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Adapting to Pesticide Regulations through Alternative Seed Treatments: Importance of the Innovation Ecosystems

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The seed sector plays a significant role in the sustainability of the agri-food system, as seeds are at the onset of the food chain. Innovation in this sector is crucial for agriculture, both in terms of food security and sovereignty and at the economic level. In France, the seed industry generates over €3 billion annually and supports more than 12,000 jobs, highlighting its economic importance. Ensuring seed health is vital for preventing crop diseases and maintaining productivity. However, traditional seed treatment methods, which heavily rely on phytopharmaceutical products, have raised concerns due to their adverse effects on health, biodiversity, and the environment. Recent regulatory changes, including Article 83 of the EGALIM law and the European Green Deal, have intensified the need for alternative seed treatments, stimulating activity within local innovation ecosystems. Over the last two decades, the main domain of innovation in the seed sector has primarily focused on novel means of plant breeding and plant genetics improvement to enhance performance and resistance (Deconinck, 2020). Furthermore, the cost of developing new varieties and investing in novel plant breeding technologies has led to a steep consolidation of the global seed sector over the last 30 years (Moschini, 2010). This consolidation has generated significant concerns regarding the intellectual property of seeds and farmers' rights to this resource (Bonny, 2017). With the recent policy orientation towards zero pesticides (Jacquet et al., 2022), the need for alternative solutions in seed treatment has become even more pressing.

Seed coating, a pivotal process in the seed industry, protects and enhances seedling establishment, often involving synthetic chemicals like fertilizers and pesticides. In France, numerous pesticides, particularly fungicides, are authorized for seed treatment, contributing to chemical residues on seeds. However, recognizing the adverse effects of chemical pesticides on food safety, the environment, and biodiversity, the EU and France have implemented restrictions, necessitating a restructuring of cropping systems. Alternative seed treatments, such as seed priming and biological control, have been explored, but challenges persist in achieving pathogen-free seeds. Nevertheless, the development and incorporation of such novel solutions into the current systems of seed cleaning, treatment, and

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conditioning necessitate the deployment of various collaboration strategies. This innovation requires the input of different stakeholders coming from different scientific background. Therefore, the development of such innovation will manifest a unique multilayered innovation ecosystem at the intersection of Biologicals, Seed, and Seed technology.

This research examines how the French seed innovation ecosystems are adapting to these challenges, focusing on the different industrial districts, Local Innovation ecosystems, and clusters that constitute it. Those layers of the innovation ecosystem features innovation intermediaries and a diverse network of public institutions, academic research centers, and private firms. The study explores the collaboration and innovation dynamics within these clusters, analyzing knowledge flows and their role in fostering collective learning and regulatory adaptation. By comparing the clusters' strategies, this research provides insights into how regional innovation ecosystems support transitions toward sustainable agriculture, addressing both local and global challenges.

Literature Review: The study of innovation ecosystems highlights the pivotal role of technological clusters in fostering collaboration, knowledge exchange, and innovation. Scholars such as Giuliani (2007) and Boschma (2010) have explored how geographic concentration of firms and institutions facilitates knowledge transfer, particularly in research-intensive sectors like agriculture. However, these dynamics are not without challenges, as coordination and knowledge-sharing across institutional boundaries can be complex (Vicente, 2016). Research has also examined the mechanisms of knowledge production and dissemination within firms and broader networks. Nonaka and Takeuchi (2004) emphasize internal knowledge creation, while Jacobides and Winter (2005) and Williamson (1995) extend this to inter-firm collaborations. Organizational forms like communities of practice and epistemic communities provide further insights into how expertise and tacit knowledge circulate within ecosystems (Amin & Cohendet, 2004).

Methodology: This study employs a mixed-methods approach to analyze innovation ecosystems and innovation processes within two French seed treatment innovation ecosystem. The methodology integrates qualitative and quantitative techniques to understand its structure and dynamics. The research begins by identifying key stakeholders, including private companies, public research institutions, academic organizations, and solution developers, mapping their roles and connections. Semi-structured interviews with representatives from these organizations will provide insights into their activities, challenges, and contributions to innovation. This qualitative data is complemented by an analysis of policy documents, industry reports, and project records for additional context. The core of the analysis focuses on modeling the networks connecting these stakeholders' using tools like Gephi and Python. This Inter and Intra ecosystem comparison will highlight how regional ecosystems differ in addressing the shared challenge of developing biological based seed treatment alternatives. Findings will be validated through stakeholder feedback and triangulation with multiple data sources (industry report, firm's investors reports, professional press), ensuring both relevance and robustness. This process grounds the analysis in the ecosystem' realities while contributing to broader theoretical insights on innovation ecosystems in agriculture, crop protection, and seed technology.

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