A functional-structural approach to analyzing agricultural innovation systems in the dairy milk sector of the region of Ghardaïa (Algerian Northern Sahara)

Amine Oulmane*, Fatah Ameur*, Amel Bouzid*, Karima Boudedja*

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Abstract

In recent years, despite its hostile environment and harsh climate, the wilaya of Ghardaïa has emerged as a leader in dairy production in Southern Algeria. This article sought to analyze how the innovation system in the dairy sector has, positively or negatively, influenced the development of the sector in this region and identify the socio-economic factors and institutions that have contributed to it. To do so, a functional-structural approach was taken. The data used were collected from semi-directive interviews and focus groups with different stakeholders involved in the dairy milk sector. Market restructuring, but also the collective organization, which is very common in the region, were found to be the main factors positively affecting the dairy sector. In addition, lobbying by the dairies and the asymmetry of power between dairy farmers and agri-food industrialists, a lack of collaboration and interaction between actors, a lack of coordination in knowledge development, and a lack of formal financing mechanisms to invest in livestock, turned out to be the factors hindering the innovation system. Finally, although the dairy sector in Ghardaïa attracts investors from the North of Algeria, and is thus a pronounced success in economic and organizational terms, the question of its sustainability is not being considered in these southern territories.

Keywords: *Innovation, Value chain, Market, Bovine, Cattle breeding, Algeria.*

1. Introduction

Given its multifaceted role in enabling socio-economic development, improving household incomes, reducing poverty in rural areas and generally enhancing food security in developing countries, livestock activity has often been taken as strategic in government development programs (Francesconi *et al.*, 2010; Headey *et al.*, 2014). In Algeria, despite its reliance on international markets to date, milk is considered as a strategic product in the same way as cereals and potatoes (Bessaoud *et al.*, 2019). It therefore receives special attention and the State considers it a priority to support the development of this sector, where demand continues to grow (Makhlouf *et al.*, 2015; Makhlouf and Montaigne, 2017). This increasing demand for milk has made dairy farming a secure investment and an opportunity to capture

* Research Center in Applied Economics for Development (CREAD), Algiers, Algeria.
Corresponding author: amine.oulmane@gmail.com

State subsidies. However, despite the current efforts and financial support mechanisms to boost the sector, national production still struggles to meet the demand for milk (Kaouche *et al.*, 2015; Kalli *et al.*, 2018). This is due to both population growth and a change in dietary habits. The latter results from the policy of price support (for imported milk) launched by the government to make up for the deficit in animal proteins observed after the country's independence and entails an absence of barriers limiting the quantities of imported milk powder (Amellal, 1995).

In Algeria, average consumption is constantly growing and is considered the highest in the Maghreb. Indeed, it increased from 35 liters in 1963 to 115 liters in 2007, and to 154 liters/inhabitant/year in 2018 (Bédrani and Bouaita, 1998; MADR, 2019). This has led to imports of large quantities of milk powder to cover national demand (40% of milk consumed comes from imports) making Algeria the second largest importer of milk powder in the world after China, and making milk the second most imported food product (in value) after cereals (Yerou *et al.*, 2019). In 2017, 465,000 tons of milk powder were imported, at an average cost of 1.41 billion dollars, amounting to 15% of the total import bill for agricultural products (Bessaoud *et al.*, 2019). Although this strategy meant the population was supplied with milk, many experts in the field criticized this orientation, which constitutes a real handicap to the development of livestock farming and is viewed as counterproductive to the policy aimed at supporting national production (Bensaha and Arbouche, 2014; Yerou *et al.*, 2019). Indeed, subsidized prices in favor of reconstituted milk produced from imported milk powder (administered at 25 Dzd/liter or 0.18 USD/liter for the consumer) explains the higher demand for this product, thus placing the local product (sold for between 65 and 110 Dzd/liter equivalent to 0.47 and 0.8 USD/liter, respectively) in a biased competitive mechanism.

Traditionally, dairy cattle farming was located in the northern regions of the country, particularly the coastline and inland plains with a humid and sub-humid climate, where forage resources are more accessible. However, milk production has been growing more and more over the past two decades in the southern regions of the country, despite their high temperatures and their arid climate. Since the 90s, and particularly in the wilaya of Ghardaïa, the milk sector has undergone restructuring and modernization of livestock farms, while involving new stakeholders. Indeed, the region has become a dairy basin as important as the northern regions of the country (Bensaha *et al*., 2012). The figures testify to a real local economy that has become established (milk production and the number of dairy cattle were 2.5 million liters and 1040 head, respectively, in 2000, and 14.5 million and 4200 head of cattle in 2020), thus attracting newcomers to invest and specialize in the various segments of the sector.

Recently, the Agricultural Innovation Systems (AIS) approach has been recognized by researchers and policymakers as a promising tool for understanding and supporting innovation processes, knowledge exchange and transformation in the agriculture and food sectors (Spielman *et al.*, 2008; Klerkx *et al.*, 2010; Ortiz *et al.*, 2013). AIS can be defined as the interaction between different actors, such as farmers, input suppliers, researchers, advisers, and consumers, together with supporting institutions and policies in the agricultural and related sectors (Brooks and Loevinsohn, 2011; Röling, 2009) that directly or indirectly influence the process of change in agriculture (Temel *et al.*, 2003). This includes the co-evolution of technological elements (e.g., new machines and/or processes, introduction of improved breeds, new products, etc.) and non-technological elements (e.g., new institutional arrangements, social norms, forms of organization, etc.), which shape the way that these actors interact, generate, share and use knowledge, as well as jointly learn (Schut *et al.*, 2015).

In line with this systemic vision of innovation, AIS is an interesting approach for our case study, because it provides a holistic vision for understanding complexity in the roles of actors, institutions, interactions between actors, infrastructures and their relationships to better characterize innovation processes (Adjei-Nsiah *et al.*, 2008). Consequently, given the transformations observed in the dairy sector in the Saharan regions, and a lack of analyses that explain the factors underlying the development in this

sector, this study set out to fill the gap in the literature on this subject by analyzing the undergoing development of the dairy milk sector in this arid region of Algeria. More concretely, the study sought to analyze the efficiency of the innovation system operating in the milk sector in Ghardaïa, highlighting how different elements of the innovation system affect organization in the dairy sector, the reasons behind its development, and to identify barriers faced by the sector, and thus put forward recommendations to strengthen the system as a whole.

2. Theoretical framework: structural-functional framework for innovation system analysis

Since the emergence of the IS (Innovation System) approach in the 1990s (Lundvall, 1992), several analytical frameworks have been developed to analyze the changes and functioning of innovation systems in agriculture (Klerkx *et al.*, 2010). These include the "Analysis of Structural Elements" (Amankwah *et al.*, 2012; Turner *et al.*, 2013) and the "Innovation System Functions" approaches (Hekkert and Negro, 2009; Hekkert *et al.*, 2007). However, these two approaches have been developed distinctly and deal with different aspects in the analysis of innovation systems.

Structural analysis has been used to assess the composition of innovation systems based on an analysis of structural elements. The latter represent the static components of the innovation system and are relatively stable elements over time (Suurs *et al.*, 2010). Four categories stand out: 1) actors (individuals and organizations), 2) institutions (rules and standards), 3) interactions (relationships between actors) and 4) infrastructures (physical or knowledge-based) (Wieczorek and Hekkert, 2012). The functional approach, on the other hand, has been used to identify problems, known as blocking mechanisms, related to several functions (Bergek, 2002; Hekkert *et al.*, 2007). Functions in an innovation system refer to the (positive or negative) contributions of one or more system components to the overall 'goal' of developing, disseminating and using innovations within a particular technological field (Bergek *et al.*, 2008). Seven key functions of AIS have been identified in the literature (Table 1): 1) entrepreneurial activities, 2) knowl-

Table 1 - Functions of innovation systems.

System functions	*Description*
F1. Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers exploit business opportunities and perform innovative commercial and/or practice-oriented experiments.
F2. Knowledge development	Technological research and development are a source of variation in the system and are therefore prerequisites for innovation processes to occur. Non-technological knowledge is also of key importance.
F3. Knowledge dissemination	The typical organizational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange.
F4. Guidance of the search	This system function represents the selection processes necessary to facilitate a convergence in development.
F5. Market formation	New technologies often cannot outperform established ones. In order to stimulate innovation, it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow.
F6. Resource mobilization	Financial, material and human factors are necessary inputs for all innovation system developments.
F7. Creation of legitimacy	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology.

Source: Suurs et al. (2010).

edge development, 3) dissemination of knowledge, 4) guidance of research, 5) market formation, 6) resource mobilization, and 7) creation of legitimacy (Suurs *et al*., 2010).

At a later stage, Wieczorek and Hekkert (2012) argued that the distinct application of one of the approaches does not provide a relevant basis for analyzing innovation systems; mainly because functions cannot be influenced without modifying at least one structural element. If structural elements are absent and/or weak, this gives rise to systemic failures or problems that hinder the development and performance of innovation systems. A coupled functional – structural analysis framework combining the two previous frameworks was thus proposed (Wieczorek and Hekkert, 2012). According to the same authors, combining the two analytical frameworks could show a more complete picture of the system being analyzed and thus lead to more effective policies in favor of a better-organized innovation system. The analysis of innovation systems thus distinguishes between structures, i.e. the elements that make up the system, and the functions or the way in which these elements work in support of innovation (Wieczorek and Hekkert, 2012).

3. Methodology

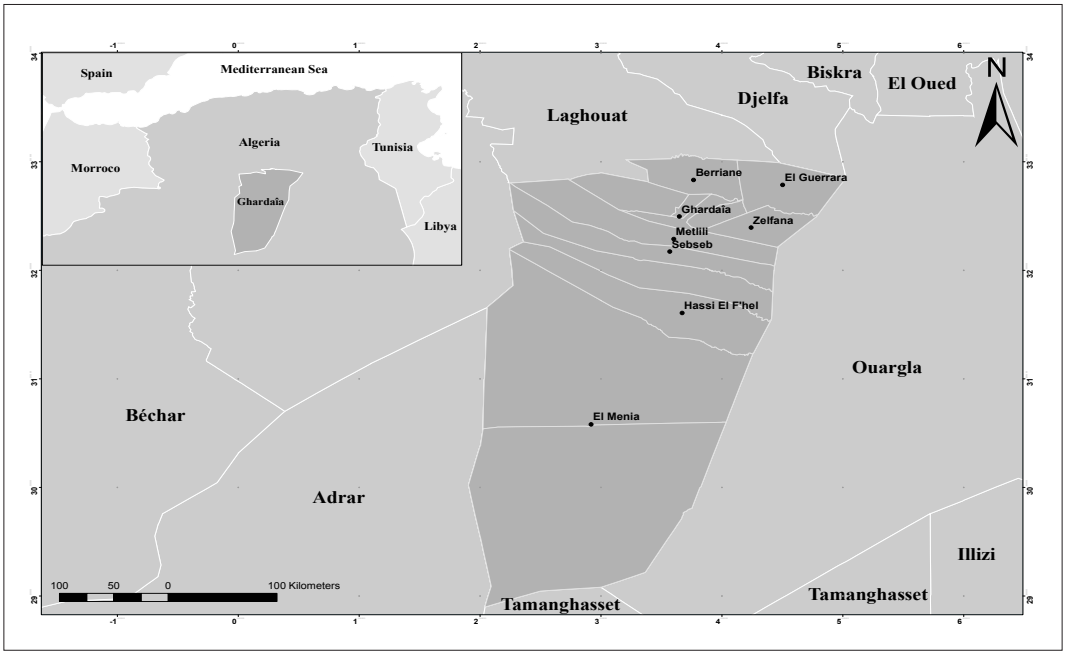
3.1. *Study Area*

The wilaya of Ghardaïa is located in the northern part of the Algerian Sahara (Figure 1) and covers an area of 84,660 km^2. Irrigation is mainly carried out using water from aquifers and particularly the fossilized Albian aquifers, i.e., the "Intercalary Continental" and "Terminal Complex" extending from the Algerian Sahara to Libya.

The territory of Ghardaïa, previously known for its date palm oases, is experiencing major changes. Other agrarian systems, stimulated by development programs, have gained importance in the region. Small structures on the periphery of oases have appeared that reproduce the same configuration as the old oases (with the date palm as the main crop). Other agricultural systems have appeared in extra-oasis perimeters rather characterized by large structures that adopt an intensive agricultural model (cereals, mainly wheat and maize for livestock feed) (Houichiti *et al.*, 2016).

Dairy farming is part of the social heritage of the inhabitants of the wilaya of Ghardaïa, where traditional livestock farming was one of the main activities of the nomadic population. Contrary to

Figure 1 - Geographical location of the study area.



goat breeding that has long existed in the region, cattle farming was introduced only after independence. In 2020, the wilaya has a herd of about 4,200 dairy cows, 172 breeders and 9 dairies – in addition to 2 dairy collection centers (Danone and Soummam). In the same year, milk production reached 14.5 million liters (DSA, 2020). Unlike in the North of Algeria, where grazing is common practice, livestock feed in the wilaya of Ghardaïa is purchased. There are therefore very few farms among the large ones in the South of the wilaya that grow fodder themselves. The number of cows per farm varies between 10 and 300 head, mainly managed in a loose-house system.

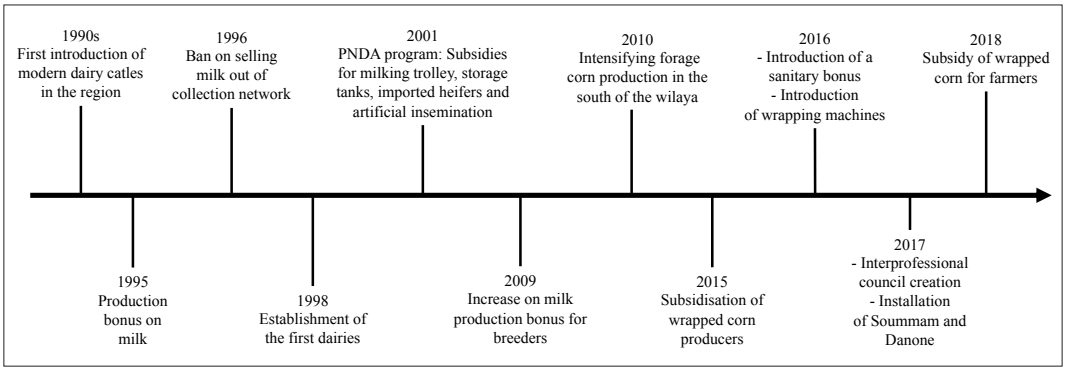
3.2. *Conceptual framework*

In this study we analyzed the innovation system characterizing the milk sector in Ghardaïa. The AIS analysis grid proposed by Wieczorek and Hekkert (2012) was used during the interviews and then for the analysis. Use of the coupled functional-structural analysis, according to which the performance of a certain function of the system is related to the presence and the quality of the structural elements (Kebebe *et al.*, 2015), allowed us to identify and discuss the strengths, as well as the type and the origin of weaknesses - based on the responses of the interviewees -, of the seven functions of the innovation system in the milk sector (Table 1). This step was essential for identifying systemic problems that fuel the weakness of functions, but also of the innovation system as a whole. After identifying the systemic problems that block the functions of the IS, we then identified strategies and tools, also called "systemic instruments" (Wieczorek and Hekkert, 2012), that can improve the functioning of the innovation system (Table 2).

3.3. *Data sources*

Several sources of information were used in this study: a review of the literature (research work on studies conducted in the region, reports and government policy documents), focus groups, and interviews of different actors in the sector. This study took a qualitative approach. As is common in AIS diagnostic work, semi-structured interviews were used (Turner *et al.*, 2016). To be representative, we have interviewed as many actors in the sector as possible. In all, 25 interviews lasted 3 weeks during December 2020 (9 dairy farmers, 4 dairies, presidents of associations, 5 fodder producers, 4 administrations, 2 veterinarians, and 1 livestock feed factories). Interviewees were selected based on their reputation in the region and their experience/knowledge about the sector. For representativeness purposes, we also consider the size of herd. In addition to interviews, a focus group with 6 dairy farmers was carried out over the same period. Participants were asked about their views on key issues associated with major livestock development programs, structural elements, systemic issues and functions of the dairy innovation system in the study area.

Figure 2 - Timeline representing the main policies and events that shaped the innovation system in the Ghardaïa dairy sector.



4. Results and discussion

F1. Entrepreneurship

Presence of investors taking economic initiatives

The interviews conducted revealed a growing interest in dairy cattle farming. There is, however, a historical dimension associated with this interest in livestock farming. Indeed, this activity builds on the traditional breeding knowledge of the region's inhabitants known by their tradition for goat breeding, but also by the logic of entrepreneurship to learn new ways of doing and valuing. Aware of the difficulty of rearing cattle in such an arid climate, investors in

Table 2 - Systemic failures in the Algerian dairy sector.

System functions	*Structural elements*	*Type of Failure*	*Systemic failure*	*Suggested systemic instrument*
F1. Entrepreneurship	Interaction	Quality	Power asymmetry between dairies and dairy farmers	Encourage associative work and the creation of cooperatives for countering dairy lobbying
	Infrastructures	Presence	Difficulties in access to land, water, energy and fodder resources	Facilitate administrative procedures for land and water access
F2. Knowledge development	Infrastructures	Quality	Low search capacity	Research funding
	Institutions	Quality	Lack of formal mechanisms for the valorization of research	Cross-sector pooled projects and problem identification
	Interaction	Presence	Fragmentation and non-integrated knowledge development	Strengthening of coordination and collaboration, cooperative research programs
F3. Knowledge dissemination	Interaction	Presence	Lack of intermediary organization between research and the field	Strengthening of research-advisers coordination
	Infrastructures	Presence	Lack of stat support to foster interactions for knowledge development and dissemination	Support for knowledge exchange, bridging instruments
	Infrastructures	Presence	Lack of space for sharing information	Creation of spaces and platforms for the exchange of information
F4. Guidance of search	Actors	Capability	Imbalance of power and lack of participatory process to produce agricultural policies adapted to local specificities	Formation of coalitions to defend the interests of dairy farmers, roadmap for the sector
F5. Market formation	Actors	Capability	Small dairy farmers remain at the mercy of the local dairies	Creation of cooperatives to reduce socio-economic differentiation between dairy farmers
	Infrastructures	Quality	Rudimentary roads and non-existence of railways to connect the South to the North	Investing in infrastructure for a better connection between regions
F6. Resource mobilization	Actors	Capability	Multiplication of middlemen taking advantage of the new fodder resource sector developed locally	Regulation and organization of the fodder market
	Infrastructures	Presence	Lack of public funding dedicated to investment in infrastructures	Loans and subsidies
F7. Creation of legitimacy	Actors	Capability	Competition between farmers and dairies	Formation of coalitions to defend the interests of dairy farmers
	Institutions	Intensity	Overrun of certain clauses in dairy farmer contracts	Regulation
	Interaction	Presence	Absence of professional organizations	Articulation of legislations for the creation of cooperatives

the region, who are considered pioneers in the sector, have taken risks by introducing modern dairy caws since the late 90s and have proven that it is possible to be competitive. Since then, cattle farming of improved breeds (mainly Holstein and Montbéliarde) has begun to spread to several regions of the wilaya by importing in-calf heifers.

The success of the pioneers in this new economic initiative inspired other farmers to invest in cattle farming, sometimes to the detriment of goat farming or vegetable crops. The expansion of farms over this period allowed the restructuring of other activities dependent on livestock breeding. In that way, small raw milk sale units or creameries have been transformed and equipped with new technologies to become dairies and offer a variety of products. A new agri-food industry has also been created locally and offers processing services. In even more extreme conditions towards the South of the wilaya, new and more sophisticated farms have also developed dairy cow breeding in addition to sheep, goat, camel and equine farming. This has been encouraged by agricultural land development programs, which have made it possible to transform, to date in the wilaya of Ghardaïa, 58,500 hectares of Saharan land (DSA, 2020). These farms (certainly few in number but in some cases reaching 300 head), which are not handicapped by access to land, differ from those in the North of the wilaya by their investment in other crops, such as fodder production, but also fruit trees and date palm cultivation. They thus have more autonomy in the management of their farms and experiment with new opportunities through the development of new strategies, such as ecotourism to add value to the products of the farm. The presence of a strong entrepreneurial base described in this study is a signal of the health of an innovation system, as described by Hekkert *et al.* (2007). Indeed, as for Menary *et al.* (2019), this entrepreneurship logic makes it possible, on the one hand, to supply the market with new products and, on the other hand, it allows the arrival and the integration of newcomers into the system.

Power asymmetries between farmers and dairies but emergence of informal arrangements

Interviews with dairy farmers and local administrations revealed that dairies, especially local ones, put pressure on small dairy farmers. The latter testify that "dairies abuse their power and exert lobbying on the sector". This strong sign of authority shows the structural imbalance of power between the actors in the sector (Table 2). Indeed, the respondents revealed, for example, that milk selling prices are set by dairies instead of being negotiated with farmers who do not have this bargaining power. As Menary *et al*. (2019) argued, these power asymmetries between actors, especially when it comes to setting prices, generate a repositioning on the "defensive", blocking any innovative initiative by dairy farmers. New forms of value chain governance are needed to mitigate the adversarial attitude between dairy farmers and dairies. Agricultural cooperatives are an example that make for improved competitiveness (Deininger, 1995; Msaddak *et al.*, 2019).

Furthermore, new institutional arrangements have been developed to manage the different asymmetries and adapt to the production and marketing environment, which is especially restrictive for some small dairy farmers. Indeed, the opening up of the market and the arrival of large dairies (Soummam in 2017 and Danone in 2018) from the North (Figure 2) – whose negotiation to integrate the local market has been initiated by some pioneer dairy farmers, which later constituted the interprofessional council (F4) – has made it possible to redistribute power between the different actors. This was a very important event for redressing dairy farming, which was on the verge of being halted. Even more, liberalization of the market from the control of local dairies has motivated farmers to invest more in livestock and produce more. As these large dairies offered interest-free credit to dairy farmers for the acquisition of modern breeding equipment (milking parlors, storage tanks) and heifers, they quickly became locally popular and attracted new farmers, and thus imposed competitive rules-of-the-game on local dairies. The repayment is made either by deducting from the milk sales or in cash.

To further encourage farmers to enter the milk market, these large dairies initiated several methods of granting credit to dairy farmers, either by subtraction from the milk produced, or in cash over a period determined beforehand. Another advantage was the State subsidy distributed through dairies, paid to farmers monthly (they anticipate the payment with their own funds, even if the State delays paying subsidies to them) so that there is a constant flow of income, whereas with local dairies several months of delay could be recorded. Other subsidy mechanisms in favor of better quality milk have been adopted by one of these companies. Its strategy targets the largest farms (3 farms in the entire wilaya, with more than 200 head of cattle each) and provides, on the one hand, a competitive advantage to large farms (farmers producing milk containing a fat content over 32% receive a bonus of 2 Dzd additional to the selling price of milk) and on the other hand, it avoids fraud because quality control (traceability) is easier when the number of farmers is reduced. Indeed, milk quality can be altered by the addition of water or other substances, which can cause losses for dairies.

F2. Knowledge development

In terms of developing new knowledge, interviews showed that this function is largely satisfied and therefore contributes to the proper functioning of the innovation system in the study region. Indeed, several decades of knowledge building and sharing by and between farmers have been a key element in encouraging dairy cattle farming. In addition, the new knowledge acquired through their experience comes to support and adapt the livestock systems to the specificities of the area. However, several systemic problems have been identified.

Fragmentation and non-integrated knowledge development

The main problem in relation to research and knowledge development highlighted by the respondents was the weak interaction within research organizations, but also with other actors in the sector (dairy farmers, extension agents, industrialists, etc.). This includes the fact that research is usually conducted in disciplinary silos, which prevents the joint development of new knowledge across disciplinary boundaries. Therefore, there is little possibility of generating solutions that meet needs in the field, leading to incompatibility between the type of knowledge developed and that requested. Indeed, the development of actionable knowledge is not based on bottom-up approaches, seeking to value and disseminate local solutions informed by knowledge specific to dairy farmers.

Vertical fragmentation is another major systemic problem hindering the development of knowledge in the dairy sector in Ghardaïa and is considered by several authors to be a barrier to innovation in different regions of the world (Lamprinopoulou *et al.*, 2014; Turner *et al.*, 2016; Menary *et al.*, 2019). This fragmentation resulting from a lack of coordination between research and development projects leads to duplication of studies (Sutherland *et al.*, 2013). Although partnership agreements and arrangements exist between different research institutions, there is a glaring gap in terms of responsible involvement of the various stakeholders in research and development. The respondents testified, for example, to the limited involvement of universities and their mitigated research results often remain at the diagnostic stage without being passed on to dairy farmers. Better coordination between the different actors to strengthen the links between them is one solution for overcoming the vertical fragmentation that exacerbates heterogeneous innovation agendas. Turner *et al*. (2016) suggested "consensus development conferences", which are ways of bringing together farmers, decision-makers and experts to address common issues for strengthening the functions of the innovation system.

Institutional problems hindering the development of knowledge

Although the rise of private farm advisory services (which was traditionally dominated by State advisory services) has led to the spread and the development of extensive knowledge related to livestock management, some challenges remain. For example, dairy farmers explained that

private advisers are represented mainly by veterinarians, which means that the issues addressed concern mainly animal health, leading to a lack of advice and therefore limited knowledge, particularly in the field of food rationing and technical management.

Another systemic problem, in relation to the development/dissemination of knowledge, is the lack of formal mechanisms for "research translation", which means that little is made of the research carried out. Indeed, the interviews showed that there is no link between research institutes and universities and agricultural extension and advisory services. This is due to the inability of researchers to translate the results of their research into simple and practical language, understandable by this target audience. As a result, unless there are skilled facilitators acting as translators, the language barrier between researchers and agri-food companies/farmers cannot be overcome (Lamprinopoulou *et al.*, 2014). Improving academic incentive structures may therefore stimulate and reward translational activity.

F3. Knowledge dissemination

Unequal access to information and lack of knowledge

The interviews conducted showed that there are several infrastructures that facilitate farmers' access to knowledge. In the study area, advisory services are delivered either by public organizations (represented by the DSA, the chamber of agriculture of Ghardaïa, etc.) or by private advisers (mainly veterinarians, agents related to dairies, and advice between dairy farmers). The surveys revealed that some actors in the sector, such as dairy farmer organizations, play a very active role in disseminating knowledge, such as the transfer of technical and market information, and therefore play an important role in the innovation system. In contrast, the gradual privatization of extension services has led to asymmetry in access to knowledge and most smallholders, who lack the financial capacity to hire such services, have been left out. The geographical nature characterized by isolated areas, the fragmented location of livestock farms, and the difficulty of access to means of communication (GSM network, Internet) are factors blocking the dissemination of information and knowledge.

The dairy farmers interviewed stated that the advisor's lack of up-to-date and effective knowledge on certain aspects is the main weakness. This was verified in the field as it was found that most efforts to improve livestock productivity, especially in relation to the local environment, have been based on technological progress (including the modernization of livestock equipment) rather than on improving farmers' knowledge on, for example, livestock management, organization, and cattle feeding. This last aspect is poorly managed in the region.

Absence of infrastructure

With regard to infrastructure, dairy farmers pointed out the absence of spaces to exchange experiences and knowledge. To address this issue, one of the dairy farmers had even undertaken the construction of a large room to serve as a space for exchanges between farmers, as well as to host organizational meetings, but also all scientific collaboration initiatives. There is an effort being made by dairy farmers who wish to organize themselves into cooperatives, considered the only possible way to protect themselves from the market and to gain access to certain common infrastructures, to facilitate milk collection, for example. This initiative is also planned to reabsorb certain inequalities in access to infrastructure and to production factors.

F4. Guidance of the search

Political instrument not adapted to the southern dairy farmers

One of the main systemic problems affecting search guidance is vertical fragmentation. This refers to the lack of a participatory process to produce agricultural policies adapted to local specificities, especially those from the South. In fact, the political instruments developed to support this sector have been designed for the northern plains, where the dairy farmers have

more autonomy in the management of their herds, through the production of fodder or by resorting to the practice of grazing. However, in the South of the country, breeding practices are soilless (the number of farms producing their own fodder is very small), which implies even higher production costs. The performance of the dairy milk sector in such regions therefore depends on several actors, even other sectors, such as the essential fodder sector, the lifeblood of the milk sector in the South. According to Turner *et al.* (2016), vertical fragmentation is a recurring problem in sectors characterized by a large number of stakeholders and/or products. In our case, the milk sector is characterized by a variety of activities (livestock, agri-food industry, fodder crops) and a multitude of actors, where each of them seeks to achieve an individual objective. In addition, the balance of power exerted by the dairies (dairy farmers' voices are not heard) means that "the guidance of search activities" is balanced in favor of the latter. However, since 2017, actions carried out by a group of farmers forming the interprofessional council (Figure 2) have come with its share of innovations, by placing the dairy farmer in the dialogue, thus refocusing the debate on common objectives. The latter is made up of breeders and a representative of the other actors of the milk sector (administrations, dairies, fodder producers, etc.). It is also a negotiation platform which invites political decision-makers to reconsider their interventions through the production of policies specific to this region. They pointed out the need to involve multiple actors in processes of reflection and self-governance, by providing sufficient platforms for interaction and spaces for experimentation, monitoring and learning, which then act as the so-called 'systemic instruments' improving overall innovation system interaction (Wieczorek and Hekkert, 2012).

F5. Market formation

Arrival of new stakeholders responsible for unlocking the market

Given the market-related factors, the creation of a competitive environment, improved milk collection and an increase in the capacity to absorb milk production are the main changes that influence market development. This is in line with Khadse *et al.* (2018) and Mier Y Terán Giménez Cacho *et al.* (2018), who showed that local market development favorable to producers is necessary to further AIS. In our surveys, respondents reported that for several years (2011 to 2016), local dairies had a monopoly on dairy farmers. Indeed, over that period, the price of milk was set by local dairies at 40 Dzd/liter. This price became disabling for farmers, who found it hard to manage, especially with constantly rising input prices. In addition, while the law stipulated that, in the milk process, dairies must supply farmers with wrapped fodder, they did not respect this part of the farmer-dairy contract. It is in response to this restrictive situation for dairy farmers that the interprofessional council was created. The latter has become a key player for the milk sector in Ghardaïa and has made it possible to reposition the farmer as a real player in the sector and has allowed debate between the different actors in the value chain. Consequently, milk prices rose to 45 in 2017, and to 48 in 2022. This increase in milk price encouraged dairy farmers to produce more and to increase the size of their herd.

Institutions supportive to market development

The interest shown in dairy farming by the local population, due to the institutional changes in the 2000s, gradually encouraged the establishment of dairies, which in turn transformed the existing livestock system in the region. Indeed, as a result of greater demand and the facility to sell the raw milk produced, the expansion of dairies motivated farmers to expand their herds. The 2000s were also characterized by changes in market structure, in the supply of dairy products, and in the technology used in the manufacturing process. Before the 2000s, milk and derivatives (butter, "*Kemaria*" which is a traditional cheese presumed to be a local product, etc.) were sold directly on the farm or in creameries. However, from 1996 – corresponding to the prohibition of milk sales outside the collection circuit (Figure 2) –, milk had to pass through collectors and then

through dairies before reaching the consumer. These dairies diversified the supply of dairy products to consumers, inducing greater demand for raw milk. This strategy allowed dairies to add value to raw milk by processing it into a variety of dairy products and thus obtain a higher margin. New milk processing and packaging technologies, in particular pasteurization and packaging in plastic bags, also helped to conquer new markets in the neighboring wilayas.

Dairy farmers faced with poor infrastructures

In recent years, strengthening of the physical structure and the establishment of an industry in the region not only benefited the wilaya of Ghardaïa, it also facilitated the supply of milk and other dairy products to southern wilayas (such as Ouargla and Tamenrasset, 200 and 1000 km away from Ghardaïa, respectively). In addition, significant investments in road construction by the public authorities have contributed to the opening up of the southern regions of the country. However, these developments only involved major roads and some rural areas in the study area remain isolated due to poor road quality. Dairies do not provide collection for farmers in these landlocked areas. The latter cover the cost of transport to the dairy themselves, without even receiving the collection bonus which is grabbed by the dairies.

F6. Resource mobilization

State subsidies to support milk production

Economic instruments applied by the State include subsidies for the benefit of all actors of the sector (dairy farmers, collectors, and dairies). Since 1995, the State has gradually introduced a mechanism of subsidies (for production, artificial insemination, collection, packaging, and feeding of livestock) in order to encourage dairy farmers and other operators to invest more, as well as to increase the volume of milk produced and collected. First of all, after fixing the market price – by the dairies –, the latter is corrected a posteriori by the public authorities by granting subsidies. A production bonus of 6 Dzd for each liter of milk produced by dairy farmers was introduced in 1995 and increased to 12 Da/liter in 2009 (Figure 2). These subsidies per unit of milk produced are paid to farmers to protect their incomes. Obtaining this subsidy is, however, governed by integration within the collection circuit and restrictions are applied to the direct sale of raw milk outside the formal circuit. An agreement is then signed between dairy farmers and dairies in the presence of local authorities – the DSA.[1] However, farmers denounce the fact that subsidies have not changed since 2009, while input prices (especially for livestock feed) have doubled since then. The latter suggest to find financial incentives in favor of breeders. One of them is to find a formula that enables the transfer of subsidies from imported milk to milk produced locally. Since 2016, a health bonus of 2 Dzd/liter has been added to the production bonus. This is subject to obtaining sanitary approval delivered by the DSA veterinary services. In addition, collectors (whether dairy farmers, independent collectors, or dairies) receive a bonus of 5 Dzd for each liter of raw milk collected. Finally, industrialists receive 6 Dzd if only cow's milk is used, and 4 Dzd/liter if the dairy incorporates imported milk powder.

Lack of formal public funding dedicated to investment in infrastructures

During the interviews, correspondents indicated that the mobilization of resources is deficient when it comes to financial and human aspects. Certainly, the government offers bonuses for the different actors in the sector (detailed in F1), as well as facilitating access to water and land through development programs. However, it has been observed that investment in livestock is expensive (cost of the stable, cows, livestock equipment, and inputs). Given their religious beliefs, people in Ghardaïa ban all banking transactions with interest rates, because these practices are prohibited under Islam. However, no

[1] Abbreviation for: Directorate of Agricultural Services.

specific financial instruments, such as Islamic bank loans, are available from public financial institutions. In the field, livestock investments and development projects have mainly been made by entrepreneurs themselves and have not been supported by the public authorities. It is for this reason that dairy farmers who want to start, invest in, or expand their livestock farming, take out informal loans, often in the family circle, to finance their investments (also explained in F1). This ability to invest is also nourished by the pluri-activity of the farms. Indeed, in many cases, livestock farming is only one activity among a diversity of activities in the study region, especially trading.

Lack of local manpower

The lack of labor in the region is also a systemic problem in relation to infrastructure. Indeed, there is a common concern about the availability of skilled labor at local level. According to the testimony of one farmer "For a long time, the local population has been weakly involved in agriculture and prefers trade-related activities because they are more lucrative". In recent years, labor needs in agricultural activities in general and, in livestock in particular, have been met by migrants from sub-Saharan African countries.

Disruption of the input market

Another systemic problem concerns institutions and arises from input market disorganization, and more particularly related to wrapped fodder. For several years, the supply of wrapped fodder was provided by dairies. However, after a failure of the government to pay subsidies to the dairies during the Covid-19 pandemic in 2020, the latter were forced to stop provisioning dairy farmers. Currently, this market is controlled by speculators, operating informally, who play the role of middlemen between farmers and wrapped fodder producers. Dairy farmers who cannot buy a sufficient amount of wrapped fodder for the whole year from fodder producers are therefore forced to buy it from these middlemen. The latter have taken advantage of the situation to sell the product at higher prices, but they at least offer the possibility of deferring payment over several months.

F7. Creation of legitimacy

Since the 90s, and with a view to encouraging local production of raw milk in order to reduce imports of milk powder, top-down actions through State policies, including subsidies and programs for access to water and land (APFA particularly), have played an important role in creating the legitimacy of livestock in the Saharan regions and particularly in Ghardaïa. This legitimacy has been reinforced by the desire to create new work opportunities in this arid area traditionally known for its date palm oases. However, this operation is open to criticism because of its poor ability to consider the specificities and realities of the field. In fact, the question of sustainability in these production systems depending on fossil water resources remains. In addition, the respondents identified the resistance of dairies to the policy of the State, with their lobbying in this sector, as the main problem that hinders the creation of legitimacy. Indeed, historically, in addition to imposing milk prices in their favor, these dairies have opposed the arrival of other industrialists from the North, hence the creation of new markets. This lobbying was also reflected in the non-application of certain clauses of the farmer-dairy contract, mainly related to the supply of wrapped fodder (explained in F5).

5. Conclusion

The analysis of IS functioning in the dairy livestock sector in Ghardaïa enabled us to identify factors favorable to IS, as well as systemic problems hindering them. The results showed how structural weaknesses have hampered the development of innovation system functions, such as entrepreneurship, knowledge dissemination, market formation and legitimacy creation. The results also showed that these blockages are most often interconnected and impact several IS functions. As a result, a weakness in one of the functions of the innovation system would in turn have a ripple effect on other functions, leading to a dysfunctional innovation system as a whole. In addition, understanding the origin of weaknesses in innovation system functions has con-

tributed to suggesting interventions for the problems encountered. These suggested systemic instruments can improve coordination between different functions and stimulate co-innovation, as well as improving institutional incentives, the capacities of actors and their interactions.

Overall, the factors that stimulate or facilitate innovation include the State's programs and policies in favor of the actors in the sector, the presence of entrepreneurs and their ability to undertake, as well as the commitment of livestock farmers, via the interprofessional council, to balance the power relationships between actors. Indeed, the latter has been key to unlocking the market through the arrival of new agri-food companies that have created a climate of competition with local dairies and has increased the demand for raw milk. In contrast, the factors that hinder innovation involve, firstly, lobbying by the dairies and the asymmetry of power between dairy farmers and industrialists, the lack of collaboration and interaction between actors, worsened by the lack of infrastructure for knowledge sharing and the lack of formal institutions in favor of it, fragmentation and lack of coordination in the development of knowledge, and the lack of formal financing mechanisms to invest in livestock.

Despite all these systemic problems, the number of head of cattle and the amount of milk collected continue to increase in Ghardaïa. Indeed, in addition to the positive points identified, made possible through several adaptations and changes in the region in recent decades, we can mention the gradual abandonment of water-intensive crops (such as horticulture and arboriculture previously part of the "three-story" production system of the old palm groves) in favor of livestock (which requires less water at farm level), the development of cereal and fodder crops in the more southern regions of the wilaya through access to new water sources and the development of new agricultural land, along with contracts and informal arrangements between actors to finance livestock or to purchase inputs. However, this development of livestock farming is taking place to the detriment of the old oasis production systems based on date palm cultivation, which applies principles of sustainable resource management, such as the circularity of water, practiced for hundreds of years. It is therefore logical that the question of the sustainability of these production systems, based on individual access to a water resource, which is to a large extent not renewable, needs to be raised in the long-term. Indeed, although dairy cattle farming has allowed these farmers to adapt to the new conditions of water scarcity on their scale, it consumes a lot of water on a larger scale, because it remains highly dependent on fodder crops, which are very demanding in terms of water. Further research is therefore needed in this direction to determine the viability of this new form of agriculture in the Saharan regions.

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