X6

Interviewed farmers shared trusting their technical advisors, even though the utilization of the information collected varies greatly from one farmer to another. Regarding agronomic issues, interviewees particularly trust distributors' sales representatives. However, they have diversified their sources of information for a more critical perspective. They consult public sources (Terres Inovia, Chambers of Agriculture, Catalogue entry data, and GEDAs' experimentation data) along with private sources (other distributors). As mentioned above, approximately half of the farmers conducted their own experimentations. This diversification of information sources suggests a search for more autonomy, which is consistent with the decision to diversify the distributors they work with in an effort to increase competition.

> I work for 1/3 with COREA and for 2/3 with CEA. So, there is some competition. Not many farmers are 100% with only one cooperative. X7

The provision of extension services has become more complicated due to farmers' disengagement from technical practices. The

lower economic perspectives of sunflower production have led farmers to conduct minimalist management itineraries. A few cooperative representatives acknowledged that even their own sales representatives have disengaged from marketing sunflower varieties due to a lack of solutions responding to farmers' challenges.

> It's a downplayed crop nowadays: one seeds, weeds, and comes back to harvest! So, there is no fungicide if it is not necessary, there is not always boron intake … it is a bit of a poor sibling. D2

Other distributors still believe in the future of sunflower and defend the utilization of agronomic solutions as a mean for reducing the effects of stressors impacting sunflower yields. However, the transition towards more diversified farming systems seems complicated as they also witness farmers' lack of motivation. As a result, farmers tend to be more demanding of chemical and genetic solutions that are easier to implement than agronomic solutions.

> If the farmer does not leverage agronomic solutions (…), we must turn to genetics because even chemistry does not manage to respond to these challenges anymore. D1

4.3. Definition of seed companies' research priorities

Seed companies' perception of demand for new varieties depends on three main criteria: production areas' soil and climate conditions, the market segments at stake in the country of interest, and the local regulations and public policies in place. Participating representatives of seed companies shared that research efforts have focused on input traits rather than on output traits, such as oleic acid content. Participating representatives of seed companies also explained that the development of output traits that respond to the demand for downstream industries is complicated due to downstream industries' need to adjust rapidly to fluctuating market conditions while varietal development takes several years. Currently, the main directions explored are herbicide resistance, which they consider as a sine qua non condition to penetrate Eastern European markets, and oleic/linoleic content.

Their responses were framed by optimistic perspectives, which they justified by the hardiness of sunflower and its tolerance to droughts. For them, the more stressed cultivation areas are, the more competitive sunflower is. They considered it is especially true in Russia and Ukraine, where no credible agronomic alternative exists whereas in Western Europe soil and climate conditions usually enable the cultivation of other crops such as canola, soybean, and sorghum.

> In a perspective of food shortages, Russia will have interest to cultivate new areas and sunflower might be one of the rare crops that can be cultivated. S1

They also believe that more frequent extreme weather conditions will strengthen the relative competitiveness of sunflower compared to cereals. Indeed, since sunflower is often associated with other cereals, changing weather conditions that negatively impact cereal yields mechanically increase the competitiveness of hardy sunflower.

> Sunflower is more profitable and wheat is penalized in dry growing conditions, and inversely in wet growing conditions. S1

Although they delivered an optimistic message, they also acknowledged the yield differential existing between experimentation growing conditions and on-farm growing conditions. They were aware of farmers' current difficulties related to pests, weeds, and abiotic stressors. In this regard, they shared their concern for the competitiveness of French sunflower production: they perceive French environmental regulations as increasing the specificity of the French market and, therefore, its isolation.

4.4. Seed companies' supranational vision

For seed company representatives, sunflower's hardiness is an advantage to adapt to abiotic stressors stemming from climate changes, sunflower is a key crop in Central and Eastern European countries, and it is also a loss leader in Eastern Europe, especially in Ukraine and Russia. Their vision of the sunflower supply chain is internationally specialized. France, where 80% of the EU sunflower research potential is concentrated,[5] is perceived as a research platform. The density of stakeholders (e.g., INRA, Terres Inovia) as well as the existence of credible experimentation networks (e.g., InVivo, Terres Inovia, and registration networks) facilitate information sharing, stimulate synergies, and foster research advances. However, R&D infrastructure is also being developed in Romania and Ukraine.

> Nowadays France is more a research tool than a target. S1

Participating representatives further explained that experimentations are conducted in research stations all over Europe before the registration step in order to assess the adaptation to soil and climate conditions of newly developed varieties. Driven by the perspective of scale economies, seed companies register varieties that best respond to a large range of soil and climate conditions to ensure marketed varieties occupy a satisfying market share. They select varieties submitted to registration based on a trade-off between market potential, fitness to average growing conditions, and registration costs.

> We are in several countries in order to assess the market adaptation of varieties that we developed. So, we have sixty-ish stations in many countries. S1

The production of seeds requires adapted soil and climate conditions along with farmers who rigorously respect specific code of practices. Seed production is also significantly delocalized. Although France and Spain are common locations to supply the Western European market, seed companies also produce seeds in Romania, Ukraine, and Turkey for the Eastern European market. However, a large share of the seed production is located in the Americas, in California and in Chili, where seeds can be grown in fall and sold in Europe for the following growing season, thus accelerating marketing and reducing storage costs.

> The production of seed was in California. We did that because it was off-season. S4

Last but not least, seed marketing is operated at the European level. In particular, the collapse of the Soviet Bloc resulted in a progressive opening of Central and Eastern European markets, a penetration that was facilitated by the lack of resources of local national public research institutes.

[5] http://www.ufs-semenciers.org/lufsenaction/lessectionsparespeces/oleagineux/Lists/pages/tournesol.aspx.

It was a bit like the eastern gold rush. (…) We entered [in Romania] in 2008. Until 2013 we had ten to fifteen percent growth rates. S4

5. Discussion

These results validate the methodological choices, which aimed to complement existing econometric results with more comprehensive qualitative results in line with Akimowicz et al. (2018). An in-depth understanding of farmers' VI adoption dynamics results from the understanding of sector regulations and shared norms that drive stakeholders' behaviors. They complement well econometric results, which can hardly deal with factors such farmers' expectations to rely on genetics to reduce losses provoked by birds, while technical advisors would preferentially turn to agronomy to remedy these problems. Overall, both public policies and the organization of the sunflower supply chain drive the dynamics of farmers' VI adoption decisions underlying their efforts to adapt to climate changes. Seed companies develop varieties that respond to their more lucrative markets, secured by an institutional environment that guarantees intellectual property rights while it also facilitates research efforts through collaborations with public research institutes. Distributors propose in priority the varieties that generate economic returns stemming from size economies. Farmers limit search costs by acquiring varieties that are available through their retailers even though these varieties do not respond precisely to their specific needs. Furthermore, this organization seems to be internalized and well accepted. Fig. 3 below summarizes the factors that constrain farmers' varietal innovation choices and show the embeddedness of farmers' decision in economic (i.e., cooperatives and seed companies' strategies), social (public policies), and environmental (climate change) constraints.

Different methodological choices would have provided equally interesting results. Instead of conducting this research in the two regions leading French sunflower production, working in regions where sunflower production is anticipated to grow significantly because of climate changes would have enabled the investigation of farmers' future needs. Although small, the size of the sample appears satisfying due to both the alignment of farmers' testimonies with other stakeholders' narratives and the strong saturation degree. This sample size is also consistent with the objective to conduct a mesoeconomic analysis based on in-depth interviews that highlight the impacts of the interactions between the many stakeholders of the sunflower supply chain. Last but not least, although a complementary quantitative survey could have been conducted to improve statistical generalizability of the results, the resources available for this project eliminated this option.

These results put into perspectives the role of public policies and local markets. The existence of local niche supply chains appears critical to sustain the cultivation of sunflower. Farmers need to market their production at a remunerating price while value-added opportunities are often in the hands of wholesalers and cooperatives. Particularly, farmers ask for price policies that reward the quality stemming from technical efforts. In this regard, the production of sunflower for high oleic acid content, a weaker variety with lower yields that also requires farmers to isolate the crop to avoid contamination, is exemplary since there is currently no strong financial incentive to support farmers' technical efforts. On the other hand, a consensus emerged on the inefficiency of environmental public policies that are either too constraining or not incentivizing enough.

In addition to distributor sales representatives, who visit cooperative members to propose pre-selected products, cooperatives also set up information days about recent experimentations as well as regular online advisory services. Although these initiatives intend to facilitate farmers' search for solutions, they are embedded in economic decision-making where marketed products must contribute to a significant increase in either collected crops or the sale of additional technical services. In their search for size economies, as well as to solve organizational matters, distributors limit the number of varieties sold. Based on participants' testimonies, over the twenty some varieties advertised on distributors' catalogs, only four to five varieties are significantly cultivated. These results echo Vanloqueren and Baret (2008) who showed that the development of varieties that respond specifically to farmers' needs is strongly constrained. On the one hand, the resulting loss of cultivated biodiversity can accelerate the development of pest resistance. On the other hand, this also shows that a new variety is not adopted only because it presents an agronomic interest: new varieties diffuse on the condition to meet economic criteria for intermediate stakeholders in charge of the distribution.

Finally, a path, which seems to stem from the registration criteria adopted by the Official Catalog, has resulted in the emergence of an institutional environment where farmers are takers of

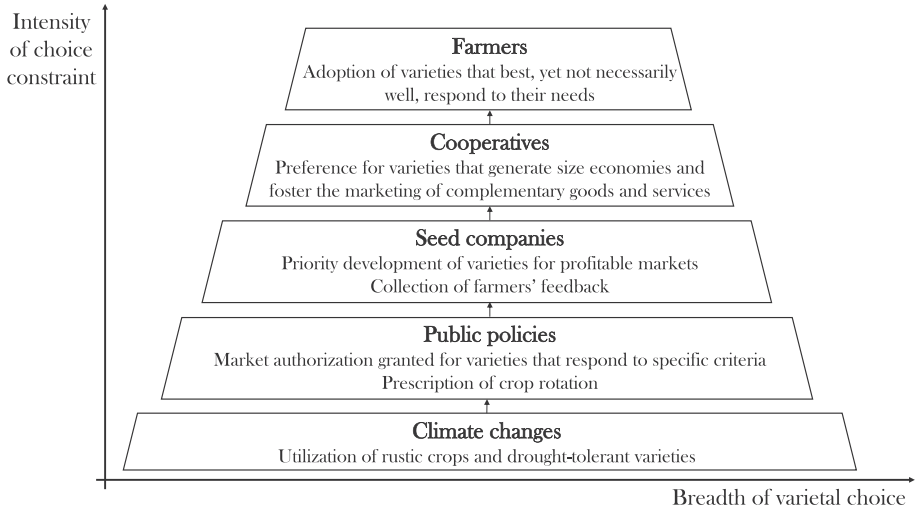

Fig. 3. The embeddedness of farmers' decisions.

VI. While French farmers expect seed companies to develop varieties that are adapted to their local growing conditions and respond to the challenges they face, seed companies appear to be more interested in the larger size of Central and Eastern European markets, thus developing varieties that are not necessarily well-aligned with French farmers' needs. Consequently, farmers spend resources seeking information to identify the varieties that best suit their needs. They also test available varieties on their fields to assess their potential. These results show farmers' dependence on seed companies and distributors. This triggers the questions of farmers' participation in varietal development procedures and the legitimacy of registration criteria. These results echo those of Bossle et al. (2016), who highlighted the role of environmental leadership and capacities for eco-innovation adoption, two factors that farmers are currently deprived of. These results also align with those of Galliano et al. (2018: 2231), whose interviewees described a dominant regime where "regulatory criteria for catalog registration, based on stringent VCU(s) [Value for Cultivation and Use (and Sustainability)] trials, do not support the creation of varieties that are adapted to specific use conditions." In short, these results confirm the need for "a participatory and decentralized selection based on the evolving nature of plants" (Op. cit.).

These results also set the stage for further research. While this study highlighted the importance of mesoeconomic analyses to understand the factors influencing farmers' varietal adoption decision-making, there is a need to investigate more specifically the interactions between public policies with other institutions such as farmers' norms, shared social knowledge and cognitive structures. Following Bromley (2008): 8), public policies can be defined as a "collective action in restraint, liberation, and expansion of individual action." Their effectiveness is tied to their acceptance and legitimization, which imply a collective learning that results in a modification of the meanings associated with the actions at stake (Del Corso et al., 2017). In this regard, a focus on place-based policies could enable more effective policies and promote bottom-up agricultural innovation. In France, the GIEE initiatives, which are spaces where farmers collectively learn, are likely to contribute to reshaping meanings. Understanding farmers' rationalities and capacities along with identifying farmers' needs to participate in seed innovation processes appear to be critical preliminary steps. Indeed, farmers' loss of decision-making power, which has characterized the evolution of the French agricultural sector since the implementation of the Green Revolution, may have resulted in a feeling of powerlessness that has hindered farmers' sense of agency. The conditions for re-empowering farmers are likely to be best tackled at the local level through the design of contextualized institutional mechanisms.

6. Conclusion

In this article, we investigated farmers' dynamics of VI adoption using semi-structured interviews with stakeholders from the entire sunflower supply chain. The results suggest that although farmers are interested in the potentialities of a hardy sunflower that can cope better with dry weather conditions than other spring crops, they face difficulties to make sunflower an economically viable crop. This has resulted in a lack of motivation for the cultivation of sunflower, which they nonetheless maintain with minimal crop management to diversify crop rotations. In this regard, farmers have taken the habit to turn towards genetics to remedy the many issues they face whereas extension service agents would rather implement agronomic solutions. In turn, although seed companies conduct R&D activities in France, due to a favorable institutional environment, the relatively small size of the French market appears to hinder the development of varieties that respond specifically to French farmers' current concerns and local growing conditions. Instead, seed companies focus more on Central and Eastern European markets where planted areas are significantly larger.

Interestingly, farmers have internalized the utilization of hybrids and do not challenge their routine utilization despite their attempts to test varieties. Farmers expect genetics to provide solutions to the many issues they face with the cultivation of sunflower, despite extension personnel's recommendations to turn to agronomic solutions. This position reveals, to a certain extent, the relatively low importance granted to sunflower by farmers. Although genetics would, in farmers' eyes, induce less field work, enable meeting crop diversification regulatory constraints, and generate a complementary income, while limiting extra costs, the absence of traits responding specifically to farmers' needs has resulted in farmers' decreasing interest in the sunflower crop. Farmers' efforts to experiment before fully adopting VI is telling of a certain trust crisis between farmers, distributors, and seed companies. It questions seed companies' stance to turn to Central and Eastern European sunflower markets, while seemingly not prioritizing the French market where most research capacities are located. It also questions farmers' capacity and willingness to innovate and develop the varieties that would best respond to their own needs. A European comparison of farmers' adoption of VI that disentangles the influence of multi-level institutional factors would therefore contribute to strengthening European farmers' capacities to adapt to climate changes.

Funding

This work is part of the SUNRISE Project funded by the French National Research Agency (ANR-11-BTBR-0005).

CRediT authorship contribution statement

Mikaël Akimowicz: Formal analysis, Writing - original draft. **Jean-Pierre Del Corso:** Supervision, Writing - original draft. **Nicola Gallai:** Supervision, Writing - original draft. **Charilaos Képhaliacos:** Supervision, Writing - original draft.

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.

Acknowledgements

The authors would like to warmly thank Caroline Tardy for her contribution to the research as well as all the research participants for their time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123654.

References

Adesina, A.A., Baidu-Forson, J., 1995. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. Agric. Econ. 13 (1), 1–9. https://doi.org/10.1016/0169-5150(95)01142-8.

Agrimer, France, 2019. Marché des oléo-protéagineux - édition octobre 2019 (Statistiques de août 2019 - septembre 2019).

Akimowicz, M., Magrini, M.B., Ridier, A., Bergez, J.E., Requier-Desjardins, D., 2013. What influences farm size growth? An illustration in Southwestern France. Appl. Econ. Perspect. Pol. 35 (2), 242–269. https://doi.org/10.1093/aepp/ppt008.

Akimowicz, M., Vyn, R.J., Cummings, H., Landman, K., 2018. An introduction to mixed methods research in agricultural economics: the example of farm investment in Ontario's Greenbelt, Canada. J. Rural Stud. 61, 162–174. https://doi.org/10.1016/j.jrurstud.2018.04.012.

Altieri, M.A., 2001. Genetically engineered crops: separating the myths from the reality. Bull. Sci. Technol. Soc. 21 (2), 130–147. https://doi.org/10.1177/027046760102100207. https://search.crossref.org/?q=Altieri%2C+M.A.+2001.+Genetically+engineered+crops%3A+separating+the+myths+from+the+reality.+Bull.+Sci.+Technol.+Soc.%2C+21%282%29%2C+130-147.

Barham, B.L., Chavas, J.P., Fitz, D., Schechter, L., 2018. Receptiveness to advice, cognitive ability, and technology adoption. J. Econ. Behav. Organ. 149, 239–268. https://doi.org/10.1016/j.jebo.2017.12.025.

Bellon, M.R., Brush, S.B., 1994. Keepers of maize in chiapas, Mexico. Econ. Bot. 48 (2), 196–209. https://doi.org/10.1007/BF02908218.

Beshir, B., Wegary, D., 2014. Determinants of smallholder farmers' hybrid maize adoption in the drought prone Central Rift Valley of Ethiopia. Afr. J. Agric. Res. 9 (17), 1334–1343. https://doi.org/10.5897/AJAR2013.8336.

Boahene, K., Snijders, T.A., Folmer, H., 1999. An integrated socioeconomic analysis of innovation adoption: the case of hybrid cocoa in Ghana. J. Pol. Model. 21 (2), 167–184. https://doi.org/10.1016/S0161-8938(97)00070-7.

Bonneuil, C., Thomas, F., 2009. Gènes, pouvoirs et profits: recherche publique et régimes de production des savoirs de Mendel aux OGM. Quæ, Versailles.

Bonneuil, C., Thomas, F., 2012. Semences, une histoire politique: amélioration des plantes, agriculture et alimentation en France depuis la Seconde Guerre mondiale. Charles Léopold Mayer, Paris.

Bosc, P.M., Sourisseau, J.M., Bonnal, P., Gasselin, P., Valette, E., Bélières, J.F., 2018. Diversity of Family Farming Around the World: Existence, Transformations and Possible Futures of Family Farms. Quae, Versailles.

Bossle, M.B., de Barcellos, M.D., Vieira, L.M., Sauvée, L., 2016. The drivers for adoption of eco-innovation. J. Clean. Prod. 113, 861–872. https://doi.org/10.1016/j.jclepro.2015.11.033.

Brisson, N., Levrault, F., 2010. Le livre vert du projet CLIMATOR (2007-2010). ADEME, Angers.

Bromley, D.W., 2008. Volitional pragmatism. Ecol. Econ. 68 (1–2), 1–13. https://doi.org/10.1016/j.ecolecon.2008.08.012.

Canfin, P., Staime, P., 2015. Climate—30 Questions to Understand the Paris Conference. Les Petits Matins, Paris.

Del Corso, J.P., Nguyen, T.D.P.G., Képhaliacos, C., 2017. Acceptance of a payment for ecosystem services scheme: the decisive influence of collective action. Environ. Val. 26 (2), 177–202. https://doi.org/10.3197/096327117X14847335385517.

Derwisch, S., Morone, P., Tröger, K., Kopainsky, B., 2016. Investigating the drivers of innovation diffusion in a low-income country context. The case of adoption of improved maize seed in Malawi. Futures 81, 161–175. https://doi.org/10.1016/j.futures.2015.08.011.

Doss, C.R., Morris, M.L., 2001. How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. Agric. Econ. 25 (1), 27–39. https://doi.org/10.1016/S0169-5150(00)00096-7.

Duong, P.B., Thanh, P.T., 2019. Adoption and effects of modern rice varieties in Vietnam: micro-econometric analysis of household surveys. Econ. Anal. Pol. 64, 282–292. https://doi.org/10.1016/j.eap.2019.09.006.

Fisher, M., Carr, E.R., 2015. The influence of gendered roles and responsibilities on the adoption of technologies that mitigate drought risk: the case of drought-tolerant maize seed in eastern Uganda. Global Environ. Change 35, 82–92. https://doi.org/10.1016/j.gloenvcha.2015.08.009.

Fisher, M., Kandiwa, V., 2014. Can agricultural input subsidies reduce the gender gap in modern maize adoption? Evidence from Malawi. Food Pol. 45, 101–111. https://doi.org/10.1016/j.foodpol.2014.01.007.

Fisher, M., Abate, T., Lunduka, R.W., Asnake, W., Alemayehu, Y., Madulu, R.B., 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: determinants of adoption in eastern and southern Africa. Climatic Change 133 (2), 283–299. https://doi.org/10.1007/s10584-015-1459-2.

Galliano, D., Magrini, M.B., Tardy, C., Triboulet, P., 2018. Eco-innovation in plant breeding: insights from the sunflower industry. J. Clean. Prod. 172, 2225–2233. https://doi.org/10.1016/j.jclepro.2017.11.189.

Gars, J., Ward, P.S., 2019. Can differences in individual learning explain patterns of technology adoption? Evidence on heterogeneous learning patterns and hybrid rice adoption in Bihar, India. World Dev. 115, 178–189. https://doi.org/10.1016/j.worlddev.2018.11.014.

Gebre, G.G., Isoda, H., Amekawa, Y., Nomura, H., 2019. Gender differences in the adoption of agricultural technology: the case of improved maize varieties in southern Ethiopia. Wom. Stud. Int. Forum 76, 102264. https://doi.org/10.1016/j.wsif.2019.102264.

IPCC, 2018. Global warming of 1.5° C. IPCC special report. https://www.ipcc.ch/sr15/download/.

JORF, 1932. Décret du 16 novembre 1932 instituant un catalogue des espèces et variétés de plantes et un registre des plantes sélectionnées de grande culture. https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000664714categorieLien=id, 12066.

JORF, 1949. Décret n° 49-773 du 11 juin 1949 Commerce des semences. https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000673134categorieLien=id, 5876.

JORF, 1960. Décret du 22 janvier 1960 instituant un catalogue des espèces et variétés de plantes cultivées, vol. 955. https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000850152categorieLien=id.

Lecomte, V., Nolot, J.M., 2011. Place du tournesol dans le système de culture. Innov. Agron. 14, 59–76.

Malassis, L., Ghersi, G., 1996. Economie de la production et de la consommation : méthodes et concepts. Cujas, Paris.

Mariano, M.J., Villano, R., Fleming, E., 2012. Factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines. Agric. Syst. 110, 41–53. https://doi.org/10.1016/j.agsy.2012.03.010.

Mason, N.M., Ricker-Gilbert, J., 2013. Disrupting demand for commercial seed: input subsidies in Malawi and Zambia. World Dev. 45, 75–91. https://doi.org/10.1016/j.worlddev.2012.11.006.

Matuschke, I., Mishra, R.R., Qaim, M., 2007. Adoption and impact of hybrid wheat in India. World Dev. 35 (8), 1422–1435. https://doi.org/10.1016/j.worlddev.2007.04.005.

McNamara, K.T., Weiss, C., 2005. Farm household income and on-and off-farm diversification. J. Agric. Appl. Econ. 37 (1), 37–48. https://doi.org/10.1017/S1074070800007082.

Palleau, J.-P., Motard, C., 2015. Bilan de campagne 2015. Terres Inovia. http://www.myvar.fr/resultats/bilan-campagne-69.html.

Pimbert, M.P. (Ed.), 2017. Food Sovereignty, Agroecology and Biocultural Diversity: Constructing and Contesting Knowledge. Routledge, New York.

Rastoin, J.L., Ghersi, G., 2010. Le système alimentaire mondial : concepts et méthodes, analyses et dynamiques. Quae, Paris.

Ricker-Gilbert, J., Jones, M., 2015. Does storage technology affect adoption of improved maize varieties in Africa? Insights from Malawi's input subsidy program. Food Pol. 50, 92–105. https://doi.org/10.1016/j.foodpol.2014.10.015.

Rosset, P.M., Altieri, M.A., 2017. Agroecology: Science and Politics. Practical Action Publishing, Rugby.

Shah, M., Grant, W., Stocklmayer, S., 2014. Adoption of hybrid rice in Bangladesh: farm level experience. J. Agric. Sci. 6 (7), 157–171. https://doi.org/10.5539/jas.v6n7p157.

Shah, M.M., Grant, W.J., Stocklmayer, S., 2016. Farmer innovativeness and hybrid rice diffusion in Bangladesh. Technol. Forecast. Soc. Change 108, 54–62. https://doi.org/10.1016/j.techfore.2016.04.015.

Shikuku, K.M., 2019. Information exchange links, knowledge exposure, and adoption of agricultural technologies in northern Uganda. World Dev. 115, 94–106. https://doi.org/10.1016/j.worlddev.2018.11.012.

Singh, R.P., Chintagunta, A.D., Agarwal, D.K., Kureel, R.S., Kumar, S.J., 2019. Varietal replacement rate: prospects and challenges for global food security. Glob. Food Sec., 100324 https://doi.org/10.1016/j.gfs.2019.100324.

Smale, M., 2011. Does household headship affect demand for hybrid maize seed in Kenya? An exploratory analysis based on 2010 survey data. MSU International Development Working Paper 115.

Smale, M., Heisey, P.W., 1993. Simultaneous estimation of seed-fertilizer adoption decisions: an application to hybrid maize in Malawi. Technol. Forecast. Soc. Change 43 (3–4), 353–368. https://doi.org/10.1016/0040-1625(93)90061-B.

Smale, M., Heisey, P.W., Leathers, H.D., 1995. Maize of the ancestors and modern varieties: the microeconomics of high-yielding variety adoption in Malawi. Econ. Dev. Cult. Change 43 (2), 351–368. https://doi.org/10.1086/452154.

Temple, L., Lançon, F., Palpacuer, F., Paché, G., 2011. Actualité du concept de filière dans l'agriculture et l'agroalimentaire. Econ. Soc. 33 (10), 1785–1797.

Vanloqueren, G., Baret, P.V., 2008. Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural "lockin" case study. Ecol. Econ. 66 (2), 436–446. https://doi.org/10.1016/j.ecolecon.2007.10.007.

Vatn, A., 2005. Rationality, institutions and environmental policy. Ecol. Econ. 55 (2), 203–217. https://doi.org/10.1016/j.ecolecon.2004.12.001.

Vatn, A., 2017. Critical institutional economics. In: Spash, C.L. (Ed.), Routledge Handbook of Ecological Economics: Nature and Society. Routledge, New York, pp. 29–38.

Waldman, K.B., Blekking, J.P., Attari, S.Z., Evans, T.P., 2017. Maize seed choice and perceptions of climate variability among smallholder farmers. Global Environ. Change 47, 51–63. https://doi.org/10.1016/j.gloenvcha.2017.09.007.

Wilber, C.K., Harrison, R.S., 1978. The methodological basis of institutional economics: pattern model, storytelling, and holism. J. Econ. Issues 12 (1), 61–89. https://doi.org/10.1080/00213624.1978.11503505.

Zeng, D., Alwang, J., Norton, G., Jaleta, M., Shiferaw, B., Yirga, C., 2018. Land ownership and technology adoption revisited: improved maize varieties in Ethiopia. Land Use Pol. 72, 270–279. https://doi.org/10.1016/j.landusepol.2017.12.047.

Zerbe, N., 2001. Seeds of hope, seeds of despair: towards a political economy of the seed industry in southern Africa. Third World Q. 22 (4), 657–673. https://doi.org/10.1080/01436590120071830.