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A typology of smallholder livestock production systems reflecting the impact of the development of a local milk collection industry: Case study of Fatick region, Senegal

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Abstract

Senegal is a country where millions of livelihoods directly depend on smallholder livestock production activities. Unfortunately, these farmers now face the effects of a changing climate and associated societal responses. In addition, the lack of understanding of the specific farmers' problems in their respective production systems by assuming homogeneity has led to inappropriate planning of interventions and inefficient utilization of resources. The variations in individual farming systems and local contexts require to understand each system separately to inform decision-makers and relevant stakeholders about specific entries of intervention for farmers based on customized needs. Using a Fatick region case study, different statistical clustering techniques were adopted to develop a livestock typology that reflects the above realities. This typology confirmed the co-existence of three livestock production cluster systems with differences and similarities in their production targets and quantities, market access, animal breeds, and the livestock management system of the animals. The studied region represented a new format of smallholder livestock development, where the implementation of a dairy processor and its milk collection centre created a new dynamic in production activities. Farmers confirmed that the extension services and a consistent market opportunity provided by the dairy processor increased local productivity and offered an alternative source of income but they have also reiterated concerns like the dairy processor's low milk buying prices which need to be addressed. To harness the growth and the regional opportunities, there is a need to establish robust and continuous collaboration structures between the Government, agro-industries, and producers. These public-private partnerships will help producers lower the cost of inputs and services and increase productivity while boosting local dairy production.

Keywords: Extension services, Milk collection centre, Market opportunities, Farmer clusters

Introduction

Senegal is one of the countries in the Sahel region whose economy is mainly based on the agricultural sector. Livestock farming is practised by 29.5% of Senegalese households (Beye et al. 2019). In 2016, the herd in Senegal was estimated to include about 3,541 million cattle, 6,678 million sheep, and 5,704 million goats

(ANSD 2016). Livestock farming contributes to household food and nutrition security and occupies nearly 60% of agricultural households (ANSD 2016), giving it vital economic and social importance. Consequently, livestock farming holds an appreciable place in the Senegalese economy with a contribution of 27.4% to the GDP of the primary sector and 4.2% to the national GDP (ANSD 2016). It is one of the fastest growing segments of the agricultural economy, fueled by rising incomes and technological and structural developments (Diallo 2015). Fatick is one of the regions in Senegal where

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livestock farming is particularly important. Unfortunately, according to recent data from the National Agency of Statistics and Demographics, Fatick region remains amongst the poorest in the country with a 67.8% poverty index (ANSD 2019), calling for urgent intervention from the Government and partners. There have been efforts from the government to enhance milk production in the region, including the support of the implementation of a milk collection centre by a dairy processor, Kirene Dairy. The latter is part of Kirene group, an agro-industrial company created in 2001 in Diass (Thiès region), 40 km south-east of Dakar. While originally specialized in the manufacture of mineral water, it launched the production of UHT sterilized milk in 2005. Its processing capacity is 10,000 L of milk per day. Since 2014, Kirene Dairy has also established a milk collection centre in Fatick region to facilitate milk collection activities. For the rest of the manuscript, Kirene Dairy will be referred to as the “dairy processor” in order to reflect their role and not just the name.

Livestock farming systems in sub-Saharan Africa and generally in humid tropics exist across a wide range of cultures and landscapes, and over time, these differences in drivers and in farm features lead to temporal and spatial variability between and within farming systems. The contextual differences in social, institutional, and biophysical realms result in different responses of farmers and communities between and within areas. Traditionally, farmers in West Africa own cattle for various purposes including milk, meat, draft animal power, milk and meat transformation activities, belongingness to specific ethnic groups, and so forth (Somda et al. 2004). As such, the farming systems are highly heterogeneous in many characteristics such as farming households' land access, cropping, livestock breeds and assets, off-farm activities, socio-cultural traits, access to markets, and livelihood orientations amongst other things (Chatellier 2019; Camara 2013; Buhl and Homewood 2000; Somda et al. 2004). The existing farming system variability is challenging to fully comprehend, leading to partial representation of reality and inefficient interventions in project planning and implementation.

The milk collection efforts by the dairy processors have brought about a new dynamic for livestock development through the specialization and intensification of milk production amongst farmers in Fatick. Indeed, the dairy processor has put in place a milk collection centre equipped with the required infrastructures (tanks, basic quality test tools, moto-bicycles, etc.) to facilitate the milk collection in many areas of Fatick region. Furthermore, it has also established a model whereby producers are subsidized with a package of inputs including animal feed, veterinary services, and training on animal husbandry practices. The presence of dairy processors and

the development of the milk industry are one of the best motivation for farmers to diversify and invest in dairying as they offer a safe and profitable market outlet; however, the success of these initiatives demand the active participation of farmers, and they require public investment or a public-private partnership (Lemaire et al. 2019; Henriksen 2009). In 2018, 110 producers delivered milk to the dairy, though more than 500 producers have been identified in the Fatick milk collection basin (Kirene 2019). In the same year, the dairy processor collected its highest volume of milk in January (6,435 L) and its lowest volume in July (3,189 L) (Kirene 2019). The present study was conducted in the Fatick milk collection basin, where all the existing production systems in the region are represented. Previous research studies in the region have focused on the characteristics, challenges, and opportunities of pastoralists who have traditionally been predominant in Senegal and in the study area (Manoli et al. 2014; Adriansen 2008; Turner et al. 2016; Kitchell et al. 2014; Boesen et al. 2014; Salmon et al. 2018). Very few studies have looked at the new dynamism of smallholder livestock production systems in Senegal (Corniaux et al. 2012; Napoléone et al. 2015), and no single study has explored this new aspect in Fatick region. In the same vein, a review of the literature (Robinson et al. 2011; Otte and Chilonda 2002; Ruthenberg et al. 1980; Dugué et al. 2004, Dassou et al. 2017) suggests few attempts to create specific typologies of livestock production systems at a national level. Our study will propose a typology and tailor-made recommendations considering these recent changes in Fatick region across the different livestock production systems, which will eventually help in effective and efficient planning and implementation of projects in livestock production system development.

Despite the invaluable contribution of the livestock sector to the economies of both Senegal and Fatick region, recent years have shown a decline in production activities as the sector is confronted with many challenges. Feed scarcity, prolonged drought, soil salinization, natural resource degradation, water scarcity, and associated societal problems are the most common challenges to livestock producers in Fatick region (Dieng et al. 2014; Zougmore et al. 2016). The pressure and consequences of these problems are not felt the same way across different production systems, and thus, to overcome these challenges, it is key to understand each livestock production system separately and propose targeted solutions based on the differences, opportunities, and challenges presented by each system. There is no doubt that the needs and urgencies for farmers vary in their respective production systems, and therefore, customized interventions tailored to specific needs and potentials presented by each farming system would foster efficient utilization of resources, help in avoiding

duplication of efforts, and respond to direct farmers' need and the production system as a whole. Recognizing and understanding variability within and amongst farms and across localities is the first step in the design of policies to help poor farmers and a key one with regard to the adoptability and performance of new technologies proposed to improve agricultural production (Tittonnell et al. 2010) and that is where typology comes into play. Furthermore, this insight would help policy-makers and other relevant stakeholders to create solutions that are economically viable (by targeting the right people with the right inputs) and positively change the livelihoods of producers, while minimizing the impact to resources depended on for survival.

The objective of this study is to develop a typology that will characterize the current livestock production systems in Fatick, while highlighting the new dynamic of smallholder animal production from the establishment of a local dairy industry in the region. This study departs from two hypotheses: (i) there is a broad range of smallholder livestock producers that may be clustered in subgroups sharing common traits (e.g. size of the herd, type of management practices, etc.), challenges (e.g. access to markets, animal feed price, access to water and land, etc.), and opportunities (e.g. closeness to markets and other extension services, productive species, locally adapted species, etc.); (ii) since 2015, the establishment of a dairy processor and its milk collection centre has brought a new dynamic which could enhance smallholder livestock production activities in the area (e.g. possibilities of veterinary and other extension services, milk collection industry, market, diversification of livestock products including milk, milk products, etc.). This study adopts a data-driven approach whereby routine husbandry practices of farmers were recorded during interviews and analysed to propose a typology that reflects the current dynamics of livestock production systems in the studied area. This will serve to show the differences, similarities, opportunities, and constraints faced by farmers in their respective production clusters across the study area and hence propose recommendations. The developed typology will also serve as a point of entry during intervention planning and provide a focalized scheme for decision-makers and other stakeholders, based on customized needs for each type of farmer.

Methodology

Brief description of the study area

Fatick region corresponds to a part of the former kingdom of Sine. It is located in the western centre of the country between 13° 35 and 14° 00 N latitude and 16° 00 and 17° 00 W longitude (Ndiaye 2006). The region has three departments (Fatick, Foundiougne, Gossas), 10 districts, 35 rural communities, and 2,097 human

settlements including 9 communes and 927 official villages. It is bounded to the east by the Kaolack region, to the west and north-west by the Thies region, to the north by the Diourbel region, and to the south by the Saloum arm of the sea that bathes Foundiougne. Fatick covers an area of 6,685 km² and has a population of 761,713 inhabitants with a population density of 114 inhabitants/km² (ANSD 2019). The climate is of the Sahelo-Sudanese tropical type characterized by 2 seasons: a rainy season from mid-June to October (rainfall ranging from 400 to 600 mm/year), a dry season from mid-October to mid-June, and a cool period from November to January (ANSD 2016). Agriculture employs more than 90% of the working population and is the mainstay of regional economic activity. Livestock activities are practised by 70% of the population (ANSD 2019). The production systems in Fatick largely include traditional methods of agriculture and types of livestock; transhumance is increasingly practised by rural agropastoralists, due to the extension of agricultural areas, the shrinking of grazing areas, and the progression of salty land (Robinson et al. 2011). The total number of departmental livestock, all species combined, was estimated in 2018 at 104,741 cattle, 156,234 sheep, 170,052 goats, 119,845 pigs, 18,786 horses, 10,077 donkeys, and 1,092,037 family poultry (ANSD 2019). Unfortunately, Fatick region remains amongst the poorest in the country with a poverty index of 67.8%, compared to 46.7% nationally (ANSD 2019). Difficult access to fodder resources, water, prolonged droughts, and the reduction of pastoral areas due to salinization and encroachment remain the major challenges for livestock smallholders (Zougmore et al. 2016; Dieng et al. 2014). Despite these constraints, livestock production still represents the mainstay of the livelihood of smallholder farmers in Fatick and it represents a big share of the region's economy. Furthermore, the recent initiatives and efforts of developing the milk collection industry and markets have an impact on the future of the livestock production systems in Fatick; all of the above make the study zone an interesting case study to explore and understand how the production systems have changed and what the whole dynamic means to the livestock farmers.

Data collection and handling

From the Regional Livestock Department database, 100 farmers from across the region were randomly selected for interviews and visits were scheduled for every selected interviewee. The researchers used random sampling and the sample was stratified to ensure the inclusion of farmers who still deliver milk, those who have never delivered, and those who stopped delivering milk to the collection centre. Typology is one of the tools that are most often used to capture the variability

of farming systems (Alvarez et al. 2014). Typology is thus that process of artificially stratifying farms into subsets or groups that are relatively homogenous according to specific criteria, e.g. have broadly similar resource bases, enterprise patterns, livelihoods, and constraints (Kuivanen et al. 2016). In research for development projects, typologies are useful to derive the best-fit farm adjustments, improved policies and innovations in order to meet the specific project goals and farmers' needs. First, in order to capture the farming system diversity and to respond to the research question, the researchers made sure to include all 9 sub-regions of Fatick for interviews to ensure the representations of all the existing farming systems (agro-pastoralists, transhumant, and milk specialized producers; Table 1). It is very important to understand that livestock producers in Senegal and specifically in the studied region are ethnically named after their traditional livestock production occupation. For example, "Peuls" (Fulani in other countries of West Africa) are known to be pastoralists by vocation, while "Serer" are agro-pastoralists but these are ethnic appellations and they cannot be used as such to represent farming system types. Second, in order to capture different farmer's situations as it relates to the dynamic brought in the area by the dairy processor, the researchers also ensured the inclusion of farmers who still deliver milk, those who have never delivered, and those who stopped delivering milk to the collection centre (Table 1). Additional interviews were conducted with 3 technical persons at the milk collection centre who oversee the liaison between producers and the dairy processor (i.e. they support milk collection, record keeping, technical aspects, etc.). The additional information provided by these local experts and technicians provides contextual elements to our results specifically regarding the dynamic of the milk collection industry in Fatick region and will be used in our manuscript to support the discussion. Data collection took place from December 2019 to January 2020. Figure 1 and Table 1 respectively show the eight communes where the survey was conducted, and the categories of producers interviewed. These communes cover an area of 1,341.75 km² and straddle the departments of Fatick

and Mbour. They are divided between two urban communes (Fatick and Diakhao) and seven rural communes (Fissel, Diarrère, Patar, Niakhar, Tattaguine, Diouroup, and Mbélacadio). A semi-structured qualitative research method was adopted, wherein the farmers were interviewed to describe their daily farming experience. The survey questionnaire was designed to capture biophysical (e.g. land size, crops, herd size, etc.), socio-economic (included characteristics of the household head (name, age, gender, and marital status), sources of income, land use patterns, use of/access to inputs, food security, livestock system, links and distances to nearby markets, and production orientation, etc.), and managerial aspects (e.g. reproduction techniques, feeding, animal housing, nutrient input use, transhumance, etc.). Like noted by other researchers, that survey approach allows to capture all the components of the farm and their interactions within the farming system they are located in (Alvarez et al. 2014). Farm visits allowed some additional checks, for instance on field area cultivated, tools owned, livestock kept (breeds, number, etc.), and crops grown amongst other things. Prior to conducting the research, the project went through both internal and external ethical approval processes.

In previous literature, smallholder farms have been characterized by demographic data, herd structure and size, facilities and machinery, feeding management, reproductive and milking production, health management, supply of inputs, area under cultivation, usage of fertilizer, and usage of concentrates, markets, prices, and income from livestock activities, etc. (Lowder et al. 2016; Muriuki and Thorpe 2001; Herrero et al. 2014; Swai et al. 2014). Based on precedent and the context of livestock farmers in the studied area, we designed a survey questionnaire to collect information on production activities at different levels. Variables in the questionnaire were both categorical and quantitative in nature and included land use, surface area, use of concentrates and fertilizers, herd size, income, prices, production capacity, reproduction, production diversity, weather adaptation, diseases, feeding, and markets. Missing data

Table 1 Sample description

Category of livestock farmers	Milk delivery to the dairy processor	Number of interviewees
Agro-pastoralist	Delivering	21
	Not delivering	30
Transhumant	Delivering	21
	Not delivering	20
Milk specialized	Delivering	8
	Not delivering	0

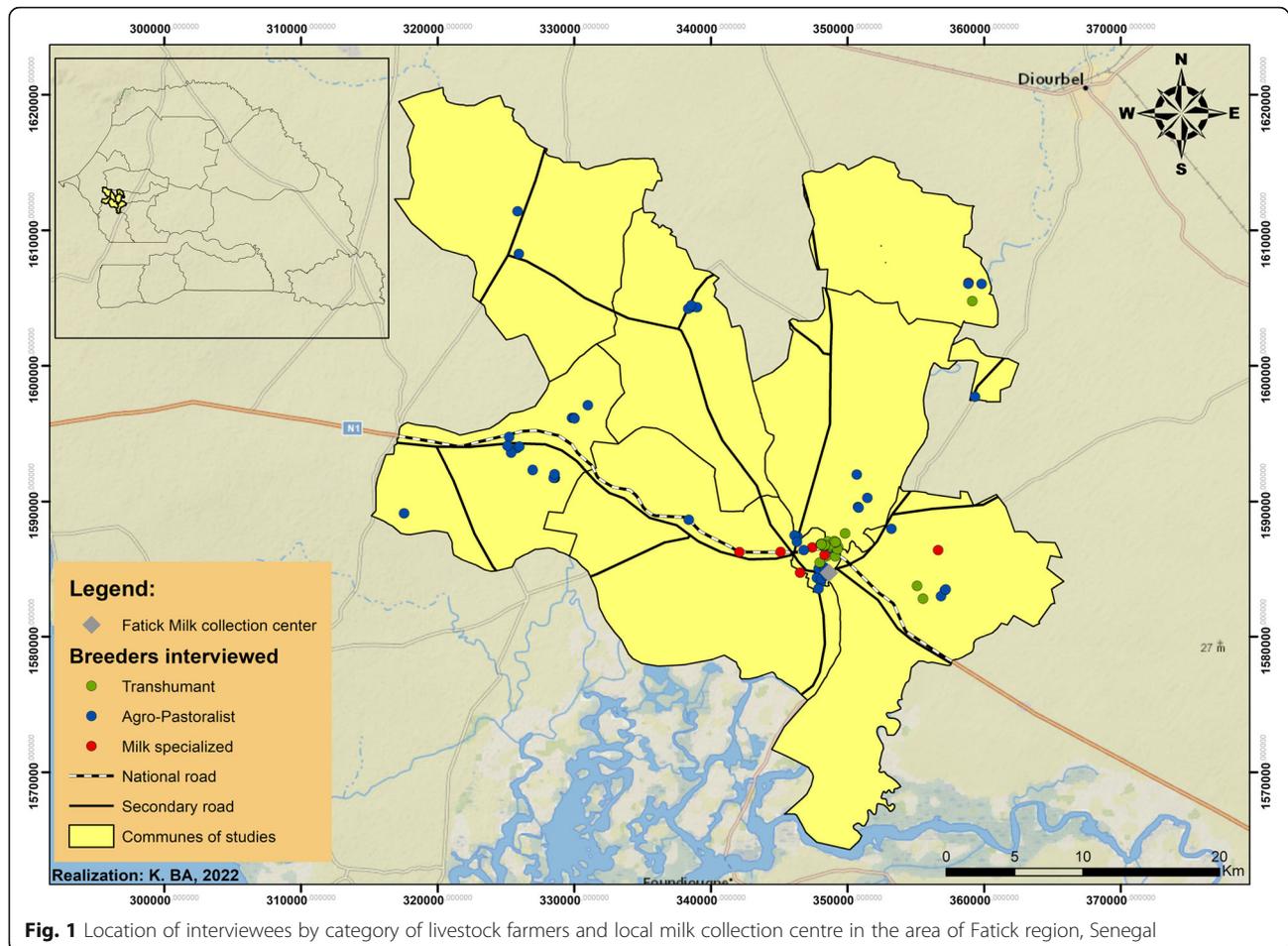


Fig. 1 Location of interviewees by category of livestock farmers and local milk collection centre in the area of Fatick region, Senegal

occurred in questions that were not required to be answered because of answers given on previous questions (for example, if farmers answered “no” for selling milk, they were not asked at how much they sold milk or which quantities, etc.). This was considered a non-applicable condition and missing data in these cases were imputed as “non-applicable”. For categorical answers, non-applicable was considered its own category. For quantitative answers, missing data due to non-applicable condition were found in purchase of fodder or crop residues (mean \pm SD: 119,238.1 \pm 173,486.3 CFA), distance to markets (3.59 \pm 6.54 km), veterinary cost (21,053.2 \pm 18,470.4 CAF), total food cost (505,872.9 \pm 1271691.9 CFA), forage production cost (111,300.0 \pm 150,474.8 CFA), and income all crop activities (368,736.9 \pm 734,893.2 CFA). For these cases, the variables were first binned into three levels based on mean, standard deviation (below average, average, and above average), and the missing data was imputed as “non-applicable”. The average level was considered to be within the range of mean \pm 0.5 times the standard deviation, whereas the below- and above-average levels were lower and greater than this range, respectively.

Statistical analysis

All statistical analyses were carried out using the R software (R Core Team 2019). Multiple factor analysis (MFA), followed by hierarchical and k-means clustering methods, was used in this study. The MFA methodology is appropriate to analyse survey data in which there is only one categorical answer by respondent per question and questions are organized into groups based on the theme they cover (Abdi et al. 2013). However, in our study, we had both categorical and quantitative (i.e. numerical) answers. Therefore, an extension of the MFA, which was developed to accommodate both types of answers (Chavent et al. 2017a), was used in this study. The MFA was carried out using the function MFAMix from the R package PCAmixdata (Chavent et al. 2017b).

The factor loads were extracted from the MFA and used to cluster farmers using the function HCPC from the R package FactoMineR (Le et al. 2008), which was adapted to work on the MFA output from the R package PCAmixdata (Chavent et al. 2017b). First, hierarchical clustering using Ward’s minimum variance method was conducted to establish the number of clusters, which was defined based on inertia gain, and medoids (Borcard

et al. 2018). Both of these parameters were then used in the k-means clustering algorithm (Balijepally et al. 2011) using the Euclidean distance. This two-step clustering approach ensures the reliability and consistency of the cluster solution (Balijepally et al. 2011; Borcard et al. 2018).

Chi-squared ($\alpha < 0.05$) and one-way ANOVA ($\alpha < 0.05$) tests were used to evaluate the association between clusters and categorical and quantitative variables, respectively. A total of 43 variables were found to be statistically different between clusters. Therefore, the ν -test was used to rank the statistically significant variables based on their relevance in describing each cluster. The ν -test indicates the extent to which a variable within each cluster differs from the overall average, in which higher values are associated with greater extent and, therefore, greater relevance (Husson et al. 2017). In this study, we selected the top five categorical and numerical variables with the greatest absolute ν -test value to describe each cluster. This kind of methods allows capturing the complexity of farming systems by considering, at the same time, numerous farm dimensions and then highlighting the ones that explain more the farm diversity (Alvarez et al. 2014).

Results

Result descriptions

A multiple factor analysis of the data showed the existence of 3 farm clusters (i.e. types) amongst the surveyed producers (Fig. 2). This analysis aimed at establishing a data-driven typology of the studied farms based on farmers' everyday practices. Amongst the 43 most significant variables that described differences across farms, 10 variables with the highest ν -test were retained as the

best descriptor for each identified cluster. The sub-set of farmers found in the intersection of clusters and the outliers within the same cluster (example: SN-SOP 54 from cluster 1, SN-SOP 84 from cluster 2, etc.; Fig. 2) suggested similarities in practice amongst farmers from different clusters at one end and differences amongst farmers within the same cluster at the other end. In other words, clusters represent farmers with the most similar practices. Being in the same cluster did not mean that practices are 100% identical amongst producers, and being in different clusters did not mean producers have no similarity in practice.

Cluster 1 was comprised of farmers that used more hours for grazing compared to the overall average grazing hours across producers (cluster 1 vs overall, mean \pm SD: 10.1 ± 2.99 vs 7.55 ± 4.10 h; Table 2). The farms in this cluster displayed the lowest milk production per farm compared to the overall average (3.75 ± 3.30 vs 8.22 ± 7.94 L). The quantity of milk sold by farmers in cluster 1 was 5 times below the overall average (1.3 ± 2.05 vs 5.26 ± 7.20 L), while the average price per litre was below the general average (122.06 ± 179.54 vs 289.00 ± 203.81 CFA). The lack of responses to market-related questions was due to the majority of farmers in this group not selling milk. In fact, cluster 1 had 88% of all the farmers who were not selling milk (Table 3). Furthermore, the average rate of cattle infections (number of infected animals per farm per year) in this cluster was higher compared to the general average of the overall sample (5.4 ± 5.96 vs 3.25 ± 4.53). Farms in cluster 1 prioritize agriculture and use animal by-products to promote soil fertility with the use of crop residues and cultivated fodder for animal feeding. These farms had different species of animals, and their practices were generally sedentary.

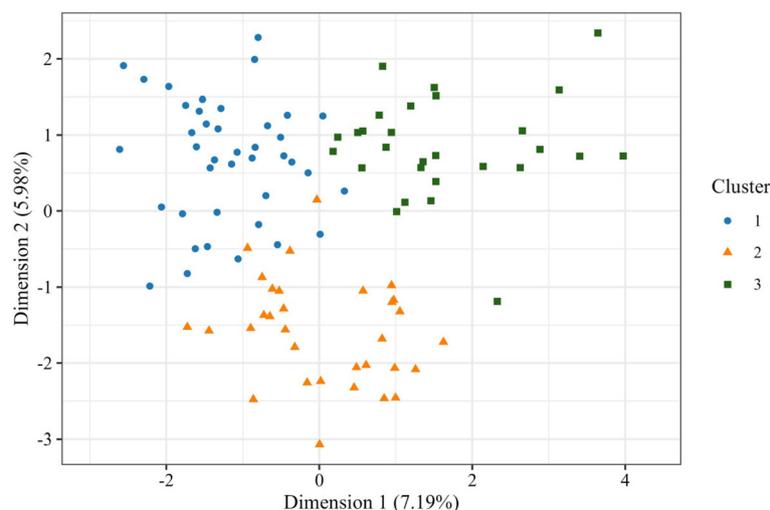


Fig. 2 Biplot in the first two dimensions' plane depicting the 3 clusters of farms. Each point represents a farm and each cluster is depicted by a different shape and colour. Labels indicated the anonymized farm ID

Table 2 Top 5 relevant quantitative variables that best describe the 40 farms from cluster 1. Overall sample = 100 farms

Variable	v-test	Cluster ¹	Overall ²	p-value ³
Milk selling price ⁴ /L	-5.52	150.6 ± 191.91	289.00 ± 203.81	< 0.001
Grazing hours in rainy season	5.00	10.1 ± 2.99	7.55 ± 4.10	< 0.001
Average litres of milk sold/day	-4.48	1.3 ± 2.05	5.26 ± 7.20	< 0.001
Average litres of milk produced/farm/day	-4.34	4.0 ± 3.32	8.22 ± 7.94	< 0.001
Number of infected cattle ⁵	3.87	5.4 ± 5.96	3.25 ± 4.53	< 0.001

¹Mean ± standard deviation on cluster²Mean ± standard deviation on overall data³Overall vs cluster ($\alpha < 0.05$)⁴Average number of infected cattle/year (all diseases included)⁵Average market price regardless of buyer type

Cluster 2 was characterized by farms with land access below the general average (cluster 2 vs overall, mean ± SD: 2.5 ± 2.60 vs 5.2 ± 5.32 ha; Table 4) and thus also had a crop land area 3 times lower than the overall average (0.90 ± 2.33 vs 3.3 ± 4.84 ha; Table 4). In this cluster, 93.8% of farmers resort to transhumance during the dry season. Artificial insemination was low, as the money spent per farmer for artificial insemination was half that of the overall average (5789.47 ± 11,783.48 CFA). The finding that only 13.6% of producers in cluster 2 use fertilizers and crop residues (Table 5) was in accordance with only 3.1% of farmers in this group combining agriculture and livestock. In cluster 2, 87.5% of farmers did not answer these questions regarding crop diversity, suggesting that very few are participating in agricultural activities. This is consistent with the finding that producers in this group had the lowest average area of crop plantations compared to the overall average, again suggesting that many of them are not involved in agricultural activities. Farmers in this group sell milk at higher prices per litre compared to the overall average price of milk per litre across groups (393.4 ± 157.84 vs 289.0 ± 203.81 CFA)

Cluster 3 was characterized by farmers that sell more than 75% of all the milk they produce (cluster 3 vs overall, average ± SD: 15.6 ± 0.64 vs 11.9 ± 10.26 L; Table 6). The average milk produced/day/farm by producers in this

cluster was almost double that of the overall average (15.6 ± 0.64 vs 8.2 ± 7.94 L; Table 5). Farmers in this cluster had cows that produced more milk per day on average than other farmers across the studied clusters (3.80 ± 2.33 vs 2.22 ± 2.27 L). In cluster 3, 67.86% of farms had one or more exotic or cross-bred cow in the herd (Table 7). The average amount of money paid per farmer in this cluster for artificial insemination services was higher than the average amount of money paid by farmers in other clusters (27,803.57 ± 1,206.49 vs 16,715.00 ± 18,134.81 CFA). A sub-set of producers in this group was mixing livestock with agricultural activities. In cluster 3, 50% of producers made income from crop activities and had a greater income from crop activities than the average made by farmers in other clusters. Farmers in this group provided less opportunity for cows to graze compared to the overall average (4.6 ± 4.10 vs 7.5 ± 4.10 h). That finding was congruent with the practice that 67.8% of producers in this cluster mix grazing and indoor housing. In fact, this group of farmers shows low transhumance rates, as only 3.54% of producers reported using transhumance as an option during the dry season.

Discussion

The analyses of surveys conducted with farmers provided crucial information to discuss the opportunities and

Table 3 Top 5 relevant categorical variables that best describe the 40 farms from cluster 1. Overall sample $n = 100$ farms

Variable	v-test	Cla/Mod ¹ (%)	Mod/Cla ² (%)	Overall (%) ³	p-value ⁴
Type of buyers for farmer's products: no answers	6.30	89.3	62.5	28	< 0.001
Farmers reducing concentrate use for environment protection: no	-5.96	14.3	20.0	56	< 0.001
Distance to markets: no answers	5.80	76.3	72.5	38	< 0.001
Selling agreement with buyers: no answers	5.64	88.0	55.0	25	< 0.001
Farmers selling milk: no	5.64	88.0	55.0	25	< 0.001

¹Proportions of farms with that answer in cluster 1 out of the overall number of farms with the same answer (e.g. out of the 28 farms, 89.3% of them gave the "no answer" response to the question "Type of buyers for farmer's products")²Proportions of farms in cluster 1 with that answer out of the number of farms in cluster 1 (e.g. 62.5% of the 40 farms in this cluster gave "no answer" to the question "type of buyers for farmer's products")³Proportions of farms with that answer out of the total number of surveyed farms ($N=100$)⁴Overall vs cluster ($\alpha < 0.05$)

Table 4 Top 5 relevant quantitative variables that best describe the 32 farms from cluster 2. Overall sample $n = 100$ farms

Variable	v-test	Cluster ¹	Overall ²	p-value ³
Total surface occupied by farmers' home (ha)	-4.21	1.3 ± 0.78	2.0 ± 1.13	< 0.001
Cost of artificial insemination (CFA ⁴)	-3.70	6875.0 ± 12546.79	16715.0 ± 18134.81	< 0.001
Total surface of land/farm (ha)	-3.52	2.5 ± 2.60	5.2 ± 5.32	< 0.001
Milk selling price ⁵ /L	3.50	393.4 ± 157.84	289.0 ± 203.81	< 0.001
Crop land area (ha)	-3.35	0.9 ± 2.33	3.3 ± 4.84	< 0.001

¹Mean ± standard deviation on cluster²Mean ± standard deviation on overall data³Overall vs cluster ($\alpha < 0.05$)⁴West African currency⁵Average market price regardless of buyers

challenges encountered by farmers in their respective clusters. The impact of the implementation of a dairy processor and its milk collection centre in Fatick on the dynamic of smallholder livestock production activities has also been discussed in this section using the collected data and the contextual elements provided by the technical persons of the milk collection centre. This section will also discuss the challenges and opportunities presented by different farmer clusters and specific recommendations tied to the need of each cluster will be proposed.

Cluster 1: Agro-pastoralists whose primary activity is agriculture which can be associated with animal breeding in remote areas without proximity to services provided by a dairy processor and its milk collection centre

The strengths of farmers in cluster 1 are found in their mixed production systems. These are diverse production systems with different animal species (cattle, small ruminants, poultry, donkeys, and horses) and crops (subsistence crops, vegetables), which is an important aspect in the context of smallholder income diversification. Furthermore, mixed farming-livestock production systems support the use of organic fertilizers and manure, use of crop residues to feed animals, and reduced overreliance

on the use of industrial feeds and inorganic fertilizers. These are good practices that have proven to be effective not only in land conservation but also in GHG mitigations if used efficiently (Robinson et al. 2011). In contrast, the results also showed that producers of this cluster had the lowest milk production per farm, lowest access to markets, and higher rates of animal diseases compared to farmers from other clusters. Though there could be other factors associated with animal husbandry practices that explain the lowered milk production, it is worth noting that producers of this cluster are agro-pastoralists. While the primary vocation of these producers is agriculture, over the years, they have learnt to take advantage of the co-existence of livestock production and agriculture. In that regard, these producers are known to have small animal herds, and so the limited quantities of milk produced are mostly reserved for household consumption. Furthermore, the position of these farms in deep remote rural areas devoid of infrastructure (i.e. electricity, roads, and cooling facilities) and far from services (i.e. extension advice, markets, and veterinary care offered by the dairy processor or other service providers) may explain the low selling capability and high rate of animal disease found in this cluster.

Table 5 Top 5 relevant categorical variables that best describe the 32 farms from cluster 2. Overall sample $n = 100$ farms

Variable	v-test	Cla/Mod ¹ (%)	Mod/Cla ² (%)	Overall (%) ³	p-value ⁴
Feeding systems: animals mostly in transhumance	8.12	75.6	96.9	41	< 0.001
Drought response: transhumance	7.73	75.0	93.8	40	< 0.001
Crop diversity ⁵ : no answers	7.21	75.7	87.5	37	< 0.001
Farmers applying combination of agriculture and livestock: yes	-7.21	1.9	3.1	53	< 0.001
Use of fertilizers and crop residues: yes	-6.90	7.8	15.6	64	< 0.001

¹Proportions of farms with that answer in cluster 2 out of the overall number of farms with the same answer (e.g. out of the 41 farms, 96.9% of them gave the "animals mostly in transhumance" response to the question "Feeding systems")²Proportions of farms in cluster 1 with that answer out of the number of farmers in cluster 2 (e.g. 96.9% of the 32 farms in this cluster gave "animals mostly in transhumance" response to the question "Feeding systems")³Proportions of farms with that answer out of the total number of surveyed farms ($N = 100$)⁴Overall vs cluster ($\alpha < 0.05$)⁵Most producers in cluster 2 do not practise agriculture. "No answer" means that in most cases they had responded "no" to the previous question that asks whether they do agriculture or not

Table 6 Top 5 relevant quantitative variables that best describe the 28 farms from cluster 3. Overall sample $n = 100$ farms

Variable	<i>t</i> -test	Cluster ¹	Overall ²	<i>p</i> -value ³
Average milk production/farm/day (L)	5.73	15.6 ± 0.64	8.2 ± 7.94	< 0.001
Average litres of milk sold/day	5.71	11.9 ± 10.26	5.3 ± 7.20	< 0.001
Grazing hours rainy season	-4.50	4.6 ± 4.10	7.5 ± 4.10	< 0.001
Average milk production/cow/day (L)	4.29	3.8 ± 2.33	2.2 ± 2.27	< 0.001
Cost of artificial insemination (CFA ⁴)	3.79	27803.6 ± 1206.49	16715.0 ± 18134.81	< 0.001

¹Mean ± standard deviation on cluster²Mean ± standard deviation on overall data³Overall vs cluster ($\alpha < 0.05$)⁴West African currency

Unsurprisingly, this has been a general trend amongst smallholder farmer settings in Senegal (Bernard et al. 2008; Van den Broeck and Maertens 2017) and in the region of West Africa (Atta et al. 2015; Bernard et al. 2008). Similar trends have also been reported by researchers in East Africa (Jayne et al. 2010) and South Africa (Matsane and Oyekale 2014). The dairy processor has been exploring solutions to extend its collection perimeters (i.e. using motor bikes with tanks), due to milk volumes being lower than the maximum capacity, said the liaison persons of the dairy. A group of producers in this cluster who reside in closer proximity have begun to benefit from the market and extension services provided by the dairy processor and its milk collection centre. The dairy processor sets limits on distances for milk collection to avoid milk quality deterioration and thus, farmers who reside further have yet to gain the advantages of the new dynamic brought by the facility. The biggest threat faced by farmers in this cluster is the heavy reliance on rain to support production activities. Unfortunately, Sahel region and Fatick area are zones where rain is limited and highly unpredictable, with prolonged drought and very fragile vegetation cover in addition to high levels of soil salinization (Zougmore et al. 2016). These are serious threats to both milk and agriculture production activities of farmers in this group

and could partially explain the low milk production characterizing this cluster.

Despite the remoteness of producers in this cluster, the dairy processor has shown willingness to collaborate in milk collection but the low milk production has been a discouraging factor for the dairy processor to justify the logistics involved in collecting milk from rural areas. Farmers in this cluster require enhanced support to have stable and functional cooperatives or organizations that could enter into agreements with a third party like Kirene Dairy to facilitate access to inputs and services. Once these collaboration platforms are established and fully operational and by resolving the issues raised by the farmers, the extension and market services and inputs provided by the dairy processor (i.e. animal feeds, veterinary services, loans, etc.) could enhance production for the farmers while helping the dairy processor to meet its processing capacity. Finally, in the mixed production systems characterizing cluster 1, agroforestry practices may also be harnessed to play a role in water conservation and feed production. In addition to serving as animal feed, crops compete with trees to send roots deeper into the soil, and improve not only nutrient cycling but also the storage and retention of rainwater.

Table 7 Top 5 relevant categorical variables that best describe the 28 farms from cluster 3. Overall sample $n = 100$ farms

Variable	<i>t</i> -test	Cla/Mod ¹ (%)	Mod/Cla ² (%)	Overall ³ (%)	<i>p</i> -value ⁴
Income from all crop activities: greater than average	5.37	87.50	50.00	16	< 0.001
Type of farmer: animals mostly in transhumance	-5.06	2.44	3.57	41	< 0.001
Drought response: transhumance	-4.95	2.50	3.57	40	< 0.001
Possession of cross-breed and exotic species: yes	4.76	61.29	67.86	31	< 0.001
Feed system during rainy season: grazing and indoor housing	-4.63	20.88	67.86	91	< 0.001

¹Proportions of farms with that answer in cluster 3 out of the overall number of farms with the same answer (e.g. out of the 16 farms, 50% of them gave the "greater than average" response to the question "income from all crops activities")²Proportions of farms in cluster 3 with that answer out of the number of farmers in cluster 3 (e.g. 50% of the 28 farms in this cluster gave "greater than average" response to the question "income from all crop activities")³Proportions of farms with that answer out of the total number of surveyed farms ($N = 100$)⁴Overall vs cluster ($\alpha < 0.05$)

Cluster 2: Transhumant breeders located in peri- and urban areas whose primary activity is livestock production which can be associated with agriculture and with proximity to services provided by the dairy processor and its milk collection centre

Cluster 2 was mainly composed of farmers who use transhumance as an adaptation strategy to feed animals, due to the scarcity of resources and significant changes in weather conditions in the study area. Transhumance has been increasing in the region mainly due to shrinking of grazing areas at the expense of housing, extension of agricultural areas, and the progression of salty land (Robinson et al. 2011). This group of farmers includes the majority of pastoralists, who consider animals not only a source of saving but also as social status by maintaining their families “legacy as pastoralists”. Hence, the majority of these producers own large animal herds. These farms have a wide range of animal species including cattle, small ruminants, and transportation animals such as donkeys and horses. Producers rely on communal grazing to feed animals through serial movements to regions where weather is favourable for grass. As a result, milk production decreases significantly during the dry months where grazing zones are almost non-existent in the region. This has been observed for pastoralists in West Africa, where producers have been forced to move to areas with greener pastures in the era of climate change as grazing zones progressively degrade (Manoli et al. 2014; Adriansen 2008; Turner et al. 2016; Kitchell et al. 2014; Boesen et al. 2014). Farmers in cluster 2 prioritize milk production and sell milk at higher prices per litre compared to the overall average price across the sample population. This may be attributed to two key factors. First, the urban and peri-urban location of many farmers in this cluster serves as strategic access to diversified markets, road infrastructures, and basic equipment for milk transportation. This is congruent with the results from other studies in Senegal (Goldsmith et al. 2004; Falletti 2012), West Africa (Rischkowsky et al. 2006), and East Africa (Van der Lee et al. 2020) where, despite other challenges in production, the proximity of producers to urban settings provides a competitive advantage to markets and access to basic infrastructures.

Second, the implementation of the dairy processor and a milk collection centre which serve as points of entry to farmers in Fatick region is believed to have brought a new dynamic to milk production activities amongst farmers especially those in cluster 2 who are the closest to the milk collection centre. As earlier mentioned, the data collection sample included farmers who actively work with the dairy processor, those who no longer work with it, and those who have never worked with it. This has allowed to explore all aspects of the new dynamic caused by the implementation of the dairy

processor. The dairy processor has established a model whereby producers are subsidized with a package of inputs including animal feed, veterinary services, and training on animal husbandry practices. Farmers have to reimburse some of the inputs like animal feed in which case corresponding amounts are subtracted from their pay at the end of the month in their milk payment cycles. The dairy equipped the milk collection centre with motorcycles and basic quality testing tools to enable fast and reliable milk collection for farmers who reside far from the centre but in reasonable distances that prevent milk quality deterioration. Milk collection is performed on a daily basis for enrolled farmers. The farmers interviewed from all the 3 clusters showed a level of satisfaction with the system implemented by the dairy processor, but nearly all of them were not satisfied with the price being paid per litre of milk. Furthermore, some farmers have reported that at some point, the dairy processor was not consistently providing the animal feed and medication as promised at the beginning, but the dairy’s liaison persons explained that this could happen due to the lack of consistency in some farmers’ commitment where, after receiving the above benefits, no longer chose to deliver milk to the collection centre. Even if the dairy processor is considered by farmers in cluster 2 as a constant and sure market all year long, there are parallel markets (i.e. local markets from Fatick ville or nearby Dakar) which actually offer higher prices but they are very fragmented and inconsistent and are unable to buy the bigger volumes especially in months of production overflow. According to farmers, the local market price can go as high as 700 CFA/L compared to 350 CFA/L paid by the dairy processor, and that was another reason given by some farmers on why they stopped delivering milk to the processor. Overall, the implementation of the dairy processor and its milk collection centre in Fatick could be an avenue to the development of the smallholder livestock production sector in the region, by offering alternative means of income to conventional live animal selling and meat production. However, in order to have a win-win situation where farmers would have more incentives to the benefits from a stable market and access to inputs while the dairy processor could also benefit from the increased local milk production needed to meet its processing capacity, the noted barriers and issues raised by farmers will need to be eliminated. Establishing platforms of dialogue between producer representatives and the dairy processor with adequate tools (such as simple format buyer-seller agreements, etc.) may support mutual understanding and respect of the terms of collaboration, while also creating a long-term sustainable business environment. There has been evidence that creating connections between smallholder farmers and medium to large enterprises acts as a

powerful mechanism to improve input and output markets and other productivity-enhancing services for liquidity-constrained smallholders (Adu-Baffour et al. 2019; Sims and Kienzle 2016; Corniaux et al. 2014). The role of the government in this process is crucial to create an enabling environment for producer and processor organizations and provide vertical coordination between them. The development of infrastructure, such as cooling and collection centres, should also be enhanced through public-private partnerships.

Another important characteristic of cluster 2 was the lowest access to land and crop land compared to other farmer clusters. The position of many producers in urban and peri-urban areas of Fatick region provides a competitive advantage in the aspects discussed previously, while also presenting with disadvantages. In Fatick urban and peri-urban areas, land and water (surface water and wastewater) usable for production activities are scarce resources due to competing outputs (including infrastructure development and household activities). Even when farmers owned land, the proper land title documents were often not in possession. This makes it difficult for farmers to plan investments in production activities, especially in the context of cities where regulations for land use require proper documentation. Despite the land scarcity, some urban farmers in cluster 2 adopted sedentary practices where few animals were kept at home and in the vicinity in case of emergencies (i.e. selling live animals, meat, or manure in urgent situations that required money at home), while others were mostly mobile (transhumance). Animals kept at home grazed during the day in the outskirts of the city with some kept in the fields at night and others brought back home. A shepherd would be employed, responsible for the conduct and maintenance of the livestock.

Cluster 3: Specialized milk producers located in peri-urban and rural areas of Fatick region with consistent and all-year-round milk production sell high quantities to the dairy processor and the remainder to parallel markets

Cluster 3 was characterized by farmers that sell more than 80% of the produced milk. Farmers of this cluster benefit from the dynamic of the dairy processor and its milk collection centre by selling the greatest quantities of produced milk. Consistent with the other two clusters, farmers in cluster 3 reiterate that a portion of the milk produced is reserved for parallel markets that offer better prices. It is beneficial for farmers and the dairy processor to build and sustain positive business relationships and maintain consistent production and markets that profit both parties. That being said, the parallel markets remain an attractive option for farmers during the dry season when the demand is usually higher than the supply, which again explain the discontentment of farmers

regarding the buying prices of the dairy processor. However, it is worth noting that during the overflow period, the parallel markets (preferred by farmers) are unable to buy the available quantities and that is the time when farmers rely on the dairy processor for milk selling.

Cluster 3 also consists of farmers whose average milk production/day/farm is nearly double that of the overall population average. Their cows produce more milk per day on average than all other farmers across clusters. Animals in this cluster remain stalled the majority of the time and from there consistently produce milk all year long. Animal feeds are predominantly industrial concentrates with a supplement of crop straws. Farmers try to maintain access to veterinary care services. The higher milk production may be attributed to the fact that farmers mainly own either pure exotic breeds (such as Holstein, Jersey, Montbeliard) or cross-breeds, which are believed to produce higher amounts of milk compared to local breeds (Seck et al. 2016; Niemi et al. 2016; Magnani et al. 2015). Most of the producers fall in the category of socio-professional workers, politicians, retired senior public servants, or other private people with sufficient economic means, advanced education levels, and good networks that enable them to mobilize resources that help to intensify production. It is likely that farmers in cluster 3 gain the most from the implementation of the dairy processor, by facilitating their transition from traditional breeders who were raising animals and producing milk largely for household consumption. The motivation of a permanent market offered by the dairy processor and accompanied extension services assured this group to invest in business-oriented milk production by leveraging their access to resources and social-professional status. Finally, it is important to realize that the wealth status of farmers has a considerable influence on their production strategies: from the breed choice and type of feeds to the adopted management practices. The results suggest that farmers in cluster 3 are wealthier than farmers in other clusters and that could explain why for example, as opposed to other farmers, they have access to expensive exotic breeds, they stall their animals and have consistent access to veterinary services.

The main challenges faced by the farmers of cluster 3 are the high production costs and the difficulty of maintaining the needs of exotic breeds less adapted to local climatic conditions. Exotic cows are also at risk from high vulnerability to local weather conditions, by lacking resistance to heat, humidity, tropical diseases, and parasites (Wilson 2018; Seck et al. 2016; Niemi et al. 2016; Magnani et al. 2015). Environmental modifications, water, and feed management strategies have all proved to be helpful in alleviating and encountering the stress for exotic animals across the tropics (Renaudeau et al. 2012). The design of animal facilities (shape, orientation,

thermo-physical properties of construction materials, ventilation, opening facilities, etc.), genetic selection for more heat-tolerant cattle, and adaptation of feeding strategies to balance water, nutrients, and electrolyte intake (for example by providing more minerals and vitamin to meet the special needs) are all suggested to be amongst the primary means of reducing adverse effects of the environment on these animals (Renaudeau et al. 2012; West 2003). Animal feed (most of which are industrial concentrates) and veterinary costs account for more than 70% of production expenditures. Forage production in the area is limited by lack of land and scarcity and high cost of water resources. Adopting supplements that do not harm the environment and which can be locally sourced may be one solution to overcome the feed scarcity challenges faced by farmers in this cluster. For example, water ferns (such as *Azolla caroliniana*) are being cultivated in ponds by farmers in India to provide extra protein to cattle and goats fed on protein-deficient elephant grass (*Pennisetum purpureum*) Eisler et al. 2014). No foreseeable preventative factors would stop the same solution from being explored in Senegal, given that water ferns are able to grow in tropical climates. Other plant extracts may also be explored, which can alter the rumen microbial population to use nitrogen and energy more efficiently and lead to increased meat and milk production with proportionally less by-product greenhouse gas and ammonia (Eisler et al. 2014). The economic and physiological benefits of cross-breeding when combined with good animal management practices have been well documented as a successful strategy in Senegal (Marshall et al. 2020; Niemi et al. 2016; Seck et al. 2016) and in the regions of Mali, Benin (Traoré et al. 2017; Ahozonlin et al. 2019), and East Africa (Wilson 2018), amongst others. In that regard, farmers in this cluster would benefit from government and private sector initiatives that promote the adoption of new breeding strategies and other technological options to help them sustain production at good levels to satisfy the ever-growing market.

Conclusion

This study revealed the existence of three types of livestock production systems in Fatick. While practice differences amongst clusters (types) were found, it is worth noting that some practices (i.e. transhumance and communal grazing) were maintained across clusters to different degrees. Farmers in cluster 1 were primarily agropastoralist and constrained by remote access to markets, inputs, and other infrastructures. Farmers in cluster 2 were primarily transhumant and constrained by a scarcity of land and fodder resources. High cost of production and susceptibility of exotic breeds to diseases were the main challenges faced by farmers in cluster 3.

Prolonged droughts, soil salinization, and other extreme weather events are generally reported throughout the literature to be common challenges that affect production activities in the area and across clusters. This study also explored the new dynamic in the livestock production sector of Fatick region brought by the implementation of a dairy processor and its milk collection centre. These facilities offer a package of extension services and a consistent market opportunity for rural and urban livestock producers. New business partnerships not only allowed farmers to generate alternative resources to sustain livelihood levels, but were also necessary to increase local milk production in line with the processing capacities of the dairy processor. This study also highlighted an existing disconnection in the agreements and expectations of both parties, especially in the price determination processes. This will require the establishment of platforms for dialogue between producer representatives and the dairy facilities to build more sustainable partnerships. A community of practice that gathers local key stakeholders to discuss issues and opportunities surrounding the sector, while also sharing individual experiences, could foster a more resilient livestock production sector in Fatick. Future studies in the area should explore sustainable approaches to establish win-win collaborations between producers of different scales and agro-industries, wherein both parties become partners who respond to the needs of involved stakeholders.

Abbreviations

ANOVA: Analysis of variance; GDP: Gross Domestic Product; HCPC: Hierarchical clustering on principal components; IFC: International Financial Corporation; MFA: Multiple factor analysis; NASD: National Agency of Statistics and Demographics Agence Nationale de la Statistique et de la Démographique-ANSD ; PCA: Principal component analysis; SD: Standard deviation; vs: Versus; CFA: "Communauté Financière d'Afrique"

Supplementary Information

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Additional file 1. Supplemental material: Descriptive statistics of additional characteristics describing the 3 livestock production clusters. Average \pm SD are reported.

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Authors' contributions

EH coordinated the project, designed the survey (investigation), developed the methodology, and wrote, reviewed, and edited the original draft and all the versions of the manuscript. EV conceptualized the project, provided funding acquisition, administered the project, provided supervision, was involved in the survey design and paper design, and reviewed and edited the manuscript. PC contributed to the conceptualization of the project and

funding acquisition, co-administrated the project, and reviewed the manuscript. KB contributed in the survey design (investigation), data collection, map elaboration, and manuscript revisions. CC contributed in the conceptualization of the project, funding acquisition, survey design (investigation), and review of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to the privacy of the study’s participants but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The questionnaire and methodology for this study were reviewed and approved by the McGill University Research Ethics Board committee (REB) (ethics approval number: # 484-0519) in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement. It was also assessed and approved by the “Commission de Protection des Données Personnelles” (CDP) of Senegal (Ref.no: 00000520 CDP). Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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