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A Methodological Approach to Evaluate Livestock Innovations on Small-Scale Farms in Developing Countries

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Abstract: The aim of the study was deepening the knowledge of livestock innovations knowledge on small-scale farms in developing countries. First, we developed a methodology focused on identifying potential appropriate livestock innovations for smallholders and grouped them in innovation areas, defined as a set of well-organized practices with a business purpose. Finally, a process management program (PMP) was evaluated according to the livestock innovation level and viability of the small-scale farms. Logistic regression was used to evaluate the impact of PMP on the economic viability of the farm. Information from 1650 small-scale livestock farms in Mexico was collected and the innovations were grouped in five innovation areas: A1. Management, A2. Feeding, A3. Genetic, A4. Reproduction and A5. Animal Health. The resulting innovation level in the system was low at 45.7% and heterogeneous among areas. This study shows the usefulness of the methodology described and confirms that implementing a PMP allows improving the viability an additional 21%, due to a better integration of processes, resulting in more efficient management.

Keywords: viability; dynamic capabilities; relational coordination; learning curve of innovation

1. Introduction

Small-scale farms represent 19% and 12% of the world's production of meat and milk, respectively. The dual-purpose (DP) bovine farms in the tropical region in Latin America constitute key organizational mechanisms in terms of security, supply, access and stability of food [1]. These smallholders live on the threshold of poverty and marginalization, within very fragile ecological systems, although with great potential for mitigating emissions of greenhouse gasses as a consequence of their low dependency on external inputs. Also, these farms represent a factor for economic feasibility, social cohesion and poverty reduction [2]. The DP system offers high degrees of resilience of its agroecosystems and it remains the prevalent model in poor countries. Also, it increases the level of diversification of livelihoods and strengthens synergies among productive activities [2]. A distinguishing characteristic of small-scale farms is their flexibility to face both climate and economic changes as a consequence of low levels of investment that might allow replacing dairy with other productive activities to assure the subsistence of the smallholder's family, *i.e.*, during wide drought season (around six months), the farmers may sell the cattle stocks and buy them again at any other better time [3]. This flexibility, coupled with the ability to generate cash, regularly permits this system to be one of the widest-spread activities in rural areas of Latin America, Africa and the Mediterranean basin [4].

Agriculture Innovation

According to [5], innovation is a process by which new ideas are transformed into practices. In agriculture, innovation was defined in the Forum for Agricultural Research in Africa by [6] as "the activities and processes associated with the generation, product distribution, adaptation and use of new technical and institutional/organization knowledge" [7]. We define innovation as an integrated system to improve agricultural productivity and agroecosystem resilience, involving different agronomic and management components within a synergistic relationship. In the same way, [8] indicates that agricultural innovation presents a dynamic view and is seen as a complex and collaborative system.

Innovation is a tool that can increase the competitiveness, viability and effectiveness of farms (Figure 1). An innovation should be socially useful, appropriate and economically viable [9,10]. When innovations are implemented by considering the technical, human and organizational resources, the dynamic capabilities and the strategic positioning of the farm will be enhanced [9]. According to [11], the innovation process allows identifying appropriate technologies and best organizational practices, which will be transferred for satisfying specific needs of the productive activity [12] (Figure 1).

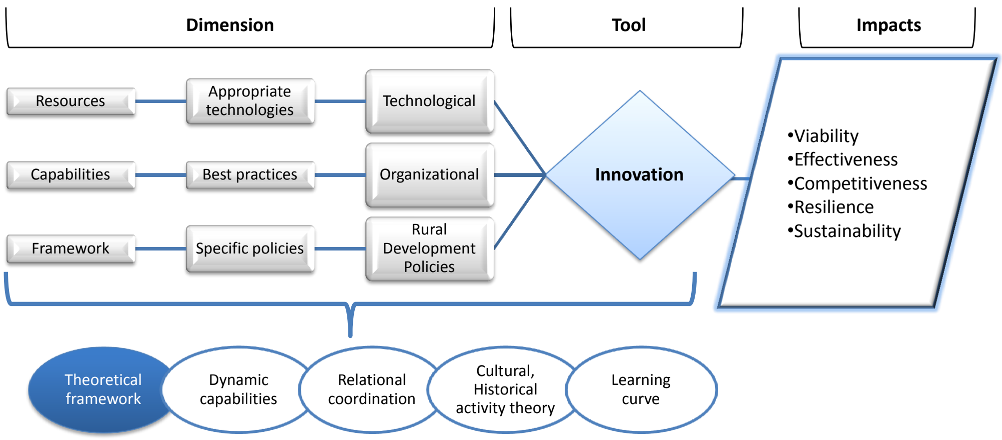

Figure 1. Dimensions of innovation in the agricultural sector.

Developing the livestock innovations (LI) concept implies improving processes and products from the holistic knowledge of the system [13]. In this way, the background of strategic management could be applied in agricultural innovation [9]. In order to create dynamic capabilities in organizations, the relational coordination framework [11] and the learning curve of innovation [14] can be considered (Figure 1).

The livestock innovation level has been previously developed in mixed systems, such as dual-purpose bovine [15], sheep-crop [16] and mixed agriculture [8,17]. In the DP system, the innovation level depends on several factors [12,18], *i.e.*, farm size (size of herd or surface), ecological zones, culture, *etc.* [19], which indicate that an increase of farm size improves production, intensification, and the innovation level. In regard to cultural factors, [7] associate an increase of technological level to higher levels of education. According to [20]: "Farmers need to innovate in their system; governments need to innovate in the specific policies they implement to support family farming; producers' organizations need to innovate for a better response to the needs of family farmers; the researchers and extension advisors need to innovate shifting from a research driven process predominantly based on technology transfer to an approach that enables and rewards innovation done by smallholders themselves".

As such, some questions arise:

Why do a lot of farmers not adopt the innovation?
What is the main reason for failure in the adoption?
What is the real level of innovation in the farms?
What are the key technologies and practices for reaching success?

The use and adoption of innovation are the result of knowing the objectives of the farms, the agroecosystems' limits and the synergies between different activities [4,21]. In this way, [2] indicate the importance of deepening the knowledge of objectives, potentials, limitations and "*right of being*" of the farms. These systems can be optimized by taking into account economic, social and environmental dimensions. Moreover, the farmer's profile (socioeconomic, managerial capacities, access to information, *etc.*) must be considered in the development of policies [22].

Knowing how an innovation has been generated and spread to the farmers is recognized to be another key factor in the success or failure of the innovation [11]. The traditional views of *top-down* and the current *bottom-up* are not sufficient and they propose joining both strategies to deal with the lack of an innovation paradigm in South Africa [8]. In addition, according to this author, farmers do contribute to innovation and should be treated as partners in agroecological innovation.

Many technological transfer projects have failed because leaders often have little background to prepare them and to identify the conditions to be successful [23]. It is necessary to provide support to the advisor for evaluating *ex-ante* the potential consequences of innovation on the structure, functioning and performance of a farm [13]. The choice of innovations and their effects in the production constitute the key challenges that can favor the development of the livestock and the increase of competitiveness of smallholders [10,16,24].

Therefore, the objective of this research is developing a methodology to deepen the knowledge of livestock innovation. In a first step, innovations are identified by asking the farmer if certain innovations have been implemented and by measuring the innovation level acquired in the farms [25–27]. Later on, the impact of innovations on the farm's performance will be evaluated.

2. Framework of the Methodological Approach

What are the objectives of smallholders?

According to [28], smallholders seek food security, family welfare (including education), and reduction of vulnerability and poverty by applying a low-cost strategy and low levels of innovation. Most of the farms are of a small-scale size and subsistence (85%), and only the 15% of the smallholders have business objectives, oriented to market. Moreover, livestock is the farm asset that potentiates food stability and supports the expansion and diversification of activities [29]. The objectives and strategies are similar in the mixed cereal-sheep system of the Mediterranean basin [12], the dual-purpose bovine system of the American tropic [14] and the small-scale farms in South Africa [26] (Table 1).

Table 1. Objectives of smallholders in developing countries.

Types of Farms	Strategic Challenges	Productive Objectives
Commercial (15%)	Increasing competitiveness	Improving productivity
Small (35%)	Reduce poverty and inequality (gender, territories, *etc.*)	Production stability, access to internal markets (step rural to urban market)
Subsistence (50%)	Food security (food supply, nutrition, health, *etc.*)	Stability of household consumption and access to funding sources.

Source: [1,19,30–32].

2.1. Steps of Methodological Approach

A livestock innovation index was built utilizing qualitative methodology according to [13,33]. The methodology included features such as collaboration, cooperation, consensus, transdisciplinary research strategy and taking into account different stakeholders of the value chain. This methodological approach provides researchers a first insight about the innovation level of the system. Subsequently, this methodology will deepen knowledge of the impact of an innovation on the performance of the farms through quantitative analysis [32].

Figure 2 shows the process to evaluate the livestock innovation level starting with the identification and selection of relevant innovations. Subsequently, the selected innovations will be grouped in areas into a program of process management for their evaluation [9]. The methodology is composed of six steps: identification of technologies, grouping in areas, building of a tool or instrument for field research, information gathering, building a database and indicators. Finally, through quantitative methodology, the effects of livestock innovations on viability are evaluated [8,12].

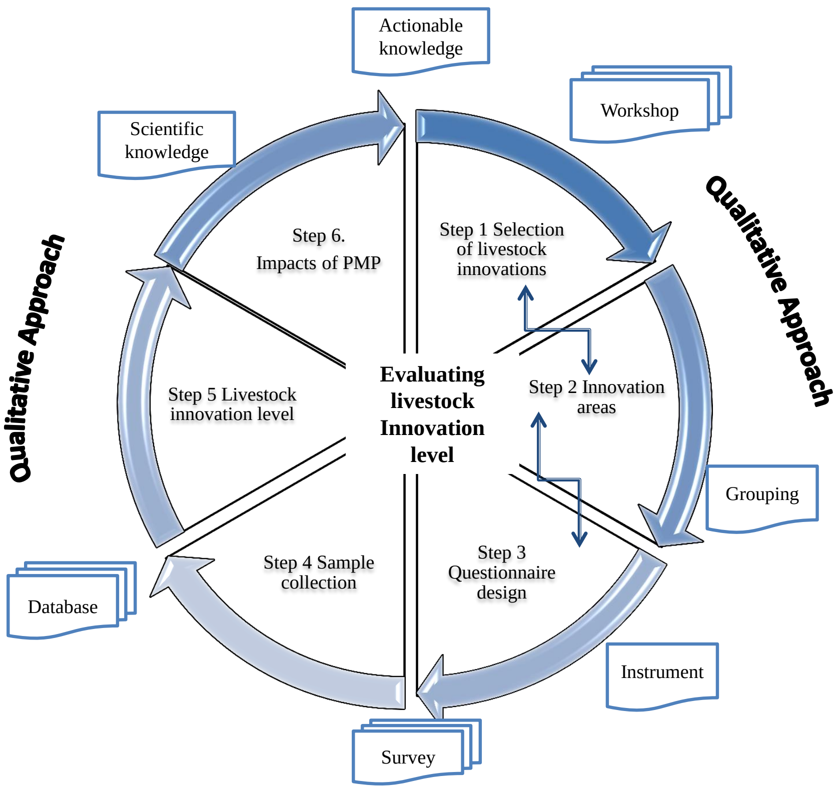

Figure 2. Steps for evaluating livestock innovations on small-scale farms.

Step 1. Identification of innovations

First, a pre-selection of livestock innovations was conducted according to their relevance for the DP system. The pre-selection was based on an extensive literature review; in addition, information *in situ* from the smallholders was gathered. In this way, 185 potential technologies for DP systems were pre-selected. Subsequently, during a workshop with the presence of the experts, each pre-selected technology was analyzed and discussed according to its relevance in the Mexican DP context.

The panel of experts was constituted by 14 specialists in livestock production: six university professors specializing in different animal production subjects such as nutrition, economy, animal welfare, health, rural policies and milk quality; five technical advisors; and three researchers specializing in milk production, animal nutrition, and reproduction. The experts presented around an average of 20 years of experience with different profiles as veterinarians, agronomy engineers, economists, chemistries, and biologists.

During the workshop, the meaning of each variable was explained to the experts' group (Table 2), including how the values were obtained, their importance for the productive process, the consistency of the innovations and the number of farms with the innovation, among others. The following issues were also raised at the working session:

- How has the adoption process been developed?
- Are the livestock innovations properly used?
- What were the reasons for success or failure for the use of livestock innovations on the farm?

Table 2. Innovations and areas in the dual-purpose system.

A1. Management	**Information System of Management and the Direct Use of Resources by Grazing**
1. Animal identification	0. Individual animals identification was not done; 1. Individual animals identification was done (ear tags, hot iron, tattooing, neck chains, *etc.*)
2. Record system	0. Record systems were not utilized; 1. Record systems were utilized to make decisions into the operation of the farm
3. Breeding management	0. There was not a specific management breeding planning; 1. There was a specific management breeding planning
4. Grazing native pasture	0. Cattle did not graze in native pasture lands; 1. Cattle grazed in native pasture lands; *Paspalum, Panicum, Bouteloua*; *etc.*
5. Grazing planting	0. Cattle did not graze in planted pasture lands; 1. Cattle grazed in planted pasture lands (*Panicum máximum, Brachiaria brizantha, Andropogon gayanus, Hyparheina rufa, Clitoria ternatea, Leucaena leucocephala*)
6. Grazing of crop residues	0. Grazing of crop residues was not done; 1 Grazing of crop residues was done *i.e.*, maize *Zea mais*, sugar cane *Saccarum officinarum*, oat *Sativa L. etc.*
7. Milking season	0. Cows are not regularly milked; 1. Cows are regularly milked; the farm is oriented to milk production
8. Type of milking	0. Hand milking was utilized; 1. Mechanical milking was utilized mainly
A2. Feeding	**Strategies for animal feeding applied by smallholders including three kinds of foods: Roughage, concentrated feeding and supplements**
Roughage	
9. Green fodder	0. Green fodders were not used; 1. Green fodders were cultivated, cut and provided directly to cattle.
10. Silage	0. Feeding with silages was not utilized; 1. Feeding with silages was utilized, *i.e.*, grass, maize, others.
11. Hay making	0. Cattle were not fed with haymaking or stubble; 1. Cattle were fed with haymaking or stubble, *i.e.*, corn, sorghum, oats, other
Concentrated feeding	
12. Processed feed	0. Cattle were not fed with processed feed; 1. Cattle were fed with processed feed including compound feed
13. Concentrate making	0. Cattle were not fed with concentrate-making feed; 1. Cattle were fed with concentrate-making feed (home-made concentrate) includes all types of grains, cereals, *etc.*
Supplements	
14. Molasses/urea	0. Cattle were not supplemented with molasses/urea; 1. Cattle were supplemented with a mix of molasses/urea
15. Grains and oilseeds	0. Grains and oilseeds were not added to cattle diet; 1. Grains and oilseeds plants were added to cattle diet (Maize, Sorghum, soya, other)
16. Multi nutritional blocks processed	0. Cattle were not supplemented with multi nutritional blocks processed; 1. Cattle were supplemented with multi nutritional blocks processed

Table 2. *Cont.*

17. Manufacture of multi nutritional blocks	0. Cattle were not supplemented with manufactured multi nutritional blocks; 1. Cattle were supplemented with multi nutritional blocks processed (home-made)
18. Common salt	0. Cattle were not supplemented with NaCl; 1. Cattle were supplemented with NaCl
19. Mineral salts	0. Cattle were not supplemented with mineral salts; 1. Cattle were supplemented with mineral salts (common salt plus Ca, P and other minerals).
20. Mineral blocks	0. Cattle were not supplemented with mineral blocks; 1. Cattle were supplemented with mineral blocks
21. Vitamin provided	0. Vitamins were not used; 1. Vitamins were provided, as A, D, E, B complex
22. Agro-industrial by-products	0. Agro-industrial by-products were not used; 1. Agro-industrial by-products awerere used, *i.e.*, dry grain such as bran; wet grain such as brewers grains; and pulps such as beet, citrus, and others
A3. Genetics	**Technologies to improve productive parameters through the preservation of the breed, and the resistance of the animals to the tropical climate and to ectoparasites**
23. Using male breeds	0. Male breeds were not utilized; 1. Male breeds were incorporated
24. Using male crosses	0. Male crosses were not utilized; 1. Male crosses were incorporated
25. Using female breeds	0. Female breeds were not utilized; 1. Female breeds were incorporated
26. Using female crosses	0. Female crosses were not utilized; 1. Female crosses were incorporated
27. Use of genetically tested bulls	0. Genetically tested bulls were not utilized; 1. Genetically tested bulls were utilized to identify morphofunctional and genetics characteristics
28. Calves selection criteria	0. Calves selection criteria were not used; 1. Calves selection criteria were used (gain weight, high weight for age, high and faster growth or others)
29. Female selection criteria	0. Female selection criteria were not used; 1. Female selection criteria were used, as milk production of the mother, the behavior of the mother, breed, udder conformation and resistance to mastitis, others
30. Sire selection criteria	0. Sire selection criteria were not used: 1. Sire selection criteria were used as productive progenitor, body conditions, performance testing, lifetime, pedigree, progeny testing, sib performance, others
31. Crossbred system	0. Crossbreed planning was not utilized; 1. Crossbreed planning was utilized: simple, sire crossbred, absorbent crossbred, others
A4. Reproduction	**Technologies oriented to improve reproductive efficiency parameters**
32. Evaluation in bulls	Breeding soundness evaluation in bulls 0. No evaluation of the reproductive capacity of bulls or no sire on the farm; 1. Evaluation of the reproductive capacity of bull is done
33. Semen evaluation	Semen fertility evaluation 0. Sperm viability was not done; 1. Sperm fertility was evaluated
34. Female evaluation	0. Evaluation of female body condition was not done; 1. Evaluation of female body condition was done before mating
35. Oestrus detection,	0. Estrus detection was not done; 1. Estrus detection was done
36. Pregnancy Diagnosis	0. Pregnancy diagnosis was not done; 1. Pregnancy diagnosis was done as rectal palpation, ultrasound scanning, others
37. Mating	0. Seasonal mating; 1. Continuous mating was done
38. Breeding policy	0. Control of the mating was not done; 1. Planning mating control.
A5. Animal Health	**Technologies geared to health, welfare, quality of the milk production and the incorporation of a sanitary milking program**
39. Health planning	0. Animal health planning was not done; 1. Animal health planning was done, includes voluntary or compulsory measures and protocols to prevent the spread of local and transboundary animal diseases
40. Vaccination program	0. Planning of vaccines and bacterins was not done; 1. Application of vaccines and bacterins was done, to prevent diseases such as *Clostridium chauvel, brucellosis, tuberculosis, derriengue, pasteurelosis, leptospirosis*, others
41. Parasite diagnosis	0. Diagnosis analysis was not utilized to identify types of parasites in feces; 1. Diagnosis analysis was used to identify types of parasites in feces

Table 2. *Cont.*

42. Internal deworming control	0. Internal deworming was not used; 1. Internal deworming was used in different kinds of animals in the herd
43. External parasite control	0. External parasite control was not used; 1. External parasite control was used
44. Mastitis diagnosis	0. Mastitis diagnosis was not done; 1. Mastitis diagnosis was done.
45. Sanitary milking program	0. A sanitary milking program was not done; 1. Sanitation practices in milking were done: cleaning and drying of the udder and teats, calf stimulation, utilization of disposable materials, control of health hazards, others.

In addition, the technical, financial and human requirements of each innovation were evaluated [34]. Later, the experts assessed each identified innovation by a Likert scale with values from one to five, where one was the least important and five the most important (Appendix 1). In the first round of assessment, those technologies which obtained the maximum score (five) in the opinion of nine or more experts were selected and the technologies with a minimum (one) qualification from nine experts were discarded. In the second round, descriptive information from the set of responses (concordance index and mean) was sent to each expert for re-examination and reconsideration of their judgment. The Ishikawa index was utilized considering a concordance level where the livestock innovations with greater than 60% of the concordance level and an average score over 3.5 were selected [35]. In Table 3, the innovations selection survey is shown.

Table 3. Selection of livestock innovations and innovation areas.

Step 1. Identification of Livestock Innovations			**Step 2. Innovation Areas**	
Livestock Innovations		**Ishikawa Index (%)**	**Innovation Areas**	**Kendall's W**
1	Animal identification	100.0	A1. Management	0.576 **
2	Record system	100.0		
3	Breeding management	92.8		
4	Grazing native pasture	92.7		
5	Grazing planting	64.2		
6	Grazing of crop residues	78.5		
7	Milking season	64.2		
8	Type of milking	71.4		
9	Green fodder	64.2	A2. Feeding	0.377 *
10	Silage	92.8		
11	Hay making	71.4		
12	Processed feed	64.2		
13	Concentrate making	100.0		
14	Molasses/urea	100.0		
15	Grains and oilseeds	100.0		
16	Multi nutritional blocks processed	71.4		
17	Manufacture of multi nutritional blocks	64.2		
18	Common salt	100.0		
19	Mineral salts	64.2		
20	Mineral blocks	92.8		
21	Vitamin provided	64.2		
22	Agro-industrial by-products	85.7		
23	Using male breeds	64.2	A3. Genetics	0.349 *
24	Using male crosses	64.4		
25	Using female breeds	64.2		
26	Using female crosses	64.2		
27	Use of genetically tested bulls	64.2		
28	Calves selection criteria	100.0		
29	Female selection criteria	85.7		
30	Sire selection criteria	85.7		
31	Crossbred system	78.6		

Table 3. *Cont.*

Step 1. Identification of Livestock Innovations			Step 2. Innovation Areas	
Livestock Innovations		**Ishikawa Index (%)**	**Innovation Areas**	**Kendall's W**
32	Evaluation in bulls	64.2	A4. Reproduction	0.376 **
33	Semen evaluation	64.4		
34	Female evaluation	64.2		
35	Estrus detection	64.2		
36	Pregnancy Diagnosis	64.2		
37	Mating	100		
38	Breeding policy	85.7		
39	Health planning	100.0	A5. Animal Health	0.591 **
40	Vaccination program	100.0		
41	Parasite diagnosis	100.0		
42	Internal deworming control	71.4		
43	External parasite control	64.2		
44	Mastitis diagnosis	100.0		
45	Sanitary milking program	64.2		

The assignment from innovations to area was significant * ($p < 0.05$); ** ($p < 0.01$).

Step 2. Grouping of livestock innovations in areas

In this stage, the selected livestock innovations from step 1 were grouped in areas according to [3,15,17] and following the methodology proposed by [9] in mixed systems. The proposed areas could be internationally useful in tropical places with dual-purpose bovine and small-scale farms, so over 50 experts from several countries were consulted online.

Initially, 15 areas were proposed: feeding, reproduction, genetics, global change resilience, animal welfare, management, production, grasslands, milk quality, animal health, public health, economy and markets, farm facilities, labor, social items, associations and sectoral policies. The selected livestock innovations were presented to the experts, so they could suggest new areas for the list (Appendix 2). Once the expert's suggestions were incorporated, the process of selecting areas started, following these criteria: (i) every selected innovation must be classified at least in one area; (ii) the set of innovation areas must be as small as possible. In the second iteration, the proposed areas were shown to the experts for their assessment and selection. In the third round, descriptive information from the set of responses (Kendall's index or the coefficient of concordance W) was sent to each expert for re-examination and reconsideration. In this round, five innovation areas were selected (Table 3).

Step 3. Questionnaire

According to the mixed systems studies from [12,15,24,31,36], a questionnaire was designed to capture information from each farm regarding the identified innovations. The questionnaire was previously validated in six pilot farms (two questionnaires by each type of farm as described in Table 1) and subsequently improved. The questionnaire was adjusted for each innovation and grouped according to experts' recommendations. The survey included between 284–300 items related to the subjects: sociology (9%), facilities (11%), reproduction (11%), feeding (13%), farm structure (10%), animal health (11%), market and economy (36%).

Step 4. Information gathering

A sample of 1650 smallholders' DP farms with 50 or fewer cows in production [16,18] was selected during the year 2011. Data were obtained from questionnaires applied directly by trained technical advisors from the livestock support program of SAGARPA (Mexican Minister of Agriculture) [10] to smallholders and included 45 livestock innovations. The average time for survey application was around 5.5 h per farm, similar to that reported by [12].

Step 5. Livestock innovation level

Figure 3 shows the innovation assessment process used in the dual-purpose bovine system in tropical regions [15,16]. One innovation index was calculated per each area [12,15]. It was based on the proportion of innovations implemented over all innovations identified. The process areas were classified using multiple-sample comparison and the significant differences between groups were analyzed with the Student-Newman-Keuls test. Subsequently, the existence of the association between areas was verified by Spearman correlations.

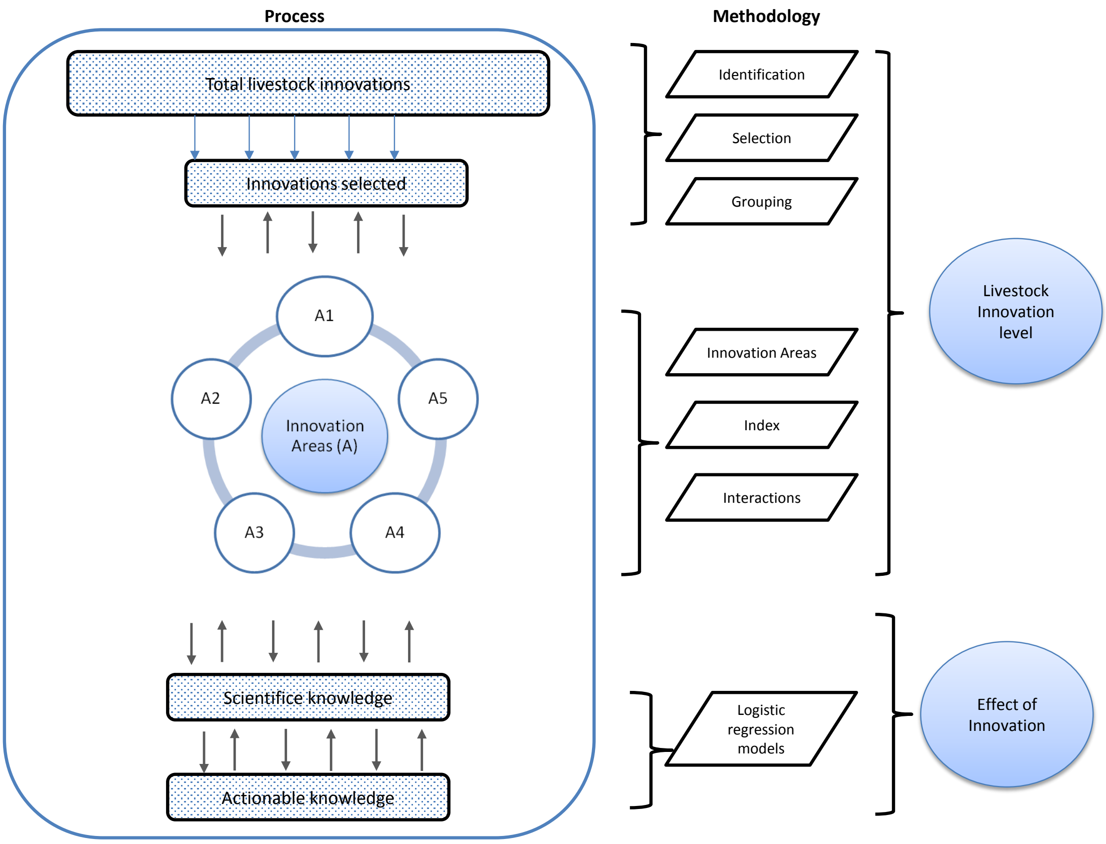

Figure 3. Evaluation of livestock innovations.

Step 6. Impact of innovations, viability and the process management program (PMP)

Viability is an aggregate index that incorporates productive, economic and social factors [3,24]. The viability of each farm was calculated according to its ability to generate sufficient profits for guaranteeing the maintenance of the family unit over the long term (positive net cash flow during three consecutive years) [37]. If a farm generated a positive economic return during three consecutive years, it could be considered as viable (Viability = 1), and non-viable in the other situations (viability = 0).

2.2. Process Management Program (PMP)

The process management program (PMP) is a strategic tool for improving farm performance outcomes and its operational agility through improving management processes. The PMP spans organizational boundaries, links farmers, and enhances information flow systems and other assets to create and deliver value to stakeholders such as customers, smallholders, and consumers [32]. The PMP was applied from grouping livestock innovations in the defined areas in step 2. For Mexican DP farms, the PMP was utilized through a livestock innovations technology transfer model, known as GGAVATT (farming livestock groups for the validation and transfer of technology). Since 1996, the GGAVATT model was developed by INIFAP in México, who were given technical assistance through an SAGARPA support program in 2011/2012 [10]. The GGAVATT model is based on active participation of farmer groups with similar production objectives. Also, in the model, the innovations developed in research centers were validated, transferred and adopted by the farmers in collaboration with other stakeholders, such as advisors, researchers and agricultural governmental officials, among others. The activities include tools such as participative diagnosis, planning, efficient use of resources, selection, implementation of innovations and results evaluation. The GGAVATT model is based on training farmers in organizational routines (collecting productive, reproductive and economic records) and it has use in the decision-making oriented to management, animal feeding, genetics, reproductive planning, health programs, milk quality, *etc*. These procedures are integrated into a transversal schema by following the specialization approach of the particular farms' objectives (milk, meat, cheese, *etc.*). This approach allows following an ordered and logical sequence of activities [9,38].

2.3. Impacts of Innovations

A binary logistic regression analysis has been applied to evaluate the impact of the PMP on the economic viability of the farm. The model is as follows:

$$P\ (y) = \frac{1}{1 - e^{x \times \beta + \varepsilon}}$$

In the model, the dependent variable, viability, is dichotomic (1/0) and it represents the viability of farms; the independent variable is whether the PMP is implemented (category = 1) or not (category = 0). The Hosmer and Lemeshow test was used to evaluate the fit of the model. The odds ratio (OR) and its confidence intervals (IC = 95%) were calculated to quantify the association between both variables. For the statistical analysis, SPSS 19.0 software was used.

3. Results

Table 4 shows that the average of the technological innovation (TI) level was 46.3% with an uneven behavior between areas, and four different groups were configured ($p < 0.01$) (Table 4). The highest TI level was viewed in A5 animal health (72%). On the opposite side, the lowest levels were found in A2 animal feeding and A4 reproductive management with 28.3% and 27.4% respectively. In addition, these two areas showed high coefficients of variation, 52.2% and 70.9% respectively. Similar patterns of technological adoption in animal health and reproduction were found by [9] in Ecuador, [10,39] with smallholders in México and [26] in Ethiopia. The efforts in improvement of animal health are based on the use of technologies for parasite control, sanitary governmental programs and the quality requirements for the dairy industry.

Table 4. Livestock innovation level (mean ± standard error) for each area (A).

Technological Areas	Innovation (*n*)	Innovation Level (%)	Q1	Q3	CV
Global innovation	45	46.3 ± 0.3	40.0	50.1	24.5
A1. Management	8	61.2 ± 0.4 [b]	50.0	75.0	24,2
A2. Animal feeding	14	28.3 ± 0.4 [d]	14.3	35.7	52.2
A3. Genetics	9	59.5 ± 0.4 [c]	55.6	66.7	25.9
A4. Reproductive management	7	27.4 ±0.5 [d]	14.3	28.6	70.9
A5. Animal health	6	72.0 ± 0.4 [a]	57.1	85.7	22.8

SE: standard error. Q1: first quartile. Q3: third quartile. CV: coefficient of variation. Different letters within column ($p < 0.01$).

Low levels of Spearman correlations were identified ($p < 0.05$), and were significant ($p < 0.01$) between the 10 pairs of areas. The highest levels of correlations were found between A5 health and A1 management, and A2 feeding and A4 reproduction, with $r = 0.35$, $r = 0.36$, and $r = 0.35$, respectively. Moreover, A1 management showed high correlation levels regarding A2 feeding, and A5 health, with $r = 0.40$, and $r = 0.35$, respectively (Table 5).

Table 5. Spearman correlation matrix among innovation areas.

Areas	A1	A2	A3	A4	A5	Global
A1. Management	1	0.40	0.19	0.16	0.35	0.60
A2. Feeding		1	0.29	0.29	0.36	0.79
A3. Genetics			1	0.25	0.27	0.59
A4. Reproduction				1	0.35	0.54
A5. Health					1	0.63
Global						1

($p < 0.001$).

Of the producers, 56% have implemented the PMP and 44% did not. The results of the binary logistic regression are shown in Table 6 and confirm the positive association between PMP and the economic viability of the mixed system. The model estimates that the likelihood of being viable economically is 5.059 times higher when a PMP system has been implemented. The Hosmer and Lemeshow ($p = 0.837$) test does not proof the absence of fit of the model, which was correctly classified in 70% of the cases. The Nagelkerke (0.176) determination coefficient and the Hosmer- Lemeshow statistic (2.7649) suggest that a PMP program explains 21% of the economic viability of farms.

Table 6. Odds ratios of included variables based on a logistic regression on the viability of farms.

Variable	Coefficient β	Std. Err.	*P*	Odds Ratio	IC 95% Odds Ratio Min	Max
PMP	1.621	0.482	0.001	5.059	1.968	13.905
Intercept	−1.459	0.351	0.000	0.233		

The second estimated model for the farms that implements a PMP (Table 7) is explained by the five innovation areas with a 62% accuracy in prediction and a Nagelkerke R^2 of 0.235 and an H-L Statistic of 7.540 (p-value Chi-Sq = 0.480). This indicates that the model is accepted to describe the probability curve of the variability of the farms with PMP. In the suggested model, the innovation area of feeding ($p < 0.05$) is shown as the explanatory variable of the viability of PMP farms; the estimated OR value for A2 feeding is 1.080, meaning that when a farm adopts a technology from A2 feeding, it has an 80% of possibility of being viable.

Table 7. Odds ratios of included variables based on a logistic regression on the viability of farms with PMP.

Variable	Coefficient β	Std. Err.	*P*	Odds Ratio	IC 95% Odds Ratio Min	Max
A1. Management	0.08	0.71	0.911	5.059	0.270	4.370
A2. Feeding	0.63	0.32	0.047	1.080	1.010	3.490
A3. Reproduction	0.43	0.39	0.033	1.280	0.720	3.280
A4. Genetics	0.29	0.34	0.389	1.540	0.690	2.590
A5. Health	0.57	0.30	0.059	1.340	0.980	3.170
Intercept	−8.54	5.85	0.144	0.004	0.009	18.510

4. Considerations and Implications

The methodology that has been built allows us, first, to identify innovations; second, to group them in innovation areas; and third, to build an index and assess the impact of the innovation. This approach is utilized as a tool for increasing knowledge and improving it for small-scale farms [40,41]. This methodology is developed in three stages: firstly, a participative methodology proposed by [12] that enables the building of synthetic indexes from a group of variables is used. Other studies use a similar methodology in livestock mixed farms on the Ecuadorian coast [12], Mexico [27] and Spain [37]. In the second stage, the data were collected. Finally, logistic regression was used to assess the impact of innovation. It was focused on the importance of implementing a process management program on the viability of the farms [25]. Nevertheless, other authors propose other quantitative methodologies to analyze the innovation [4], such as principal components, cluster analysis and structural equations. Also, the use of these methodologies could improve the results achieved.

The association among process areas through Spearman correlations has been confirmed, according to [26] in Ethiopia and [15] in Ecuador. Independently from the used innovation, the innovation must be studied as a systemic-organizational approach, which considers all innovation areas. It is based on several attributes of the system, such as adaptive and holistic character [34]. Moreover, positive interactions were found among the different areas and the implementation of new innovations often requires promoting a process management program that allows reaching an adequate level of innovation adoption [9]. The authors of [23] indicate than innovation is not a linear process; on the contrary, it is very interactive, collaborative, collective, transdisciplinary and requires the consensus of several stakeholders [11,15].

The development of this mixed methodology, both qualitative and quantitative, implies an approximation between science and reality, with a growing preoccupation with the improvement of government policies for rural development and the challenges faced by the smallholders and family farms (viability, food supply, food security, *etc.*). According to [23], in order to deepen the new paradigms, the question mainly is: what are the links between livestock, food industry, science and rural livelihoods for small-scale farms?

The obtained results agree with [31], who found that the innovation level in agriculture depends on the flows of knowledge and the quality of the linkages between producers and other agents of the value chain. The Organization for Economic Cooperation and Development OECD 2011 report considers that most of the smallholders lack appropriate technical assistance for innovation adoption [39]. In this way, [36] estimate that only between 3% and 10% of smallholders in Mexico get technical assistance. This value is very low, regardless of the quality of the service, the process of adoption, the impact, and the used innovation consistency. The authors of [42] indicate that the promotion of innovations by technical advisors is necessary; apart from this, there are external and internal financial factors that address the success of technological adoption.

Livestock innovation in developing countries requires a systemic approach as a priority, where all activities on the farm are considered independently of the direct productive results, because the farms have different objectives and strategic challenges, as has been shown in Table 1 ([1,19,30–32] among others). Most farmers are small-scale, with a low or null technological innovation level, and have an urgent need for technical support and a perception of "nothing changes". There is a constant dilemma: are the subsidies a tool for inequality [43]?

Therefore, this research seeks to identify the pathways for innovation in order to enhance the desired impact in the smallholders' livelihoods and to link the innovation to the improvements in economic, social and environmental results [25]. The developed study is prospective and preliminary, although the innovation areas' impact is verified on the farms' viability. Different studies have shown that the process management program (PMP) develops a very important role in the profitability of farms for the adoption of technology and managerial practices [10,15,37,44]. However, the PMP is not directly observed or measured, and furthermore, its effects are multi-factorial and hierarchical. This situation makes it difficult to develop statistical models that allow analyzing its causal diagram [37]. The usefulness of the proposed logistic model resides in its capacity to establish associations among the managerial factors (PMP) and viability, although the knowledge of the mechanisms that underlie the mixed systems' interrelation is insufficient [45]. The results are interpreted as correlated approaches and they indicate that the implementation of the process management program favors the economic viability of the farms. Future studies should be oriented to the synergies that appear among the management of processes, the economic development and the environmental sustainability, as indicated by [46], in the long term. Apart from this, [47] indicate that PMP contributes to corporate responsibility by orienting the processes according to the needs of smallholders, and it constitutes a factor for social sustainability.

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Appendix 1. Assessment Innovation in Mexico

Following the meaning of the values described below, point out the next: **1** lowest importance to **5** greatest importance. According to your opinion: The uses of innovations in dual-purpose systems have importance . . . "

N	Innovations	Assessment 1(less)→5 (plus)				
		1	2	3	4	5
1	Animal identification					
2	Record system					
3	Breeding management					
4	Grazing native pasture					
5	Grazing planting					
6	Grazing of crop residues					
7	Milking season					
8	Type of milking					
9	Green fodder					
10	Silage					
11	Hay making					
12	Processed feed					
13	Concentrate making					
14	Molasses/urea					
15	Grains and oilseeds					
16	Multi nutritional blocks processed					
17	Manufacture of multi nutritional blocks					
18	Common salt					
19	Mineral salts					
20	Mineral blocks					
21	Vitamin provided					
22	Agro-industrial by-products					
23	Using male breeds					
24	Using male crosses					
25	Using female breeds					
26	Using female crosses					
27	Use of genetically tested bulls					
28	Calves selection criteria					
29	Female selection criteria					
30	Sire selection criteria					
31	Crossbred system					
32	Evaluation in bulls					
33	Semen evaluation					
34	Female evaluation					
35	Oestrus detection					
36	Pregnancy Diagnosis					
37	Mating,					
38	Breeding policy					
39	Health planning					
40	Vaccination program					
41	Parasite diagnosis					
42	Internal deworming control					
43	External parasite control					
44	Mastitis diagnosis					
45	Sanitary milking program					

Appendix 2. Identification of Process Areas in Dual-Purpose Bovine System

Follow the meaning of the values described below. According to your opinion, select one innovation area for each process area.

N	Innovations	A1. Management	A2. Feeding	A3. Genetics	A4. Reproduction	A5. Animal Health	6. Other
1	Animal identification						
2	Record system						
3	Breeding management						
4	Grazing native pasture						
5	Grazing planting						
6	Grazing of crop residues						
7	Milking season						
8	Type of milking						
9	Green fodder						
10	Silage						
11	Hay making						
12	Processed feed						
13	Concentrate making						
14	Molasses/urea						
15	Grains and oilseeds						
16	Multi nutritional blocks processed						
17	Manufacture of multi nutritional blocks						
18	Common salt						
19	Mineral salts						
20	Mineral blocks						
21	Vitamin provided						
22	Agro-industrial by-products						
23	Using male breeds						
24	Using male crosses						
25	Using female breeds						
26	Using female crosses						
27	Use of genetically tested bulls						
28	Calves selection criteria						
29	Female selection criteria						
30	Sire selection criteria						
31	Crossbred system						
32	Evaluation in bulls						
33	Semen evaluation						
34	Female evaluation						
35	Oestrus detection						
36	Pregnancy Diagnosis						
37	Mating,						
38	Breeding policy						
39	Health planning						
40	Vaccination program						
41	Parasite diagnosis						
42	Internal deworming control						
43	External parasite control						
44	Mastitis diagnosis						
45	Sanitary milking program						

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