Review Article

How do agricultural policies foster digital co-innovation in agriculture in Benin?

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"**The Role of Agricultural Policies in Promoting Digital Co-Innovation in Benin's Agricultural Sector"**
This revised title is more concise while still capturing the essence of the paper. It also shifts the focus slightly toward the active role of policies in "promoting" digital co-innovation, which might make the scope clearer and more direct.

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ABSTRACT

Aims: Agricultural policies play a pivotal role in shaping innovation processes within the agricultural sector. This paper analyzes how these policies actively foster digital co-innovation in Benin agriculture.
Methodology: We employed a mixed-methods approach, combining a systematic review based on the PRISMA-RR method—which involved screening over 100 documents to retrieve relevant data—with 48 key informant interviews and case studies involving 32 participants
Results: The results indicate that agricultural policies not only promote stakeholder inclusion but also facilitate collaboration and enhance the complementarity of their contributions towards developing digital innovations. Moreover, the inclusion of young holders of digital startups is found to be fundamental for driving these innovations, as they bring fresh perspectives and technological expertise.
Conclusion: Therefore, effective agricultural policies must prioritize inclusion, collaboration, complementarity, and coordination to induce impactful digital innovations. This research is original in its integration of a systematic review with a case study to illustrate how public policies can effectively foster the development of digital innovations in agriculture, which is now recognized as current agricultural revolution.

Keywords: Agricultural policies; digital co-innovation; innovation systems; agriculture; Benin

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1. INTRODUCTION

Today, the use of digital technology in agriculture, referred to by the terms “digitalagriculture”, “precision agriculture” or “e-agriculture” [1], is widely promoted. The scientific discourse on this agricultural approach emphasizes its positive impact on productivity and its environmental considerations [2]. Advocates emphasize addressing pressing global challenges including food security, climate change, and environmental degradation [3]. Digital agriculture is recognized as the fourth agricultural revolution due to the profound transformation facilitated by digital innovations in agriculture [4]. The immense potential of this approach for major sustainable development issues, arouses particular enthusiasm among stakeholders at different scales. Internationally, major organizations such as the European Union [EU] [5]), the World Bank [6], the Food and Agriculture Organization of the United Nations Agriculture [FAO] [7] are deeply engaged in this realm. In Africa, more than 33 million farmers and pastoralists use digital solutions, with the possibility of registering 200 million by 2030. Similarly, the number of digital innovations introduced in agriculture increased from 41 in 2012 to 390 in 2019 [8]. This rise aligns with the commitment of African regional institutions to the issue of digital technology in agriculture. Recently, African Union (AU) Digital Agriculture Strategy for 2024 to 2030 was published [9].

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This strategy indicates that on a national scale, Benin is a country relatively well prepared for agriculture, according to its Digital Agriculture Readiness Index (DPAN). Several digital innovations are being used in the country's agricultural sector, most of them dedicated to farm advisory services [10].

However, in general, integrating of digital innovations into agriculture has encountered significant barriers, primarily from digital inequalities, rendering some farmers inaccessible to the associated benefits [11]. These digital inequalities refer to inequalities in access to resources, services, and information, resulting in the exclusion of numerically small-scale farmers from the advantages of digital solutions [12]. Even for those who overcome these inequalities, some digital innovations impose limitations, compelling farmers to resort to mechanical use or in some cases, complete non-adoption [13].Another challenge arises from standard digital innovations that fail to address specific farmer constraints, ultimately undermining the true potential of digital advancements in agriculture [14]. The analysis of these constraints reveals a disconnect between these innovations and the practical needs of farmers, underscoring the exclusion of farmers from the innovation process as a fundamental issue in digital agriculture. Therefore, co-innovation is considered the most appropriate innovation process in digital agriculture [15]. This paper shows how this collaborative process of digital innovation in agriculture, is promoted by agricultural policies.

Indeed, co-innovation is an innovation process by which stakeholders, including potential innovation users are involved in the development of the innovation. Possible conflicts are diagnosed early in the process by including farmers, ensuring that innovations are tailor-made, adaptable and sustainable [16,17]. Co-innovation, therefore, makes it possible to avoid information gaps and ideally respond to real needs, interests, and demands [18,19], stimulating the innovativeness of farmers and significantly narrowing the gap between digital innovations and the practical requirements of farmers. Recognizing the significance of digital co-innovation in agriculture, it becomes essential to delve into its scientific exploration. Moreover, various studies on digital agriculture advocate co-innovation as an ideal process [20,21,4,22,23] without explicitly addressing the critical factors that must underpin its promotion. In this context, policies play a decisive role in fostering collaborative innovations [24].

Effectively designed policies induce successful co-innovation [25,26]. They impact co-innovation by influencing innovation systems, interactions between actors [27], and stakeholders' collaboration [28]. [29]and [30] further emphasize that policies can actively encourage the participation of potential users in the co-innovation process and serve as instrumental tools for overcoming implementation constraints in co-innovation approaches. The determining nature of policies, linked to the present context of digital agriculture, suggests that agricultural policies then impact digital co-innovation in agriculture. In the specific context of Benin, numerous digital innovations have emerged within the country's digital agriculture landscape, often involving collaboration among private sector entities, Non-Governmental Organizations (NGOs), Technical and Financial Partners (PTF), and government agencies [10]. This suggests that co-innovation processes have played a substantial role in developing various innovations in digital agriculture in Benin. However, the precise mechanisms through which Benin's agricultural policies effectively promote this digital co-innovation process remain to be elucidated. This study, by showing the link between agricultural policies and this innovation process, thus provides evidence of participatory approaches involving farmers in digital innovation processes in agriculture, which was little mentioned in the literature [31]. In developing countries like Benin, where digital inequalities between farmers are quite pronounced, digital co-innovation in agriculture appears as an innovation process that makes it possible to circumvent these inequalities and improve the effectiveness of digital innovations. By showing how agricultural policies are

promoted, political decision-makers will see more clearly the levers they must rely on to promote this process in digital agriculture further.

This study focuses on the Benin case due to a significant commitment to e-agriculture, whichvarious political decisions have demonstrated. Notably, the country has adopted its e-agriculture strategy for 2020-2024 [32] and several digital agriculture initiatives have already been implemented [33]. Agricultural policies can be assessed at the national, departmental, municipal, and village levels. Given Benin's governance structure, which is characterized by decentralization, policies at the national level profoundly influence those at lower echelons. Consequently, this paper focuses on the national scale to unravel the dynamics of agricultural policy influence on digital co-innovation in Benin's agriculture.

2. THEORETICAL AND ANALYTICAL FRAMEWORK

Several authors have conducted recent studies on co-innovation [34; 35; 36; 37]. [38] define co-innovation as a collaborative and iterative approach to jointly innovate, produce, and scale technologies. The involvement of stakeholders in general and those for whom the innovation is intended in particular makes it possible to analyze possible constraints upstream, allowing for more effective considerations. The conceptualization of co-innovation varies among scholars, with [38] aligning it with the views of authors who perceive co-innovation as an approach, such as [39] and [40]. Others view co-innovation as a broader “paradigm” as expressed by [41]. On the other hand, for some researchers, co-innovation is a process [42, 27], while for others, it is the result of this process [43]. In navigating these nuanced meanings that, amid these various meanings that at their core, are not mutually exclusive, we adopt the perspective of co-innovation as a process with distinct phases, considering it as an approach embracing a "bottom-up" orientation in contrast to "top-down" approaches. In this paper, digital co-innovation in agriculture is conceived as the process involving stakeholders in the development of a digitally presented innovation intended for agricultural purposes.

Several authors have attempted to define the key elements that makeup co-innovation,relying on two theories that, while differing in form, share substantial similarities: [44] theory and [45] “5Co” theory. Bitzer and Bijman define co-innovation as considering three elements: collaboration, complementarity, and coordination. Collaboration emphasizes the involvement of multiple actors within the same innovation process, complementarity underscores the intelligent integration of technological, organizational, and institutional innovations, and coordination involves adjustments and changes made in the course of innovation development. Other works also support these three key characteristics of co-innovation: collaboration [46], complementarity [47], and coordination [48]. In a co-innovation process, collaboration emphasizes the actors, complementarity underscores the interdependence of their contributions, and coordination consolidates the harmonization of participation and contributions to achieve the intended innovation. The analysis of multi-actor platforms for agricultural knowledge management carried out over several decades revealed the inefficiency of coordination mechanisms poses a significant bottleneck [48].

The alternative theory proposed by [45] defines co-innovation through five points: collaboration, complementarity, coordination, convergence, and co-creation. Unlike Bitzer and Bijman's theory, Saragih and Tan introduce convergence as the alignment of diverse ideas expressed during the co-innovation process towards a specific objective. In contrast, co-creation refers to adding value to the created output. Convergence and co-creation essentially complement the three points common to both theories. The 5 Co theory establishes an association between complementarity and convergence, and between co-creation and collaboration. While the two theories share substantial similarities, the practical

difficulty lies in distinguishing convergence from complementarity. Hence, for the examination of how agricultural policies in Benin promote digital co-innovation in agriculture, we rely on the foundational theory of Bitzer and Bijman.

Indeed, agricultural policies are the measures taken by the State to induce targeted changes in the agricultural sector. Several studies have approached agricultural policies by referring to their institutional, regulatory, operational [33,49], and organizational [50] frameworks. These frameworks include laws, decrees, institutions, projects/programs, and methods of organization, to approach the question of agricultural policies. Political choices made by decision-makers at the national level that can influence the implementation of digital agriculture, specifically in terms of collaboration, complementarity, and coordination in digital innovation systems, are integral elements for consideration in this work. Key indicators or variables associated with collaboration involve the implementation approach adopted by agricultural policies (inclusive or exclusive), the actors within the digital agriculture ecosystem and innovation systems, and political initiatives to strengthen partnerships. These elements shed light on the actors and facilitate an assessment of agricultural policies that favor collaboration in the development of digital innovations in agriculture. Regarding complementarity, the observed elements are the interdependence between actors introduced by agricultural policies, political provisions favoring partnerships, and indices of interdependence and partnership. Finally, elements observed for coordination include coordinating actors, initiatives, modes, and types of coordination within digital agriculture. Figure 1 illustrates the analytical framework of this study.

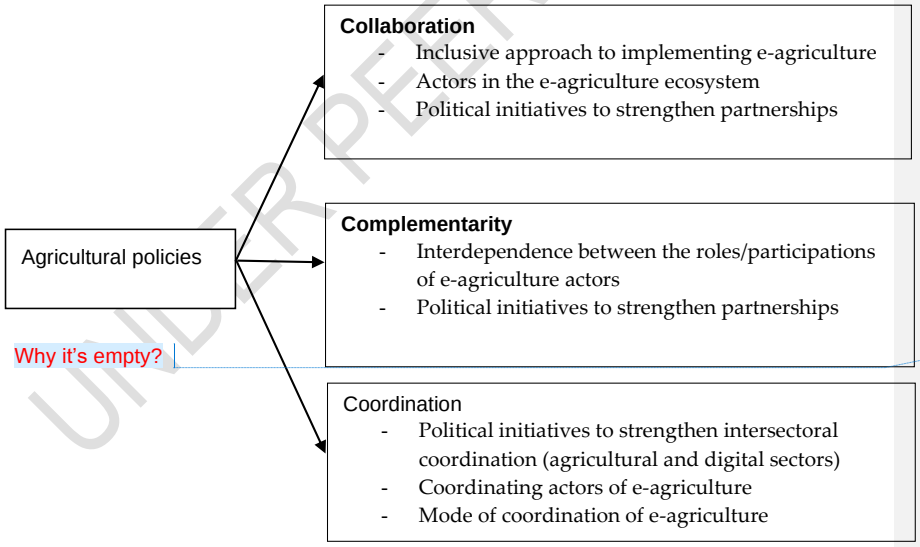

Fig. 1. Analytical framework

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3. MATERIAL AND METHODS

To analyze the extent to which Benin's agricultural policies foster digital co-innovation in agriculture, we applied the rapid review (RR) method, recognized as a powerful evidence-based decision-making tool at the policy level [51]. This review is carried out using the PRISMA-RR method consists of four main phases: Identification, Screening, Eligibility, and Evidence retrieval**.** Furthermore, we collected data from key informants and a selected case study.

3.1. Data collection from the literature

3.1.1 Identification

To meet the main objective of this study, we searched for potential documents from which data could be extracted. For this purpose, we utilized a search string composed of key and relevant words related to the subject investigated in this paper. These words were chosen based on expressions commonly used in the literature referring to agricultural policies, digital technology, and digital innovations. Given that the systematic review is already focused in Benin, we broadened the search to explore all documents dealing with agricultural policies related to e-agriculture in the country. So, the search string was as follows: ("Agricultural Polic*" OR "Policy Framework*" OR "Agricultural Strateg*" OR "Government Initiative*" OR "Public-Private Partnership*" OR "Policy Implementation") AND (digital OR ICT OR technology) AND (Benin OR "West Africa"). This string enabled us to thoroughly explore Scopus and Web of Science, which are among the largest databases of scientific citations and references [52]. Additionally, a hand search was conducted on Google, Google Scholar, and the websites of several key agricultural institutions. At the end of this initial phase, we identified 30 articles on Scopus and 78 on Web of Science. A total of 108 articles were identified, including 8 duplicates that were subsequently removed. The screening process was then carried out on the remaining 100 articles.

3.1.2 Screening

This phase of the methodology involved examining primarily the abstracts of the articles previously identified to exclude those that were less relevant. For this purpose, inclusion and exclusion criteria were predefined, and articles that did not meet these criteria were excluded. These criteria pertained to the focus of the paper, study area, its quality, accessibility, and language. Table 1 presents the inclusion and exclusion criteria. Based on these criteria, of the 100 articles screened, only eleven articles were retained, representing 11% of the total articles identified.

3.1.3Eligibility

During this phase, all articles retained from the previous screening phase (n=11) were thoroughly read. In addition to these, further documents were sourced based on the criteria outlined in Table 1. This additional material included six documents from Google Scholar, four from Google, and two from the website of the MAEP (Ministry of Agriculture, Livestock and Fisheries). A complete and careful reading was undertaken for each document. Only those that specifically addressed aspects of Benin's agricultural policies related to digital co-innovation in agriculture were retained for further analysis. Specifically, the documents selected showcased elements of agricultural policies that emphasized collaboration, complementarity, and/or coordination within the digital innovation ecosystems in agriculture in Benin and a rigorous methodology outlining the procedural approaches used within the studies. Using these eligibility criteria, we reviewed all 23 documents. This review process

led to the exclusion of 14 documents, ultimately retaining nine that provided substantive evidence on how Benin's agricultural policies are fostering co-innovation in digital agriculture (see appendix).

3.1.4Evidence retrieval

In the final phase of our application of the PRISMA-RR method, we focused on extracting key elements that demonstrate how Benin's agricultural policies support digital co-innovation in agriculture. The documents provided insights into the aspects of these policies that act as catalysts for collaboration among various stakeholders, complementarity between different actors in fostering digital innovations, and coordination of stakeholder contributions in the development of digital agricultural innovations. Additionally, we assessed evidence regarding the effectiveness of these policies within the country's e-agriculture framework. The analysis of these elements was conducted through narrative analysis, employing both ex-ante and ex-post approaches. Figure 2 presents PRISMA-RR method applied.

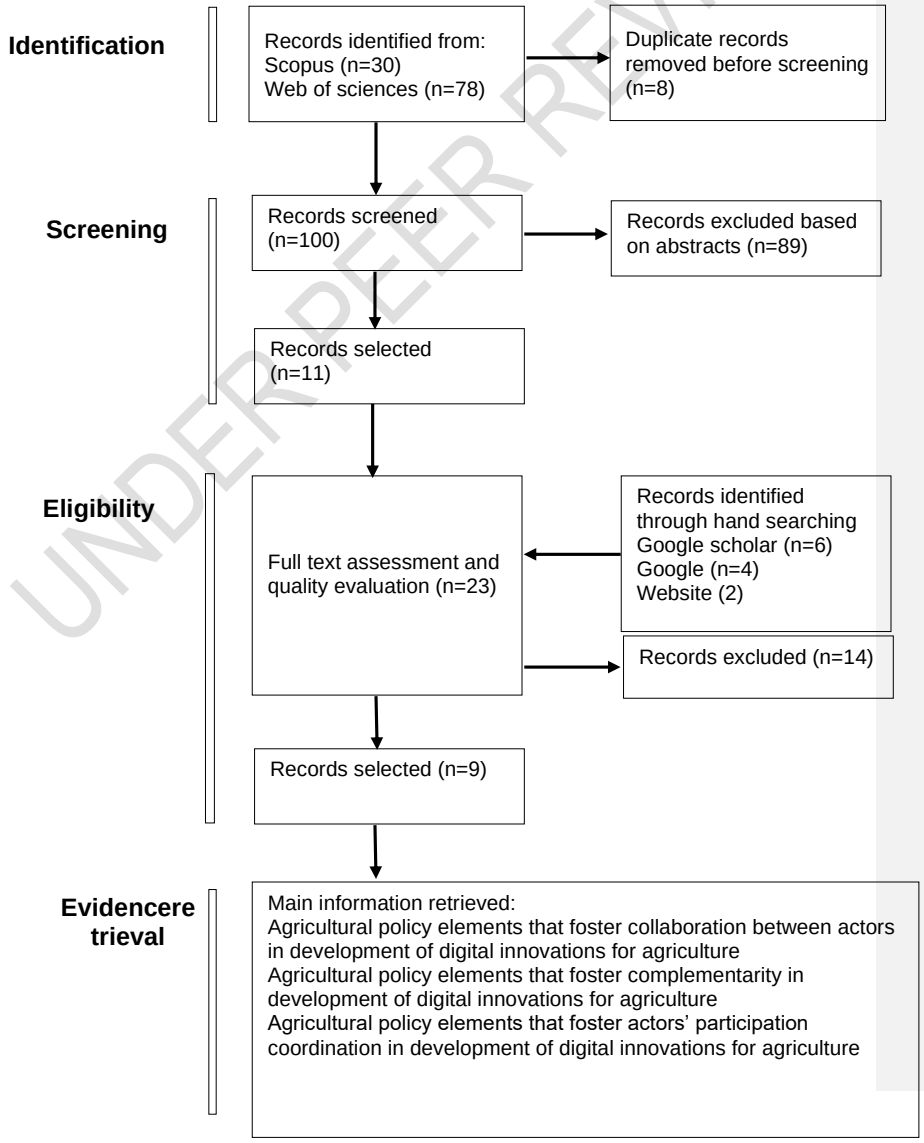

Fig. 2. Overview of PRISMA-RR method applied

3.2Empirical data collection

Apart from the literature review, we collected data from key informants. In this context, we participated in two different conferences named “Salon des TIC” in Benin, held in 2019 and 2022 organized by Benin Government. These “Salon des TIC” events gathered stakeholders from various sectors involved in the agricultural digitalization system, including farmers' associations, NGOs, the Ministry of Agriculture, Livestock and Fisheries (MAEP), researchers, and private start-up organizations. The conferences provided a platform to showcase digital innovations and discuss challenges and perspectives related to digital agricultural development. Participation in these events allowed us to easily access key informants from diverse backgrounds for data collection regarding the agricultural landscape in Benin. During these events, we interviewed six representatives from the MAEP, ten from NGOs, eight researchers, and twenty-four individuals who are holders of digital agriculture startups (see Table 1).

Table 1. Key informants interviewed

Category	Number of key informants interviewed
Ministry of Agriculture, Livestock andFishery	6
NGOs	10
Researchers	8
Startups / private enterprises	24
Total	48

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The study also involves a case study of the digital co-innovation process to enrich the data collected from the literature and key informants. Our aim is to analyze the process from the beginning to capture the interactions and ongoing developments, as well as how policy influences the operational level. To achieve this, we selected one project named DigiCLA from a list obtained from the MAEP that aligns with our objectives. The DigiCLA project aims to promote digital innovation to combat the Fall Armyworm (FAW) affecting maize in West Africa, particularly in Benin. The DigiCLA project is being implemented over two years, from 2022 to 2024, by a consortium consisting of the University of Parakou (UP) through the Laboratory of Research on Innovation for Agricultural Development (LRIDA), Eclosio (an NGO affiliated with the University of Liège), and TIC Agro Business Center (TIC ABC), a center of excellence in information and communication technology applied to agriculture. We were involved in key activities carried out in the project, such as the development of a digital application (Agricef) through participation in workshops organized within the project and the dissemination of the application in rural areas. During this period, we reflexively collected data from 32 participants, including four researchers, two individuals from TIC ABC, three from Eclosio, and 23 farmers.

4. RESULTS AND DISCUSSION

4.1 To what extent do agricultural policies foster digital co-innovation in agriculture?

4.1.1 Collaboration

Benin's agricultural policies, before fostering collaboration, initially promoted the in-clusion of stakeholders in the country's e-agriculture ecosystem. The analysis of the collected documents reveals three distinct periods in Benin's e-agriculture ecosystem: from 1960 to 1995, a top-down approach prevailed, with radio being the primary digi-tal tool and the State playing a central role in digital innovations. Between 1996 and 2016, agricultural policies shifted towards more participatory approaches, involving farmers as active stakeholders in the ecosystem. During this period, digital innovations such as radio, telephone, television, and GPS were introduced in the country's agricul-ture. Since 2017, Benin's agricultural policies have embraced multi-actor approaches, emphasizing the inclusion of numerous stakeholders in the country's digital innova-tion ecosystem [33]. Benin Government embrace an inclusive approach to digital e-agriculture, as outlined in the [32] report. This emphasis on inclusion aligns with the digital aspirations articulated in the Beninese Government's Action Program [53,54]. This political choice in nature and strategical by implication, first materialized through the development of the national e-agriculture strategy inclusively [32], a de-velopment which was inspired by the framework of the FAO and the International Telecommunications Union (ITU) and which also requires stakeholder engagement. The national strategy is presented in a document that presents an inventory of digital solutions present in the country. It analyzes existing policies and strategies for this purpose, defines a vision, objectives, and an action plan for this agricultural emer-gence, as well as a monitoring-evaluation system, from 2020 to 2024 [9]. The adoption of this inclusive approach by agricultural policies has enabled key stakeholders to be found in the digital agriculture ecosystem in general and in digital innovation systems. It is also to confirm this desired and recorded inclusion that the [32] specifies this: “A national approach to electronic governance which has been developed inclusively, in-volving representatives of the government and other key stakeholders, will ensure the identification of capacity building needs based on the state of ICT and the needs of the field in Benin, ensuring that no key stakeholder group is excluded from the process”. This inclusion promoted by agricultural policies is conducive to collaboration in the development of digital innovations in agriculture.

Indeed, across these three delineated periods, collaboration evolved significantly. Ini-tially, it was nearly absent, but over time, it transitioned from collaboration solely be-tween state actors and farmers to now involving a broader spectrum of stakeholders in the development of digital innovations in agriculture. By including key strategic ac-tors, representing pivotal stakeholders in the country's e-agriculture, a dynamic of in-teraction and collaboration is instigated. These collaborative efforts inherently follow the principle of inclusion. According to [10], there are seven types of actors in the digi-tal agriculture ecosystem who collaborate currently in developing digital innovations for agriculture in Benin. These include private actors who represent 34% of the actors in Benin’s digital agriculture ecosystem. They are the majority and are followed by NGOs/CSOs (Civil Society Organizations) (17%), public actors (13%), and Technical and Financial Partners (PTF) (13%). In addition to these actors, there are those in the minority represented, in particular, incubation/acceleration structures (7%), research and teaching actors (7%), and farmer organizations (7%). So, the inclusion of these stakeholders, favorized by agricultural policies, induces new collaborations in the de-velopment of digital innovations introduced into the country's agriculture. It is crucial to note that these seven actor categories are not uniformly engaged in all innovation processes.

Collaborations are context-dependent. As part of the “technical assistance to farmers through information and communications technologies” project, for exam-ple, there was a collaboration between public and private actors. This collaboration fa-cilitated the development of digital innovations, specifically call centers providing farmers with agricultural information to enhance productivity [32].

In addition to fostering collaboration within digital innovation systems through inclu-sion, the strengthening of public-private partnerships (PPP) through Benin's agricul-tural policies is also an important lever. Indeed, in component 6 of Axis 2 of the Strate-gic Agricultural Sector Development Plan (PSDSA, 2017-2025), the State strengthens PPPs through the establishment of laws and decrees favorable to the development of PPP contracts, support to private initiatives entering into the country's agricultural policy [55]. These PPPs are facilitated by the prior inclusion of private actors in Benin's agriculture policies. Consequently, by strengthening these partnerships, agricultural policies inherently boost relationships and interactions between the public and private sectors, fostering collaboration among diverse actors. This collaborative environment extends to the agricultural sector as a whole, influencing digital agriculture and, by implication, digital innovation systems. Notably, collaborations between the public and private sectors are prevalent, with TIC ABC, a private company, emerging as a key player in shaping the landscape of digital agriculture in Benin [10].

In summary, Benin's agricultural policies, by adopting an inclusive approach to im-plementing digital agriculture, first include stakeholders in the ecosystem of this agri-culture and digital innovation systems. This inclusivity manifests through a diverse array of actors shaping the institutional framework of digital agriculture in Benin, fos-tering collaboration across different implementation scales of digital agriculture and within digital innovation systems. With diverse actors already included, policymakers, through agricultural policies, actively promote collaboration between public and pri-vate entities by reinforcing Public-Private Partnerships (PPPs). The inclusion facilitat-ed by the country's agricultural policies emerges as a pivotal initiative shaping the collaborative landscape among stakeholders. However, despite this effort, collabora-tion between these actors remains weak [10].

The actors collaborating in digital agriculture innovation systems depend on those previously included in the country's digital agriculture ecosystem through agricultural policy mechanisms. The quality of collaboration is firstly linked to the nature of the actors included in the innovation systems. Consequently, an arbitrary, non-strategic inclusion, characterized by the involvement of inappropriate actors in digital innova-tion systems, inevitably hampers the productivity of collaboration. In such a case, the irregularities observed in the collaboration between actors reduce the prospects of success in the digital co-innovation process in agriculture. Agricultural policies, there-fore, offer a means to leverage insights gained from observed collaboration challenges and stakeholder needs, facilitating adjustments in the inclusion of stakeholders. Intel-ligent and strategic inclusion, guided by agricultural policies, becomes imperative for fostering successful collaboration and, by extension, ensuring the triumph of the digital co-innovation process in agriculture.

4.1.2Complementarity

Benin's agricultural policies, before fostering collaboration, initially promoted the toshow how agricultural policies foster complementarity in digital innovation systems, we analyzed the varied participation of stakeholders and their contributions through-out the innovation process. This approach underscores how stakeholder involvement aligns with and enhances the overall process. Examining the evolution of e-agriculture in Benin across three distinct periods highlights notable shifts. From 1960 to 1995, ag-ricultural policies primarily adopted

a top-down approach, which led to limited, static, or absent complementarity in the development of digital solutions. In contrast, from 1996 to 2016, the focus shifted towards more participatory strategies, integrating farmers into the e-agriculture ecosystem. This transition facilitated the emergence of complementarity between state actors and farmers, with the latter providing valuable local insights that enhanced the use of digital technologies in agriculture [33]. This complementarity has evolved further since 2017, marked by increased inclusion of ac-tors in the ecosystem, resulting in a more dynamic and diversified e-agriculture land-scape. The inclusion of stakeholders, as driven by the agricultural policies of the coun-try, went beyond assembling random actors in Benin's e-agriculture ecosystem. It in-cluded strategic actors whose roles and respective participations are required for the development of digital innovations, thereby fostering complementarity.

Within the country's e-agriculture ecosystem, actors from both the agricultural and digital sectors are commonly found, with the MAEP overseeing the agricultural sector and the Ministry of Digital and Digitalization (MND) leading the digital sector. As e-agriculture is a mix of agriculture and digital technology, the involvement of partic-ipants from both sectors is imperative for the development of digital innovations in agriculture. Therefore, agricultural policies, by integrating actors from the agricultural and digital sectors into Benin's digital agriculture ecosystem, promote complementari-ty in participation across various levels and within innovation systems. This comple-mentarity between the two sectors is further solidified by the establishment of a de-partment with a digital focus within the MAEP, known as the Information Systems Department (DSI), realizing synergy between the two sectors [32].

The connection between the public and private sectors is another form of complemen-tarity induced by Benin's agricultural policies in the development of digital innova-tions in agriculture. Agricultural policies, by adopting an inclusive approach to im-plementing e-agriculture, have created an ecosystem that involves both public actors and private actors, including TIC ABC, Jinukun Sarl, Zoom agro, Vartlab-Benin [33]. Public actors play a crucial role in implementing the country's e-agriculture strategy, while private actors, for the most part, drive digital innovations and provide essential knowledge and digital expertise [10]. Agricultural policies further enhance this com-plementarity between the public and private sectors by strengthening Public-Private Partnerships (PPPs) in agriculture. The very term "partnership" implies a form of com-plementarity. As result, many digital innovations available in Benin agriculture, come from complementarity between public actors and private enterprises [32].

Beyond sector-specific typology, the inclusion driven by agricultural policies has also cultivated a general complementarity involving the seven types of actors present in today's e-agriculture in Benin. Each type constitutes a stakeholder whose participation in the development of digital innovations in agriculture is crucial. State actors take the lead, defining policies and ensuring alignment with these policies. Technical and Fi-nancial Partners (PTFs) provide necessary financial and technical support, the private sector offers digital resources and research centers contribute vital knowledge. Addi-tionally, NGOs/CSOs support farmers in the utilization of digital innovations. Farmers are recognized as essential stakeholders, and Benin's agricultural policies actively promote their meaningful participation in digital solution development. For example, these policies mandate farmer involvement in the planning, execution, and assessment of agricultural advisory services [56], with digital innovations primarily utilized for e-extension purposes in Benin [57]. The participation of each actor contributes to the development of digital innovations and their effective use.

The analysis shows that the agricultural policies of Benin, by allowing the inclusion of actors, especially strategic actors, in the digital agriculture ecosystem, promote the complementarity

of participation of these actors in the development of digital innova-tions for agriculture. This inclusion allowed for the presence of actors from both the agricultural and digital sectors, public and private, and various actors whose contribu-tions and participation in the development of digital innovations in agriculture are complementary. Agricultural policies, by promoting inclusion and, more importantly, strategic inclusion, thus encourage complementarity in innovation systems.

However, the complementarity of actor participation and contributions makes sense only when they collaborate. Collaboration, therefore, gives rise to contributions and complementary participation from stakeholders in the development of digital innova-tions in agriculture. Weak collaboration has repercussions on actor participation, on the complementarity of their contributions to the development of digital innovations, and ultimately, on the process of digital co-innovation in agriculture. Hence, the ob-served weak collaboration within Benin's digital agriculture ecosystem underscores a missed opportunity for cooperation, partnerships [10], and consequently, complemen-tarity. Therefore, healthy and sufficient collaboration is necessary to induce effective, complementary participation and ensure the success of the digital co-innovation pro-cess in agriculture. In cases where stakeholder participation is unsatisfactory, adjust-ments to collaboration between actors can be made, thanks to agricultural policies, providing room for course correction.

4.1.3Coordination

Following these three periods observed in Benin's e-agriculture, agricultural policies have gradually included different actors in the ecosystem of this agriculture. Thus, the participations and contributions of these actors to the development of digital innova-tions are increasingly diversified, and as a result, the coordination of these has become more dynamic and demanding over time. From a coordination historically based only on state interventions, over time it has covered the farmers participation, then today, the contributions of several other actors.

Coordination issues at different levels of the agricultural sector are a concern of agri-cultural policymakers in Benin. Thus, policy measures are implemented to enhance the coordination of interventions, encompassing agriculture in general, e-agriculture, and digital innovation system. Indeed, in its Strategic Development Plan for the Agricul-tural Sector (PSDSA), the country has defined five major areas of intervention includ-ing improving the governance of the sector. As such, policies have provided for the strengthening of intersectoral coordination at different scales. This emphasis on coor-dination stems from the observed low governance levels in the agricultural sector. Specifically, in digital agriculture, the necessity to strengthen intersectoral coordina-tion is prompted by the underutilization of Information and Communication Tech-nologies (ICT) in the country's agriculture. To this end, the country's agricultural poli-cies promote the synergy of intra and intersectoral actions and the development of digital agriculture [55]. Particularly in digital agriculture, these policy provisions im-ply a reinforcement of synergy between actions within the agricultural sector, as well as between agriculture and digital technology, at different levels and implicitly within digital innovation systems. Thus, by strengthening intersectoral coordination, agricul-tural policies promote the coordination of actions in digital agriculture and therefore in digital innovation development.

Additionally, Benin has established an organizational framework for e-agriculture tasked with coordinating interventions, actions, and participations, overseen by the MAEP and the MND [10]. This is also a participatory coordination involving the In-formation and Digital Systems Agency (ASIN). This framework ensures the coordina-tion of interventions between the agricultural and digital sectors for e-agriculture. It also ensures the coordination of

interventions between the public and private sectors through the Small and Medium Enterprises Development Agency (ADPME) which serves as a liaison between the two sectors. In essence, the organizational framework of digital agriculture in Benin coordinates interventions between the agricultural and digital sectors, as well as between the public and private sectors. This coordination co-vers interventions in Benin's e-agriculture and therefore in innovation systems. The presence of such actors constitutes favorable factors for coordination in the country's e-agriculture. Overall, the country has formulated agricultural policies to enhance the coordination of interventions in digital agriculture, both between the public and pri-vate sectors and between the agricultural and digital sectors. Policy mechanisms, such as strengthening intersectoral coordination and establishing an organizational frame-work for digital agriculture, are designed to facilitate coordination of interventions and participation in digital agriculture and, by extension, in developing of digital in-novations in agriculture, ultimately promoting co-innovation.

Coordination is instrumental in promoting the efforts and participation of the actors involved in the process of digital co-innovation in agriculture. It harmonizes the con-tributions of digital and agricultural participations of stakeholders to achieve the en-visioned digital innovation. Coordination, therefore, holds significant importance. As a result, a low level of coordination between the digital and agricultural sectors is detri-mental to co-innovation processes and to digital innovations by extension. It is the complementary participation of the actors involved in the process that are coordinat-ed. Similar to the previously examined constructs, the possibility of adjustments re-mains opened. Indeed, coordination difficulties may necessitate restructuring actor complementarity. Overall, the relationship between complementarity and coordina-tion remains dynamic, with feedback loops between the two constructs.

4.2Lessons from the case study key informants interviewed

The DigiCLA project in Benin is a perfect illustration of public policy commitment, as well as the importance of inclusion, collaboration, complementarity, and coordination in digital co-innovation processes in agriculture. The project is implemented by a pub-lic institution, the Laboratory for Research on Innovation for Agricultural Develop-ment (LRIDA) at the University of Parakou, in partnership with the NGO Eclosio and the private company TIC Agrobusiness Center (ABC). Within the framework of the project, these actors co-created a digital innovation: the AgriCef-Maïs app, a digital solution designed to help farmers combat the Fall Armyworm (FAW) in an agroeco-logical manner. This initiative brought together various stakeholders whose contribu-tions were crucial for the effectiveness of the digital solution. In particular, farmers were included in the co-innovation process that led to the creation of this solution. For example, a farmer after the first workshop of "AgriCef" development said:

"Participating in the workshop for the development of the AgriCef application was enlight-ening. It allowed us, as farmers, to voice our challenges directly and collaborate on solutions that truly address our needs. This process has given us hope that technology can help us combat the Fall Armyworm effectively while improving our maize production."

This reflects the positive impact of farmer inclusion in the digital co-innovation pro-cess and highlights their active role in shaping solutions that meet their agricultural needs.This inclusion fostered collaboration between project stakeholders and potential users of the digital solution—namely, the farmers. Without the prior involvement of farm-ers, this collaboration would not have occurred, thereby reducing the chances that the digital innovation would face challenges related to efficiency and adaptability. As one of the project agents from Eclosio mentioned,

"*We involved farmers to identify a common agricultural problem of general interest and ensure that digital solutions are a promising al-ternative."*

Once included, we observed collaboration among all these actors, charac-terized by both physical and virtual interactions. Their respective contributions, when combined, helped develop the digital innovation. The research actors (LRIDA) pro-vided knowledge from their research to address digital inequalities and identify agroecological methods that are both relevant and accessible to farmers. The private company TIC ABC handled the digitalization process, while the NGO Eclosio sup-ported farmers in using the proposed digital solution. In the early stages, farmers' con-tributions brought adaptability and effectiveness to the innovation. Thus, the contribu-tions of all parties were complementary, illustrating complementarity in the digital co-innovation process in agriculture. Although these contributions were complemen-tary, they needed to be coordinated and aligned toward constructing the digital inno-vation. This project not only reflects the favorability of public policies but also high-lights the dimensions of inclusion, collaboration, complementarity, and coordination inherent in the process of digital co-innovation in agriculture.

The participation in the various “Salon des TIC” organized in Benin reveals significant insights regarding the influence of policy on digital co-innovation. The emergence of numerous e-agriculture start-ups, particularly among the youth in Benin, demontrates a growing trend towards digital integration in agriculture. These initiatives are bol-stered by the annual organization of the “Salon des TIC,” which serves as a vital plat-form for participants, especially young innovators, to showcase their digital solutions aimed at enhancing agricultural systems. The “Salon des TIC” is not merely a national event; it attracts innovators from across Africa and beyond, fostering an environment of collaboration and knowledge exchange. As noted by Dr F.O, a researcher participant of the “Salon des TIC”,
“They [refering to Salon des TIC] are crucial for bridging the gap between policy and practice, allowing young entrepreneurs to align their innovations with governmental priorities and funding opportunities.”
This alignment is essential for creat-ing a supportive ecosystem that encourages the growth of digital enterprises. Howev-er, while these events promote innovation, they also highlight challenges faced by dig-ital entrepreneurs. Many start-ups encounter barriers such as limited access to financ-ing, inadequate infrastructure, and regulatory hurdles that can stifle growth. D.T, a Start-up holder, expressed this concern:
"While we have great ideas and solutions for dig-ital agriculture, navigating the bureaucratic landscape can be daunting. We need policies that not only support innovation but also simplify processes for start-ups.”
The role of policy in fostering a conducive environment for digital co-innovation cannot be overstated. Ef-fective policies can facilitate access to resources, provide necessary training, and create frameworks that encourage collaboration among stakeholders. As highlighted in dis-cussions at the “Salon des TIC,” there is a pressing need for policies that address these challenges while promoting inclusivity and equitable access to technology.

4.3Process of inducing digital co-innovation in agriculture through agricultural policies?

We realize that before actors collaborate in innovation systems, they must first have been included through the adoption of the inclusive approach for e-agriculture in Benin. The initial step involves the (i) inclusive approach adopted for e-agriculture in Benin. This approach facilitates the integration of diverse stakeholders into the digital agriculture ecosystem and in development of digital innovations for agriculture. This inclusive environment sets the stage for subsequent collaborative endeavors. Inclusion precedes collaboration (ii), as various actors, having been included, engage in collaborative efforts. Agricultural policies provide additional impetus for collaboration, establishing an environment conducive to joint initiatives. During the collaboration, each actor involved brings his contribution, participation

in (iii) complementary way. Human interactions being dynamic, feedback mechanisms come into play. The quality of complementarity may necessitate a reevaluation of the collaborative structure. The final stage involves the harmonization and coordination (iv) of actors' contributions and respective participations. This coordination effort is crucial for realizing the co-innovation process and the envisioned digital innovation. Notably, coordination may unveil the need for intervention in the complementary participation of stakeholders. Agricultural policies are strategically designed to encourage and facilitate both complementarity and coordination.Overall, the findings reveal a sequential progression, emphasizing the interplay between inclusion, collaboration, complementarity, and coordination. However, setbacks are also observed. Indeed, we can note that state actors collaborated with farmers, when agricultural policies, by adopting an inclusive approach, favored the inclusion of new actors in the Benin e-agriculture ecosystem. From an existential collaboration, agricultural policies have therefore made it possible to start again with the inclusion of new actors. Also, despite the complementarity of contributions and participation made by old actors in the development of digital innovations in agriculture, agricultural policies favored new collaborations. The same goes for the coordination and complementarity of actors in the e-agriculture ecosystem. Simply put, the process by which Benin's agricultural policies promote digital co-innovation in agriculture is not linear and rigid. It is rather flexible and iterative. This framework underscores the nuanced and interconnected nature of the elements involved in fostering digital co-innovation in agriculture through effective agricultural policies (figure 3).

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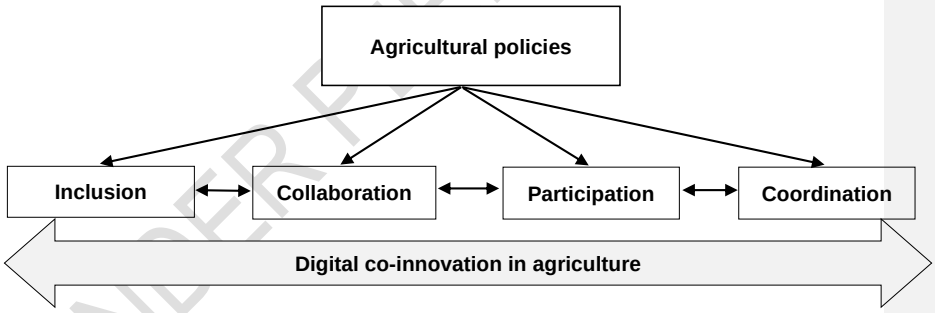

Fig. 3. Process of induction of digital co-innovation in agriculture through agricultural policies

5. DISCUSSION

This paper primarily aims to elucidate how the agricultural policies contribute to the promotion of digital co-innovation in agriculture. This objective is grounded in the recognition of co-innovation as a crucial mechanism for mitigating uncertainties inherent in digital agriculture, coupled with an acknowledgment of the pivotal role that policies play in determining the success or failure of this process. The study delves into the foundational

constructs of digital co-innovation in agriculture, particularly focusing on the influential impact of agricultural policies.

To show how agricultural policies promote digital co-innovation in agriculture, our approach draws upon the foundational theory proposed by [44], which identifies collaboration, complementarity, and coordination as pivotal elements within the realm of co-innovation. The outcomes of our investigation not only affirm and elaborate on these constructs but also introduce novel elements that contribute to a comprehensive understanding of the interplay between agricultural policies and digital co-innovation in the agricultural landscape. This research seeks to refine the theoretical underpinnings and practical insights surrounding the dynamic relationship between policy frameworks and the promotion of digital co-innovation in agriculture. Indeed, agricultural policies play a pivotal role in shaping the landscape of digital agriculture through their adoption of an inclusive approach. This is materialized by the presence of different actors in digital agriculture in Benin in general and in innovation systems in this case. As highlighted by [27], the impact of agricultural policies on innovation systems is significant, laying the groundwork for subsequent collaborative endeavors among stakeholders. The premise of this inclusive strategy is particularly crucial, as it precedes and influences the collaborative dynamics within innovation systems. Without the proactive inclusion facilitated by agricultural policies, these stakeholders might not find themselves engaged in innovation systems, thereby diminishing the likelihood of fruitful collaboration. In addition to the constructs identified by Bitzer and Bijman - collaboration, complementarity, and coordination - this study underscores the paramount importance of inclusion. [47] aptly emphasize the indispensability of inclusion in the co-innovation process, advocating for equality of opportunity in expressing preferences [58]. It also implies a proactive stance against the exclusion of individuals [59]. In essence, the study sheds light on the foundational role played by inclusion in the overarching framework of digital co-innovation in agriculture, offering a nuanced perspective that aligns with contemporary discussions on equity, accessibility, and the democratization of innovation processes.

Then, our analyses reveal that following inclusion, agricultural policies lead to collaboration between stakeholders in digital innovation systems and the implementation of digital agriculture in general. [28], as well as [27] in their work, also established this positive relationship between policies and collaboration in co-innovation processes. Upon closer examination of the actors included in innovation systems, it becomes apparent that agricultural policies have played a strategic role beyond mere inclusion. Instead of assembling actors randomly, these policies have strategically grouped them, fostering a scenario where the contributions and participation of each actor are inherently complementary. Therefore, the complementarity in co-innovation process hides stakeholders' participation. Participation, as revealed in this study, is thereby identified as a key vector of co-innovation [47,60]. This perspective sheds light on the intricate relationship between policies and the pivotal question of participation in co-innovation processes, a dimension somewhat obscured in these existing theories of co-innovation. It underscores the realization that inclusion alone does not guarantee participation [61]. In essence, the agricultural policies implemented foster complementary participation among actors in digital innovation systems in agriculture, setting the stage for harmonization and coordination necessary for the realization of digital innovation. It is worth noting that the effectiveness of co-innovation can be influenced by the types of actors involved and the collaboration strategies deployed by them [62].

Furthermore, Benin's agricultural policies actively promote the coordination of participation in digital agricultural innovation systems through the establishment of an organizational framework. This framework, by strengthening intersectoral coordination and facilitating collaboration between the agricultural and digital sectors, consequently promotes

coordination within digital innovation systems. Overall, agricultural policies act as a catalyst for digital co-innovation in agriculture by sequentially inducing inclusion, collaboration, complementary participation, and coordination, ultimately culminating in the innovation itself. This study, by establishing meaningful connections between these concepts, distinguishes itself from other works that often isolate the influence of policies on specific points within a co-innovation process, thereby contributing original insights to the scholarly discourse.

6. CONCLUSION

In this paper, our main objective is to show the extent to which agricultural policies promote digital co-innovation in agriculture, starting from three key constructs of this collaborative process: collaboration, complementarity, and coordination. Moving beyond theoretical considerations that were initially focused on co-innovation processes, we have not only addressed new dimensions influenced by agricultural policies but have also delineated the interconnections among these constructs. How agricultural policies promote digital co-innovation in agriculture is described as follows: Inclusive approach is a starting point. The foundation lies in the inclusive approach embraced by political decision-makers to implement digital agriculture in the country. Opting for inclusivity, Benin's agricultural policies actively encourage the incorporation of stakeholders into digital innovation systems in agriculture. In tandem with inclusion, agricultural policies strengthen public-private partnerships, thereby laying the groundwork for collaboration. This collaboration is essential for the synergistic efforts of actors engaged in digital innovation systems in agriculture. As a natural progression, collaboration paves the way for increased complementary participation of actors in digital innovation systems. Agricultural policies further contribute to the co-innovation process by establishing an organizational framework for digital agriculture. Simultaneously, efforts are directed towards reinforcing intersectoral coordination. These measures are instrumental in orchestrating and streamlining stakeholder participation.Finally, the coordination of stakeholder participation is achieved through the organizational framework and intersectoral coordination, resulting in the effective development of innovations in digital agriculture. Agricultural policies promote digital co-innovation in agriculture, thus promoting inclusion, collaboration, complementarity and coordination in the development of agricultural digital innovations. However, it's essential to note that the processes through which policies promote co-innovation are not strictly linear. Feedback loops are inherent, allowing for adjustments and refinements based on ongoing assessments and changing dynamics. This study shows theoretically how agricultural policies promote digital co-innovation in agriculture. Further work could follow this study, but from an empirical perspective.

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APPENDIX

Appendix A

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