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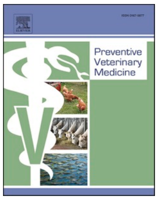

Stochastic model to assess bioeconomic impact of PRRS on pig farms in Costa Rica

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ABSTRACT

Despite the economic importance of PRRS and its high prevalence in Costa Rica, there are no studies on the bioeconomic impact of the disease in the country or, even, in Central America. Such studies are essential in finding cost-effective preventive measures tailored for different production circumstances. Therefore, the objective of this study was to evaluate economic and production parameters of a PRRSV-infection for a medium-sized farrow-to-finish pig farm system in Costa Rica with a farm-level stochastic Monte Carlo simulation model. The effect of PRRS was assessed by scenario analysis, in which a baseline PRRS-free situation was compared against three alternative scenarios that assumed low, medium and high PRRS effects. The PRRS effects were based on data from local farms, scientific literature and expert opinion. Sensitivity analyses were performed to assess the impact of key input parameters on output variables. Results show that at the animal level, changes between the baseline and the PRRS-high scenario were estimated as: + 25 d in age to slaughter, − 9.9 pigs to slaughter (per breeding sow/yr), + 6% annual replacement rate, − 255 d in sow productive lifetime, - 6.9 mo in age at culling of sows, and + 24 non- productive days. For a medium size local farm (n = 588 sows), a reduction of 5826 fat pigs to slaughter per farm/yr from baseline compared to PRRS-high scenario was observed. PRRS-induced loss per farm per year was estimated at -US $142,542, US $180,109 and -US $524,719 for PRRS-low, medium and high scenarios, respectively. Revenues/costs ratio changed from 1.12 in the baseline to 0.89 in the PRRS-high scenario. The production cost per kg carcass weight increased from US $2.63 for the baseline to US $3.35 in the PRRS-high scenario. PRRS-induced loss was estimated at US $77.1 per slaughtered pig/yr and US $892 per breeding sow/yr for the PRRS-high scenario. Results from the model indicate that pig farms with medium to high prevalence of PRRS will require optimal market conditions in order to have positive economic outcomes. These results can be helpful in the design of better control strategies for PRRS.

1. Introduction

Porcine reproductive and respiratory syndrome (PRRS) is a viral disease caused by the homonymous virus (PRRSV). It may persist in affected farms for years, exacerbating chronic animal health effects and economic losses. This disease is characterized by reproductive failure, including abortions, stillbirths, and premature farrowing (Collins et al., 1992), as well as production losses due to increased mortality, decreased feed efficiency, and reduced average daily gain (Wensvoort, 1993; Zimmerman et al., 2012), resulting in significant economic losses. Annual cost of PRRSV infections to the USA pig industry was calculated at US $ 560.75 million in breeding herds and US $493.57 million in growing-pig populations (Neumann et al., 2005). Nathues et al. (2017) reported losses by US $ 694.2 per sow/yr.

PRRS was first detected in Costa Rica in 1996 (Bermúdez-Zamora, 1996), and was subsequently reported in further studies (Ugalde-Morales, 1998; Pineda-Sáenz, 2001; Castro-Mena, 2006; Guzmán-Saborío, 2020). PRRSV type II is the prevailing species in Costa Rica, and it is endemic in most pig farms in the country (Guzmán-Saborío, 2020). The prevalence of positive farms was 44% (11/25), located in six of the seven provinces of Costa Rica. Overall, 58% (344/596) of the pigs were seropositive to PRRSV (Meléndez et al., 2021).

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Despite the economic importance of PRRS and its high prevalence in Costa Rica, there are no studies on the bioeconomic impact of the disease in the country or, even, in Central America. The calculation of financial losses is especially of importance to help provide a better overall view of the impact of disease and to contribute to estimating the extent of the losses to be avoided (Dijkhuizen et al., 1997). Assessing PRRS impact at the farm level may also help to identify areas within the production system that are more sensitive to the disease, and to design more cost-effective prevention or management strategies.

To estimate the bioeconomic impact of animal diseases, various types of models have been proposed, ranging from simple to more complex, stochastic, individual, or agent-based models (Dijkhuizen et al., 1997; Rahmandad and Sterman, 2008; Carpenter and Sattenspiel, 2009; Dürr et al., 2013; Patyk et al., 2013; Liang et al., 2017; Dolechek et al., 2018). Stochastic simulation is an efficient way to model natural processes due to its ability to capture the uncertainty and variability that are intrinsic to complex systems as animal production systems are (Soize, 2013; Liang et al., 2017; Dolechek et al., 2018; Nathues et al., 2018; Wang et al., 2018). Stochastic models use probability distributions estimated from historical data or deduced from expert opinion to indicate uncertainty and variation in factors that limit the outcome (Wang et al., 2018). Besides, stochastic models can account for interrelationships between input variables and provide confidence intervals around the output estimates. Stochastic modeling, however, heavily depends on the availability of reliable data needed to properly describe variation and uncertainty.

Recently, a few studies have investigated the bioeconomic impact of PRRS on pig farms (Holtkamp et al., 2013; Nathues et al., 2017; Renken et al., 2021; Zhang et al., 2022). In USA, regression analysis on national production data was used to assess PRRS impact at country level (Neumann et al., 2005; Holtkamp et al., 2013). Economic analysis of PRRS outbreaks in nine sow herds was performed using a partial budgeting approach (Nieuwenhuis et al., 2012). At farm level, Zhang et al. (2022) applied cost and revenue analysis to estimate PRRS impact in four Chinese farms. A farm level stochastic simulation model was developed to study PRRS bioeconomic effects under nine different scenarios (Nathues et al., 2017). The same model was later used to assess economic effect of PRRS in twenty one pig herds in Germany (Renken et al., 2021).

Results from these studies have shown that the impact of PRRS on pig farms can be highly variable, depending on multiple factors, such as the prevalence of the disease, type of farm and the production circumstances affecting the farm (Velasova et al., 2012; Nathues et al., 2018). Reduction in farrowing rate associated to PRRS has been reported between 6.2% (Olanratmanee et al., 2011) and 10.9% (Neumann et al., 2005). In the same way, the decrease in number of pigs weaned per sow/yr due to PRRS have been estimated in the order of 1.44 (Holtkamp et al., 2013), 1.92 (Valdes-Donoso et al., 2018), or 4.72 (Neumann et al., 2005).

All aforementioned studies were carried out in temperate regions and studies under tropical circumstances do not exist. Pig production under tropical circumstances differs with respect to non-tropical circumstances in aspects such as the type of housing, genetics, environment, pig density as well as management programs and investments. Given the location of Costa Rica within the equatorial zone, several factors combine to facilitate the appearance and permanence of PRRS. Costa Rican climate is characterized by warm temperatures and high humidity, which may promote PRRSV dissemination (Cuéllar-Sáenz, 2021). Seropositive herds are mainly in the central and northern areas of the country, due to the high density of pig farms in this region.

Development of a bioeconomic simulation model to investigate bioeconomic impact of PRRS under tropical circumstances can contribute to first insights in the height of the impact of the disease, and can be a starting point for evaluation of prevention and management strategies. Therefore, the objective of this study was to evaluate production and economic parameters of a PRRS-free baseline scenario against three scenarios with low, medium and high PRRS effects for a medium-sized farrow-to-finish pig farm system in Costa Rica, using a stochastic simulation model. Moreover, this model was built taking into consideration variability and uncertainty in farm and market related input variables.

2. Material and methods

2.1. Modelling approach

A farm-level bio-economic stochastic Monte Carlo simulation model was developed to represent the bioeconomic performance during one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system, working under the tropical circumstances prevailing in Costa Rica. The basic structure of the model was built in MS-Excel with stochastic elements added by @RISK software for Excel, version 5.5.0 (Palisade Corporation, 2009). Input variables were specified by probability distributions, while biological and economic output parameters were derived as mathematical functions of these input variables. The entire model, with disabled stochastic components, is provided as supplementary data to the online version of this paper (Supplementary material, section: Model). The effect of PRRS on biological and economic parameters was assessed by scenario analysis, in which a baseline PRRS-free scenario was compared against three alternative scenarios that assumed low, medium and high PRRS effects.

2.2. Model development for baseline scenario

The bio-economic model relied on the specification of input parameters describing the baseline PRRS-free scenario for the system under study. Between-farm variation in input parameters for the baseline scenario was simulated by drawing random samples from different probability distributions. Input parameters that were assumed unaffected by PRRS (Tables 1, 2, 3) are presented separately from those that were assumed affected (Table 4). Specific input parameters are presented for breeding (sows, gilts and boars; Table 1) and production stages (pre-weaning, nursery and fattening; Table 2).

The choice of adequate probability distributions to represent input parameters relied on different criteria, according to the type of variable and availability of information. @RISK distribution-fitting option was used to assess the goodness of fit for different distributions applied to real panel data provided by 17 pig farms (supplementary material, section: Farm data). This was mainly the case for breeding and reproduction parameters (Tables 1 and 4). These variables generally showed heavily skewed distributions, which were described using functions such as Lognormal, Loglogistic, Extreme Value or Exponential. When no real data was available, distribution parameters were based on previous studies or authors' expertise (Tables 1 to 4).

Baseline values for breeding and production parameters were partially based on average performance observed in local farms that had been previously tested negative for PRRS (Tables 1 and 2; supplementary material, section: Farm data). Production parameters were mostly assumed as normally distributed with standard deviations based on the assumption of very low (1%, i.e., dressing percentage), low (5%, i.e., feed consumption, growth rates, costs, prices) or moderate (10%, i.e., mortality, culling rates) variation coefficients (Tables 2 and 4). To minimize the impact of extreme values, samples were restricted between percentiles 1 and 99 within each probability distribution.

Fixed target body weights of 7, 30 and 100 kg were assumed for weaning, nursery and fattening production stages, respectively (Table 2), according to most common practices in local pig farms (Padilla-Pérez, 2007; Campabadal, 2009; Vargas-Céspedes et al., 2018). Linear growth rates with normally distributed between-farm variation were assumed for each production stage. Between-farm variation in growth rates was based on observed local performance (Campabadal, 2009).

Economic parameters for the baseline scenario (Tables 1 and 2), such

Table 1
Assumed average values ($\overline{X}$) and their distribution (σ) for input parameters related to breeding and assumed unaffected by PRRS during one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

	Unit	Distribution	$\overline{X}$	σ	Source
Sows					
Number of adult breeding sows	n	*fixed*	588	-	Arango-Trujillo (2020)
Adult weight	Kg	Normal	200	10	Campabadal (2009)
Daily feed consumption during gestation	Kg	Normal	2.75	0.14	Campabadal (2009)
Daily feed consumption during lactation	Kg	Normal	7.00	0.35	Campabadal (2009)
Price per kg feed (gestation period)	US $	Normal	0.53	0.03	C.N.P (2022)
Price per kg feed (lactating period)	US $	Normal	0.59	0.03	C.N.P (2022)
Labour costs per sow per day	US $	Normal	0.05	0.001	M.T.S.S (2022)
Other fixed costs (per sow per litter)	US $	Normal	5.00	0.25	Arango-Trujillo (2020)
Gilts					
Target weight at first service	Kg	*fixed*	130	-	Campabadal (2009)
Proportion of gilts selected for sale	%	Normal	30	3	Authors expertise
Daily weight gain (exit nursery to first service)	Kg	Normal	0.50	0.03	Campabadal (2009)
Daily feed consumption (exit nursery to first service)	Kg	Normal	2.25	0.11	Campabadal (2009)
Price per kg feed	US $	Normal	0.55	0.02	C.N.P (2022)
Labour cost (per gilt per day)	US $	Normal	0.03	0.002	M.T.S.S (2022)
Other fixed costs (per gilt, entire period)	US $	Normal	4.75	0.24	Arango-Trujillo (2020)
Sale price	US $	Normal	300	15	C.N.P (2022)
Boars					
Adult weight	Kg	Normal	325	15	Campabadal (2009)
Annual replacement rate	%	Normal	33	3.3	Supp. Farm data
Involuntary culling rate	%	Normal	2	0.2	Supp. Farm data
Sows to boar ratio	n	Normal	100	10	Supp. Farm data
Daily feed consumption	Kg	Normal	3.50	0.18	Campabadal (2009)
Price of replacement	US $	Normal	2700	135	C.N.P (2022)
Price semen (per AI doses)	US $	Normal	10.0	0.05	Arango-Trujillo (2020)
Labour cost (per boar per year)	US $	Normal	1.18	0.06	M.T.S.S (2022)
Other fixed costs (per boar per year)	US $	Normal	315	15.8	Arango-Trujillo (2020)

as costs for breeding, transportation and processing, or fixed farm costs, were obtained from a local consulting firm that provided average economic indexes for medium sized (500–1000 sows) pig farms (Arango-Trujillo, 2020). This information was available for specific production stages as well as for the entire production cycle. Other economic data, such as feed and pork prices and labour costs, were obtained from publicly available information provided by government institutions (C.N.P, 2022; M.T.S.S, 2022; Tables 1 and 2).

To account for possible interrelation between input parameters, linear correlations in the range between 0.40 and 0.85 were assumed (Table 3). The magnitude of some correlations, such as litter size vs. stillbirths vs. % mummies was based on trends observed in real farms (supplementary material, section: Farm data). In other cases, values were based on biological assumptions according to authors expertise, such as the high correlation assumed between daily weight gain and daily feed consumption. Economic parameters, such as feed or treatment costs or product prices were also assumed with high positive correlation, because these all are equally affected by prevailing market conditions (Table 3).

2.3. *PRRS scenario analysis*

Three alternative scenarios, assuming low, medium and high PRRS effects, were compared against the baseline scenario (Table 4).

In Costa Rica, type II is the prevailing species of PRRSV, and it is endemic in most pig farms in the country (Guzmán-Saborío, 2020; Meléndez et al., 2021). This species is also known to produce more pronounced respiratory effects than type I (Martínez-Lobo et al., 2011). Therefore, the effect of PRRS in the present analysis was assumed to act all over the entire production cycle, causing increased mortality and reproductive failure in breeding, as well as delayed growth, increased time to market and higher mortality and veterinary costs in growing pigs.

Parameters known to be affected by PRRS were selected based on previous studies (Neumann et al., 2005; Olanratmanee et al., 2011; Nieuwenhuis et al., 2012; Holtkamp et al., 2013; Nathues et al., 2017; Renken et al., 2021). Baseline values for these parameters were based on average performance of local PRRS-negative farms (supplementary material, section: Farm data). In the case when performance for PRRS negative farms was equal or worse than positive farms, the respective input parameter was based on the farm with the best performance among those negatives to PRRS, following the procedure described by Renken et al. (2021). Input parameters assumed unaffected by PRRS kept values identical to baseline scenario.

For PRRS-low, medium and high scenarios, input parameters assumed to be affected by PRRS were modified by fixed values reflecting the intensity of PRRS effect (Table 4). These values were derived from a combination of information sources, in the next priority order: local data for PRRS-positive farms (supplementary material, section: Farm-data), data from previous local studies (Guzmán-Saborío, 2020; Meléndez et al., 2021) and data from other non-local studies (Neumann et al., 2005; Olanratmanee et al., 2011; Nieuwenhuis et al., 2012; Holtkamp et al., 2013; Nathues et al., 2017; Renken et al., 2021). When local data were not available on a certain parameter, authors' expertise was applied to adapt non-local data to local circumstances (Table 4).

2.4. *Biological and economic output variables*

Biological output parameters were calculated at the animal and farm level. For a complete description of all formulae see provided supplementary material to the online version of this paper (section: Model). Calculation of main output variables is described below with the abbreviations we also used in the supplementary material.

The number of pigs to slaughter per breeding sow per year (PFSY) is calculated by the number of weaned pigs per year (PWSY), corrected for the mortality during nursery (1-NUIC%) and during finishing (1-FAIC

Table 2

Assumed values ($\overline{X}$) and their distribution (σ) for input parameters related to production stages and assumed unaffected by PRRS during one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

	Unit	Distribution	$\overline{X}$	σ	Source
Pre-Weaning (birth to 7 kg)					
Birth weight piglets	kg	Logistic	1.52	0.14	Campabadal (2009)
Labour costs (per piglet alive/ per day)	US $	Normal	0.26	0.012	M.T.S.S (2022)
Other fixed costs (per piglet alive / preweaning)	US $	Normal	4.50	0.23	Arango-Trujillo (2020)
Nursery (weaning to 30 kg)					
Target final weight	kg	*fixed*	30	-	Campabadal (2009)
Daily feed consumption	kg	Normal	0.63	0.03	Campabadal (2009)
Price per kg feed	US $	Normal	0.56	0.03	C.N.P (2022)
Labour costs (per weaner per day)	US $	Normal	0.06	0.003	M.T.S.S (2022)
Other fixed costs (per weaner per period)	US $	Normal	2.40	0.13	Arango-Trujillo (2020)
Fattening (30–100 kg)					
Target final weight to slaughter	kg	*fixed*	100	-	Campabadal (2009)
Daily feed consumption	kg	Normal	2.50	0.13	Campabadal (2009)
Dressing percentage	%	Normal	78	1.0	C.N.P (2022)
Price per kg carcass weight at slaughter	US $	Normal	2.90	0.15	C.N.P (2022)
Price per kg feed	US $	Normal	0.54	0.03	C.N.P (2022)
Plant processing cost	US $	Normal	16.0	0.80	Arango-Trujillo (2020)
Transportation cost	US $	Normal	2.00	0.10	Arango-Trujillo (2020)
Labour costs (per pig per day)	US $	Normal	0.02	0.001	M.T.S.S (2022)
Other fixed costs (per pig per period)	US $	Normal	1.00	0.05	Arango-Trujillo (2020)

Table 3

Linear correlations assumed in the modeling for input parameters.

Correlated input parameters	Correlation	Source
Daily weight gain vs. Daily feed consumption (within stages)	0.75	Authors expertise
Replacement rate vs. culling rate	0.40	Supp. data
Litter size vs. % stillborn vs. % mummies	0.50	Supp. data
Labour cost (between different stages)	0.85	Arango-Trujillo (2020)
Feed price (between different stages)	0.85	Arango-Trujillo (2020)
Health treatment costs (between different stages)	0.50	Arango-Trujillo (2020)
Fixed costs (between different stages)	0.85	Arango-Trujillo (2020)
Sale prices of boars vs. gilts	0.85	C.N.P (2022)

%), minus the number of gilts needed to replace the culled sows (1 * [RPR%+GIC%]).

To obtain biological parameters at the farm scale, previous calculations performed at the breeding sow level were scaled according to the number of adult breeding sows in the farm (ABSW, Table 4). Final outcome was expressed as kg of live pigs or carcass weight per farm/year.

Total annual revenues (TREVFY), costs (TCOFY), and profit (TREVFY-TCOFY) per farm per year were calculated. Farm revenues were obtained as the sum of revenues related to the sale of fat pigs (REVSP) + culled sows (or boars) (REVSB) + the sale of replacement gilts (REVGI), when these were in excess or replacement requirements. Farm costs were obtained as the sum of costs related to feeding of pigs in different stages (COSFE1–5), breeding (COSBR), transport and processing (COSTRP), health treatment (COSHT), labour (COSLAB), and other fixed costs (COSOT). Further details on assumed costs were given in Tables 1, 2, and 4.

Other parameters related to economic efficiency were also derived, such as revenues/costs ratio or production cost per kg carcass weight. By comparing baseline to the PRRS scenarios, other parameters such as PRRS-induced loss per farm per year, PRRS-induced loss per slaughtered pig per year, and PRRS-induced loss per breeding sow per year were also obtained. Further details on all these calculations are provided in the supplementary material.

Sensitivity analysis was also performed in order to estimate marginal change in farm profit (US $ per year), associated to one standard deviation increase in each input parameter. This analysis also provided break-even points for different scenarios. Results of this analysis were summarized by a tornado graph.

2.5. Model verification and validation

Verification and validation of the model was done by applying techniques described by Sargent (2011). In order to ensure that stable solutions were obtained, output parameters were tested for convergence, defined as a 95% chance that the mean of the tested outputs was within 3% of its true value (Palisade Corporation, 2009). Animation was performed to dynamically monitor distribution properties of input and output variables through the iteration process. Final distributions for input variables were compared to intended distributions. Achieved correlations between input variables were also compared to intended correlations. Simulation results were screened for occurrence of mathematical or numerical errors.

Validation of the model was initially performed by face validity procedures (Sargent, 2011), checking for biological consistency of output parameters according to authors expertise. Sensitivity analysis also allowed for a thorough evaluation of model consistency over the entire set of input combinations (50,000), and to test for reasonability (direction and magnitude) of observed relationships between different input and output variables, according to authors expertise. In a second step, calculated outputs for biological variables in the baseline scenario were compared, when available, against real data from PRRS negative farms (supplementary material, section: Farm-data). Further comparison of results from baseline scenario was also performed against values reported in previous local studies (Salazar-Villanea and Dorado-Montenegro, 2018; Vargas-Céspedes et al., 2018). Calculated economic performance was compared to real data supplied by a local consulting firm (Arango-Trujillo, 2020) considering aspects such as distribution of costs and revenues, revenues/cost ratio and production cost per kg of carcass weight. Regarding PRRS effect, results were compared to similar simulation studies such as Nathues et al. (2017) and Renken et al. (2021), as well as studies performed on the impact of PRRS in real pig farms, such as Neumann et al. (2005), Nieuwenhuis et. al (2012) and Holtkamp et al. (2013).

Table 4

The assumed values ($\overline{X}$) and their distribution (σ) for a baseline scenario (no PRRS) and the change in values for different PRRS scenarios (low, medium, high) for input parameters assumed affected by PRRS during one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

	unit	Baseline Scenario		Marginal change under PRRS-scenario			
		Distribution	$\overline{X}(\sigma)$*	Low	Med	High	Source
Sows							
Conception rate	%	Pert	90 (3.3)[a]	-2	-4	-6	al
Abortion rate	%	Lognormal	2 (1)[a]	+ 1	+ 2	+ 3	adef
Interval weaning to first-service	d	Lognormal	6 (4)[a]	+ 2	+ 4	+ 8	al
Repeated breeding rate	%	Lognormal	6 (5)[a]	+ 3	+ 6	+ 9	adef
Mortality rate in adult sows	%	Lognormal	3 (2)[a]	+ 1	+ 2	+ 3	al
Culling rate in adult sows	%	Normal	27 (2)[a]	+ 1	+ 2	+ 3	al
Health treatment costs (Per sow per litter)	US $	Normal	15 (0.7)[b]	+ 0.75	+ 1.50	+ 2.25	bd
Pre-weaning							
Litter size	n	Extreme Value	11.6 (0.9)[a]	-0.5	-1	-2	adefgh
Stillborn rate	%	Exponential	1.8 (1.5)[a]	+ 1	+ 2	+ 3	af
Mummies rate	%	Lognormal	1.6 (2.2)[a]	+ 1	+ 2	+ 3	af
PRRS morbidity rate	%	*fixed*	0	+ 10	+ 20	+ 30	l
Daily weight gain	kg	Normal	0.23 (0.01)[c]	-0.05	-0.10	-0.15	acde
Involuntary culling rate	%	Lognormal	6 (6)[a]	+ 1	+ 2	+ 3	adegh
Health treatment costs (Per piglet alive)	US $	Normal	5 (0.25)[b]	+ 0.25	+ 0.50	+ 0.75	bl
Nursery							
Involuntary culling rate	%	Normal	2.5 (0.25)[a]	+ 1	+ 3	+ 5	degil
PRRS morbidity rate	%	*fixed*	0	+ 10	+ 20	+ 30	dejkl
Daily weight gain	kg	Normal	0.42 (0.01)[c]	-0.10	-0.15	-0.20	deil
Health treatment costs (Per weaner)	US $	Normal	2 (0.1)[b]	+ 0.1	+ 0.2	+ 0.3	bdl
Fattening							
Involuntary culling rate	%	Normal	2 (0.2)[a]	+ 1	+ 2	+ 3	adehi
PRRS morbidity rate	%	*fixed*	0	+ 10	+ 30	+ 50	del
Daily weight gain	kg/d	Normal	0.875 (0.05)[c]	-0.1	-0.15	-0.2	cdhi
Health treatment costs (per pig/yr.)	US $	Normal	1.3 (0.06)[b]	+ 0.1	+ 0.20	+ 0.30	bdi
Gilts and boars							
Involuntary culling rate gilts (From weaning to 1rst farrowing)	%	Normal	5 (0.5)[a]	+ 1	+ 2	+ 3	ah
PRRS morbidity rate	%	*fixed*	0	+ 10	+ 20	+ 30	jkl
Daily weight gain gilts (From exit nursery to first service)	kg	Normal	0.42 (0.01)[c]	-0.10	-0.15	-0.20	cl
Health treatment costs (per gilt/yr.)	US $	Normal	12.50 (0.63)[b]	+ 0.63	+ 1.25	+ 1.88	bl
Health treatment costs (per boar/yr.)	US $	Normal	2.6 (0.13)[b]	+ 0.13	+ 0.26	+ 0.39	bl

*@RISK complete functions describing distributions are given in supplementary material, section Model.

Information sources: [a] Supplementary material (section: farm-data), [b]Arango-Trujillo (2020), [c]Campabadal (2009), [d]Nathues et al. (2017), [e]Renken et al. (2021), [f]Olanratmanee et al. (2011), [g]Nieuwenhuis et al. (2012), [h]Holtkamp et al. (2013), [i]Neumann et al. (2005), [j]Meléndez et al. (2021), [k]Guzmán-Saborío (2020), [l]Authors expertise

3. Results

3.1. Baseline scenario and sensitivity analysis

The simulation model produced stable solutions and convergence was confirmed for all output parameters. No calculation errors or output values outside the normal biological ranges were observed. After 50,000 iterations descriptive statistics and histograms were obtained for 64 different input variables (supplementary material, section: Inputs) and 269 output variables (supplementary material, section: Outputs). Final distributions were compared and confirmed according to specified input parameters.

Results obtained from the baseline scenario represent PRRS-free local farm performance. The model calculated that 159 d are required for a pig to reach the required target weight of 100 kg, distributed in periods of 24, 55, and 80 d in pre-weaning, nursery and fattening stages, respectively (Table 5). The simulated farm produced 24.6 piglets born alive per breeding sow, of which 21.8 will reach the market, to produce an amount of 2182 kg of live pigs to slaughter (Table 5). The model calculated that the standard medium-size farm (588 sows) will produce 1291 litters and 14,997 newborn piglets, for a final number of 12,659 pigs and 1,265,905 kg of live pigs to slaughter per year (Table 6).

Results of economic analysis under baseline scenario reflect farm profitability under current circumstances for PRRS-free farms. Revenues and costs under baseline scenario were close to US $ 3.0 and 2.7 million, respectively, with an average final profit estimated at US $322,651 per farm per year (Table 7). Revenues were mainly obtained from slaughtered pigs (95.7%), with much lower contributions from culled sows and boars (2.5%) and the sale of gilts (1.8%) (Fig. 1). Costs were mainly due to feeding (74.6%), followed by transport and processing (8.5%), labour (6.3%), health treatment (5.2%), breeding (0.7%), and other fixed costs (4.5%) (Fig. 1). Mean production cost was estimated at US $2.63 per kg of carcass weight (Table 7).

From the sensitivity analysis, specific input parameters were identified, external or internal to the farm, with a larger impact on farm profit (Fig. 2). As can be seen, parameters with a larger positive association with farm profit remained, in descending order: carcass price, daily weight gain (fattening pigs), litter size, dressing percentage and conception rate. All these variables, except for carcass price, are also known to be affected by PRRS. According to the model, an increase of one standard deviation in carcass price (US $0.15, Table 2) was associated with an increase of US $137,277 in farm profit. On the contrary, parameters with the larger negative impact on farm profit were the price of feed (fattening pigs), daily feed consumption (fattening pigs), pre-weaning involuntary culling, interval weaning to first service, and percentage of mummies. As an example, an increase of one standard deviation in price of feed (US $0.03 kg, Table 2) was associated with a decrease of US $64,810 in farm profit.

Table 5

Calculated mean animal-level output values ($\overline{X}$)for the baseline scenario (No PRRS) and the mean values ($\overline{X}$)and relative change (% Δ) for scenarios with low, medium and high affectation by PRRS for a one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

Parameter within stage	Unit	Baseline	PRRS-Low	PRRS-Medium	PRRS-High
Pre-Weaning		$\overline{X}$	$\overline{X}$ *(% Δ)*	$\overline{X}$ *(% Δ)*	$\overline{X}$ *(% Δ)*
Days to Weaning	d	24	24 (0)	26 (+8)	30 (+25)
Nursery					
Time spent at nursery	d	55	56 (+2)	59 (+7)	64 (+16)
Age at exit	d	79	81 (+3)	85 (+8)	94 (+19)
Feed consumption (per piglet)	kg	34.5	35.3 (+2)	37.2 (+8)	40.2 (+17)
Feed conversion	kg	1.50	1.54 (+3)	1.62 (+8)	1.75 (+17)
Fattening					
Time spent at fattening	d	80	81 (+1)	85 (+6)	91 (+14)
Final age to slaughter	d	159	162 (+2)	170 (+7)	184 (+16)
Feed consumption per pig (weaning to slaughter)	kg	235	238 (+1)	248 (+6)	266 (+13)
Feed conversion (weaning to slaughter)	kg	2.52	2.56 (+2)	2.67 (+6)	2.86 (+13)
Feed conversion (fattening period)	kg	2.86	2.89 (+1)	3.01 (+5)	3.23 (+13)
Gilts					
Time spent as replacement	d	200	205 (+3)	213 (+7)	228 (+14)
Age at first service	d	279	285 (+2)	299 (+7)	322 (+15)
Age at first parity	d	394	401 (+2)	415 (+5)	439 (+11)
Sows					
Farrowing rate	%	88	85 (−3)	82 (−7)	79 (−10)
Interval weaning to effective service	d	8	11 (+38)	14 (+75)	19 (+138)
Farrowing interval	d	146	149 (+2)	154 (+5)	163 (+12)
Litters per sow/year	n	2.50	2.44 (−2)	2.37 (−5)	2.24 (−10)
Piglets born alive per litter	n	11.2	10.6 (−5)	9.8 (−13)	8.7 (−22)
Weaned piglets per litter	n	10.5	9.8 (−7)	9.0 (−14)	7.9 (−25)
Age at culling	mo	40.6	38.0 (−6)	35.7 (−12)	33.7 (−17)
Annual replacement rate	%	30.0	32.0 (+7)	34 (+13)	36 (+20)
Litters per sow lifetime	n	5.76	5.05 (−12)	4.35 (−24)	3.60 (−38)
Productive lifetime	d	840	754 (−10)	671 (−20)	585 (−30)
Nonproductive lifetime	d	47	57 (+21)	63 (+34)	71 (+51)
Feed consumption, per lactating sow/year	kg	419	418 (<1)	434 (+4)	467 (+11)
Feed consumption, per pregnant sow/year	kg	336	344 (+2)	352 (+5)	366 (+9)
Breeding sow (per sow/ year)					
Litters	n	2.20	2.07 (−6)	1.94 (−12)	1.77 (−20)
Piglets born alive	n	24.6	21.9 (−11)	19.0 (−23)	15.4 (−37)
Weaned piglets	n	23.2	20.4 (−12)	17.5 (−25)	14.0 (−40)
Pigs to slaughter	n	21.8	18.7 (−14)	15.5 (−29)	11.9 (−45)
Kg of live pigs to slaughter	kg	2182	1870 (−14)	1550 (−29)	1188 (−46)

Table 6

Calculated mean farm-level output values ($\overline{X}$, per farm/year) for the baseline scenario (No PRRS) and the mean values ($\overline{X}$)and relative change (% Δ) for scenarios with low, medium and high affectation by PRRS for a one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

	units	Baseline	PRRS-Low	PRRS-Medium	PRRS-High
		$\overline{X}$	$\overline{X}$*(% Δ)*	$\overline{X}$*(% Δ)*	$\overline{X}$*(% Δ)*
Litters	*n*	1291	1217 (−6)	1138 (−12)	1039 (−20)
Newborn piglets	*n*	14,997	13,527 (−10)	12,083 (−19)	9988 (−33)
Piglets born alive	*n*	14,465	12,860 (−11)	11,170 (−23)	9033 (−38)
Weaned piglets	*n*	13,641	11,998 (−12)	10,309 (−24)	8246 (−40)
Gilts selected for replacement	*n*	382	400 (+5)	417(+9)	435 (+14)
Gilts selected for sale	*n*	176	176 (0)	176(0)	176 (0)
Culled adult sows culled	*n*	159	165 (+4)	171(+8)	176 (+11)
Present adult boars	*n*	6	6 (0)	6(0)	6 (0)
Services required	*n*	1404	1409 (<1)	1404(<1)	1366 (−3)
Pigs entering fattening	*n*	12,917	11,178 (−14)	9325 (−28)	7193 (−44)
Fat pigs to slaughter	*n*	12,659	10,843 (−14)	8952 (−29)	6833 (−46)
Kg live pigs to slaughter	*kg*	1265,905	1084,259 (−14)	895,204 (−29)	683,331 (−46)
Kg carcass weight (Fattening pigs)	*kg*	987,405	845,722 (−14)	698,258 (−29)	532,997 (−46)
Kg carcass weight (Culled sows and boars)	*kg*	27,338	28,351 (−4)	29,360 (−7)	30,372 (−11)

Table 7

Calculated economic output parameters (mean $\overline{X}$, with percentiles P5%and P95%between brackets) for the baseline scenario (No PRRS) and scenarios with low, medium and high affectation by PRRS for a one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

Parameter	Baseline	Low-PRRS	Medium-PRRS	High-PRRS
	$\overline{X}$	$\overline{X}$	$\overline{X}$	$\overline{X}$
Total revenues (US $/farm/yr)	2991,734 *(2485,892/ 3525,066)*	2581,719 *(2137,944/ 3052,862)*	2158,773 *(1781,546/ 2563,536)*	1682,300 *(1379,292/ 2016,308)*
Total costs (US $/farm/yr)	2669,083 *(2290,916/ 3069,543)*	2401,610 *(2060,868/ 2765,051)*	2161,082 *(1855,324/ 2491,399)*	1884,369 *(1616,702/ 2180,341)*
Total, profit (US $/farm/yr)	322,651 *(17,459/ 641,321)*	180,109 (−84,179/ 456,123)	-2309 *(−225,919/ 230,396)*	-202,068 *(−382,215/ −16,200)*
Revenues/Costs ratio	1.12 *(1.01/1.24)*	1.08 *(0.96/1.19)*	1.00 *(0.90/1.11)*	0.89 *(0.80/0.99)*
Production cost (US $/kg carcass weight)	2.63 *(2.45/2.83)*	2.76 *(2.56/2.96)*	2.98 (2.76/3.21)	3.35 *(3.09/3.64)*
PRRS-induced loss (US $/farm/yr)		-142,542 (−186,322/ −100,737)	-324,960 *(−415,438/ −238,187)*	-524,719 *(−668,349/ −387,486)*
PRRS-induced loss (US $/slaughtered pig/yr)		-13.2 *(−16.7/ −9.7)*	-36.4 *(−44.9/ −28.0)*	-77.1 *(−94.8/ −56.6)*
PRRS-induced loss (US $/breeding sow/yr)		-242 *(−317/ −171)*	-553 *(−707/ −405)*	-892 *(−1137/ −659)*

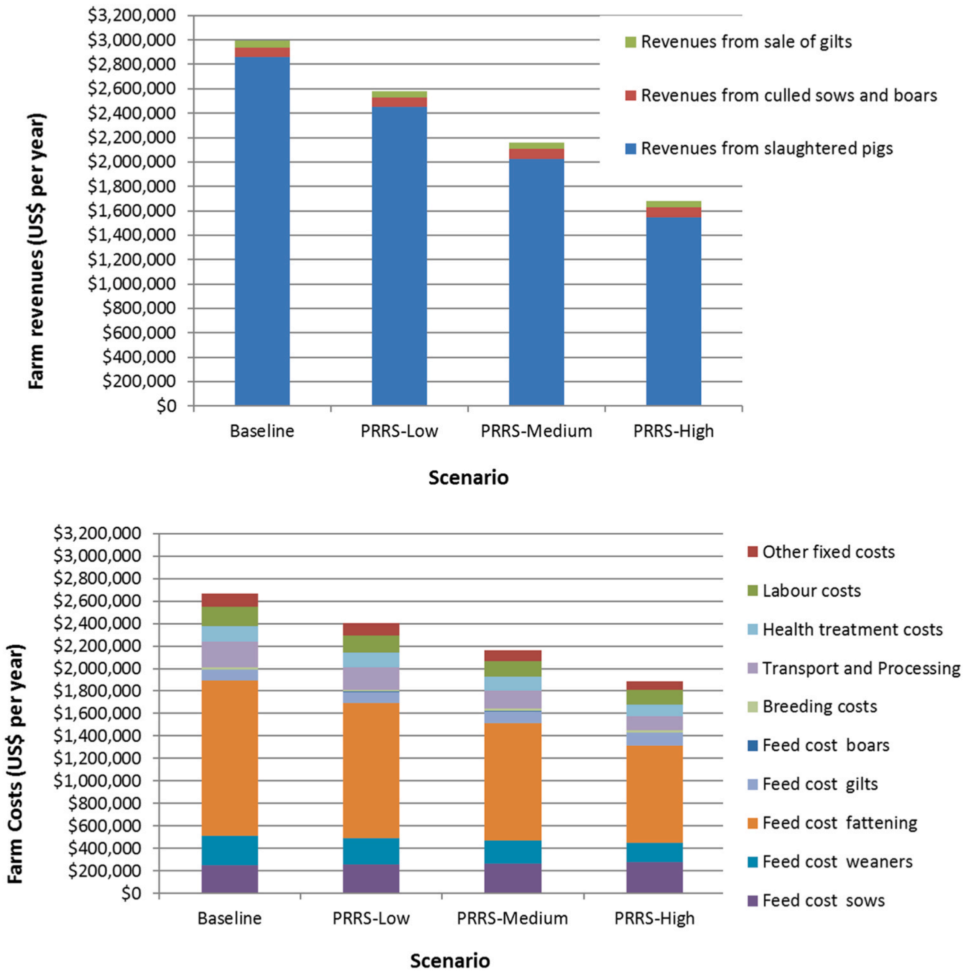

Fig. 1. Calculated distribution of revenues (upper) and costs (lower) for the baseline scenario (No PRRS) and scenarios with low, medium and high affectation by PRRS for a one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

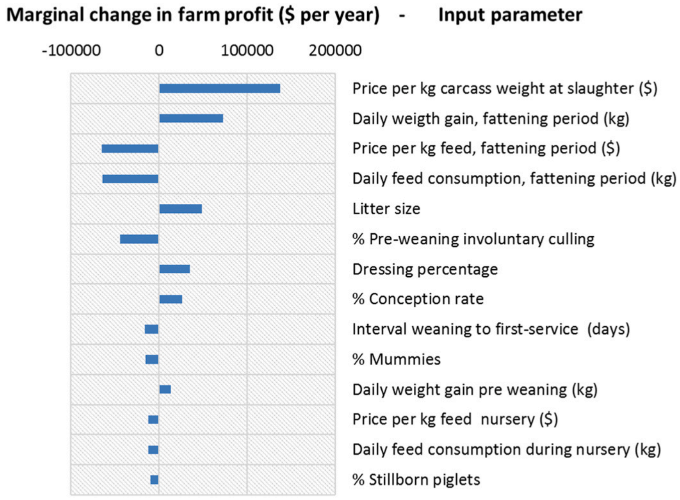

Fig. 2. Results of the sensitivity analyses expressed as the calculated marginal change in farm profit (US $ per year) associated to one standard deviation increase in corresponding input parameters under the baseline scenario (no PRRS) for a one-year production cycle of a medium-sized (588 breeding sows) farrow-to-finish pig farm system in Costa Rica.

3.2. PRRS scenarios

The model provides valuable insight about which variables within the production system are more sensitive to PRRS and to what extent this translates into economic loss at the farm level. At the animal level, most of the output variables calculated by the model showed a significant decrease in performance as the level of PRRS increased (Table 5). As a result of lower growth rates, average age to slaughter increased by 25 d from baseline scenario compared to PRRS-high scenario. Feed consumption (per animal/yr), and feed conversion, were also higher for PRRS scenarios compared to baseline. For gilts, the model calculated an increase of 43 days in age at first service from baseline compared to PRRS-high scenario.

The reduced reproductive performance linked to PRRS caused a decrease of 9.9 pigs to slaughter (per breeding sow/yr) in PRRS-high scenario compared to baseline scenario (Table 5). This reduction in fertility was also responsible for the observed increase of 6% in annual replacement rate, which also caused a reduction of 255 d in productive lifetime and 6.9 mo in age at culling of sows, while the average non-productive time increased by 24 d.

At farm level most of the output variables calculated by the model also showed a significantly lower performance as the level of PRRS increased (Table 6). The decrease in fertility, together with the increase in time required to reach the target market weight, caused a reduction of 5826 (46%) live pigs to market per farm/yr from baseline compared to PRRS-high scenario (Table 6). Decreased fertility was also responsible for the increase in number of gilts selected for replacement and the number of culled sows.

Regarding the economic analysis, the model calculated a progressive decrease in both, farm revenues and costs, as a result of PRRS (Fig. 1, Table 7). The reduction in revenues was far larger than the reduction in costs (Fig. 1, Table 7), consequently farm profit was reduced by US $ 142,542 from baseline to PRRS-low scenario, and turned negative for PRRS-medium and high scenarios. PRRS-induced loss was estimated at US $ 524,719 per farm/yr for PRRS-high scenario. Revenues/costs ratio changed from 1.12 in the baseline to 0.89 in the PRRS-high scenario.

Confidence intervals (P5%-P95%) for farm profit were wide for all scenarios, which reflect the large impact of variability and uncertainty (Table 7). For baseline scenario, 96% of the simulated farms achieved positive economic margin. This rate decreased rapidly to 87%, 48% and 4% for PRRS-low, medium and high scenarios, respectively. Results from sensitivity analysis showed that profitability in PRRS-positive scenarios was only achieved when average carcass prices were US $2.92 (low), US $2.98 (medium) and US $3.09 (high), compared to US $2.91 for baseline scenario. The production cost per kg carcass weight increased from US $ 2.63 in the baseline to US $ 3.35 in PRRS-high scenario (Table 7). PRRS-induced loss was estimated at US $ 77 per slaughtered pig/yr and US $ 892 per breeding sow/yr for PRRS-high scenario.

4. Discussion

A stochastic simulation model was developed to compare economic and production parameters of a PRRS-free baseline scenario against three scenarios with low, medium and high PRRS effects, in a farrow-to-finish pig farm system in Costa Rica. The main difference in technical results between the baseline and the PRRS-high scenario were estimated as: + 25 d in age to slaughter, − 9.9 pigs to slaughter (per breeding sow/yr), and + 24 non- productive days. PRRSV-infection in a medium farm was estimated to decrease the number of fat pigs to slaughter by 14%, 28%, and 44%, which resulted economically in a loss of US $142,542, US $180,109 and US $524,719 per year for PRRS-low, medium and high scenarios, respectively. The production cost per kg carcass weight increased from US $2.63 for baseline to US $ 2.76, 2.98, and 3.35 in the different PRRS scenarios. PRRS-induced loss was estimated at US $77.1 per slaughtered pig/yr and US $892 per breeding sow/yr for PRRS-high scenario. These data add to other models, because the variability is taken into account in the input parameters and is reflected in the output parameters, both technically as economic.

4.1. Model performance

For the baseline scenario, calculated means for output variables obtained from the model were similar to values obtained from real farms that tested negative for PRRS (supplementary data, section: Farm data). Baseline model predictions for farrowing rate (88%), farrowing interval (146 d), and litters per farrowed sow/yr (2.50), were similar to best-case values observed for PRRS-free real farm (88.7%, 146 d and 2.46; respectively), while other parameters, such as the number of piglets weaned per sow/yr (23.2), replacement rate (30%) and nonproductive days (47 d) were similar to mean values observed in real farms (23.1, 35.8% and 42.3, respectively) (supplementary data, section: Farm data). These performance parameters are also within the range of parameters reported previously for local pig farms (Salazar-Villanea and Dorado-Montenegro, 2018; Vargas-Céspedes et al., 2018).

On the other hand, some output values calculated for the baseline scenario were generally better than previously reported performance for pig farms within Costa Rica. This was expected because baseline scenario in the model was defined to represent the performance of PRRS free farms, while the real situation is that PRRS is already present in a large proportion of farms within the country (Meléndez et al., 2021).

In our model, a fixed target body weight of 100 kg at slaughter was assumed, which resulted in an average age at slaughter of 159 d (90%CI: 152–167 d) for the baseline scenario. This is also consistent with local pig farms, in which final age and weight to slaughter has been reported to vary between 148 d (101 kg) to 188 d (115 kg) depending on the region within the country, the production system, and the genetic lines being used (Vargas Céspedes et al., 2018).

For the baseline scenario, our model calculated 88% (90%CI: 81–92) farrowing rate, 2.5 (90%CI: 2.36–2.60) litters per farrowed sow/yr, 2.2 litters per breeding sow (90%CI: 1.67–2.49), and 26.4 (90%CI: 22.8–30.0) weaned piglets per farrowed sow per yr. These results are also in line with local data, even though reproductive parameters are highly variable among local pig farms. A former study reported an average farrowing rate of 84.3%, 2.3 litters per farrowed sow/year and 23.6 weaned pigs per farrowed sow/yr (Salazar-Villanea and Dorado-Montenegro, 2018).

In the same way, our model calculated 2182 kg live pigs to slaughter per breeding sow/yr (CI90%: 18375–2535) for the baseline scenario, while local farms reported from 1770 to 2019 kg live pigs to slaughter per sow/yr (Castro-Villescas, 2022). Regarding economic parameters, the production cost calculated by our model for the baseline scenario was US $ 2.63 (90%CI: 2.45–2.83) per kg of carcass weight, which was in the same range as values reported locally, ranging between US $ 2.63 and US $ 2.85 for farms of different sizes (Arango-Trujillo, 2020).

4.2. PRRS effect

Regarding the impact of PRRS on biological parameters of pig farms, our results are generally consistent with previous studies, whether these were based on simulation or real data. Reduction in farrowing rate associated to PRRS has been reported between 6.2% (Olanratmanee et al., 2011) and 10.9% (Neumann et al., 2005), which is consistent with the reduction between 3% and 9% obtained for PRRS low/high scenarios in our study. In the same way, the decrease in number of pigs weaned per sow/yr have been reported in the order of 1.44 (Holtkamp et al., 2013), 1.92 (Valdes-Donoso et al., 2018), or 4.72 (Neumann et al., 2005), compared to values between 0.7 and 2.6 per farrowed sow, obtained for PRRS low/high scenarios in our study.

The estimated economic loss per slaughtered pig per yr ranged between US $ 13.2 and US $ 77 for low and high PRRS scenarios, respectively, while corresponding estimates per sow/yr ranged between US $ 242 and US $ 892. Although recent estimates from similar studies are scarce, but they are in the same range (Nathues et al., 2017; Renken et al., 2021; Holtkamp et al., 2013).

Economic parameters and assumptions vary widely in time and country, thus economic results from different models are difficult to compare. Besides, economic effects of PRRS depend highly on the production system, the stages assumed affected and the degree of affection assumed for PRRS. Despite these limitations, some coincidences can be found between different studies. Our results suggest that the decrease in farm revenues for PRRS-scenarios was mainly due to the large reduction in the number of slaughtered pigs. This finding has been also described as “revenue foregone” in previous studies (Dijkhuizen et al., 1997; Holtkamp et al., 2013; Nathues et al., 2017; Renken et al., 2021). Likewise, the decrease in farm costs (per year) in our model was mainly associated to lower animal inventory, which leads to lower feed costs, especially during the fattening stage. This has also been addressed as “costs saved” in previous studies (Dijkhuizen et al., 1997; Nathues et al., 2017; Renken et al., 2021).

Previous studies carried out in Costa Rica have reported the presence of PRRS in six of the seven provinces. The prevalence of positive farms was 44% (11/25), and overall, 58% (344/596) of the pigs were seropositive to PRRSV (Meléndez et al., 2021). These results strongly suggest that pig farms in Costa Rica are probably located between the medium and high PRRS-scenarios described in the present study, while a smaller number can be in the low prevalence scenario. Locally, several factors combine to facilitate the appearance and permanence of the disease within the country. According to the geographical distribution of PRRSV in Costa Rica, the seropositive herds are mainly in the central and northern areas of the country, due to the high density of pig farms in this region. Besides, according to a previous study, age and ecozones were significantly associated with PRRSV seroprevalence (Meléndez et al., 2021). Costa Rican climate is characterized by warm temperatures and high humidity, which may promote PRRSV dissemination (Cuéllar-Sáenz, 2021). Heat is known to act as an immunosuppressive factor especially in the areas closest to the sea. Sudden changes in temperature, sometimes between 10 and 15 degrees, can occur within the same the day.

Results from the sensitivity analysis also demonstrate that some of the input variables with the highest impact on farm profit, such as daily weight gain, litter size, pre-weaning mortality, conception rate, or percentage of stillbirths and mummies, are also among the variables that are most affected by PRRS. This confirms the high impact of PRRS of pig farms economics. Sensitivity analysis also demonstrated that farms suffering from PRRS will require very favorable market conditions in order to be profitable. The current circumstances, however, are quite the opposite, with local feed price close to $0.55 per kg.

With this study, the need for increased care and better management for this economic disease was reinforced. It is necessary to strengthen biosecurity, by identifying the main internal and external risks that affect farms. Factors such as the introduction of new animals to the farm (replacements and boars), uncontrolled artificial insemination, the transport of animals and the movements of pigs and people between the stages favors the permanence of the disease. Certain practices, such as the transfer of newborn piglets to other litters during the first 72 h after birth as well as mixing piglets at weaning, also favor the spread of the virus. Therefore, farms should make an effort to separate weaning and pass it to another place, such is the case of single-site farms.

Clearly, the extent to which all afore-mentioned practices will be cost-effective highly depends on specific farm efficiency parameters, the expected impact of a disease outbreak, and prevailing market circumstances. In this sense, this model can be used to balance the costs of implementing different prevention strategies against the costs implied by the disease. Biosecurity is a critical point in the country and especially with respect to PRRS. Preventive programs are weak, and vaccination has only just begun in the country, not without a feeling of misbelief. Eradication has been proposed as an alternative, however, given its high economic cost, it has been difficult to put it into practice. Finally, it is important to stress the lack of precise information regarding the extent of dissemination of this disease within the country and its current impact on pig industry. In this sense, our hope is that the model presented here will contribute to filling this knowledge gap.

5. Conclusion

The stochastic model described in this study provides a useful information to quantify the potential costs caused by PRRS and its overall impact at the farm level. The model demonstrated the high bioeconomic impact of PRRS in a farrow to finish pig farm system in Costa Rica. In the PRRS-high scenario 38% reduction in liveborn piglets and 44% less pigs entering the finishing barn, resulting in maximum loss of US $ 892 per sow and US $ 77.1 per fat pig.

Results from the model are the first attempt to estimate current impact of PRRS in local farms, which can be helpful in the design of better control strategies for this disease.

Assessing the impact of PRRS at the farm level may aid in the design of cost-effective prevention and management strategies, tailored for specific production circumstances and expected disease impact scenarios.

The impact of PRRS on the biological parameters of pig farms are generally consistent with previous studies whether based on simulation or real data.

The calculated losses give a good hint of the economic damage due to PRRS for the pig industry in Costa Rica.

Declaration of Competing Interest

All authors have no conflict of interest to report.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.106032.

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