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Cost-efficiency of mastitis control strategies on smallholder dairy farms

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ABSTRACT

Mastitis poses significant challenges to the global dairy industry, including smallholder farms, which contribute substantially to global milk production. In Indonesia, where smallholder farming is vital to the dairy sector, mastitis represents a substantial obstacle to sustainable milk production and farm profitability. The objectives of this study were to estimate the costs associated with mastitis on Indonesian smallholder dairy farms and evaluate the cost-efficiency of various mastitis control strategies. A stochastic Monte Carlo bio-economic simulation model was employed to mimic mastitis dynamics and to estimate the economic effect on a typical Indonesian dairy farm of 4 cows. Input parameter values were gathered from various sources including literature, fieldwork data collection, local research reports, and expert insights obtained from staff of a local cooperative, veterinarians, local university experts, and authors' expertise. Somatic cell count values were added to the model to monitor udder health and milk quality per time period of 2 wk. Blanket dry cow therapy was also included to refine mastitis dynamics. All simulation outcomes were aggregated per year and per farm. Results indicated that clinical and subclinical mastitis incurred costs of €101.98 and €73.22/farm per year, respectively. Clinical mastitis costs were primarily driven by culling (45%) and discarded milk (27%), whereas subclinical mastitis costs were shared between production loss (52%) and blanket dry cow therapy (48%). Five mastitis control strategies were evaluated, including postmilking teat disinfection, a higher manure removal frequency, washing udders with soap, udder health monitoring using the California Mastitis Test (CMT), and antibiotic treatment for subclinical mastitis. Among these, postmilking teat disinfection emerged as the only strategy with a positive net economic benefit, significantly reducing mastitis incidence and associated economic losses. This study further suggests that the cost-efficiency of udder health monitoring using the CMT and antibiotic treatment for subclinical mastitis depends on substantially reducing mastitis incidence. This finding highlights the need for farmers to combine with other cost-efficient control strategies, rather than relying solely on CMT and treatment strategy. Farmers, therefore, need to adopt strategies to lower the incidence rates of clinical and subclinical mastitis, thereby offsetting the costs when applying these strategies. In conclusion, the study emphasizes the economic burden of mastitis on smallholder dairy farms and the critical need for efficient control strategies to support improving the profitability and sustainability of smallholder dairy farms.

Key words: mastitis management, smallholder dairy farms, mastitis economic burden, bio-economic simulation

INTRODUCTION

Smallholder dairy farming plays a pivotal role in global milk production. Reportedly, ~53% of the world's dairy production takes place in low- and middle-income countries, where milk is predominantly produced by smallholder farmers (OECD-FAO, 2021). Similar to high-income countries, mastitis, the inflammation of the mammary gland, represents a substantial obstacle to sustainable milk production and farm profitability in such dairy farming systems (Getaneh et al., 2017; Sah et al., 2020; Khasanah et al., 2021) because of its high incidence (Nuraini et al., 2023; Zalizar et al., 2023) and effect (Getaneh et al., 2017; Romero et al., 2018; Mekonnen et al., 2019). Mitigating mastitis will, therefore, not only improve milk yield and quality but also

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-25. Nonstandard abbreviations are available in the Notes.

Table 1. Input parameter values for modeling the farm and cow dynamics on a typical Indonesian smallholder dairy farm containing 4 lactating cows

Parameter	Estimate (SD)	Unit	Distribution	Reference
Farm size	4	Cows	Constant	Fadillah et al., 2023a
Parity			Discrete	Hetherington et al., 2023
1	0.25			
2	0.23			
3	0.20			
4	0.15			
5	0.09			
6 and above	0.08			
Calving interval			PERT	Hetherington et al., 2023
Minimum	365	d		
Most likely	414	d		
Maximum	499	d		
305-d yield (SD)	4,500 (675)	kg	Normal	Hetherington et al., 2023
Parity adjustment factors for milk yield			Constant	Hartanto et al., 2020
Parity 1	0.99			
Parity 2	1.02			
Parity 3	1.03			
Parity 4 and above	1.11			
Calving season adjustment factors for milk yield			Constant	Hetherington et al., 2023; Susanto et al., 2023
Season 1 (dry)	0.97			
Season 2 (rainy)	1.03			

enhance the sustainability and resilience of smallholder farms (Tricarico et al., 2020).

Understanding the dynamics of mastitis is crucial for designing targeted control strategies (Gussmann et al., 2019a). Mastitis is multifactorial and has many risk factors (Fuenzalida et al., 2015; Fredebeul-Krein et al., 2022). By identifying these, efficient control strategies, both preventive and curative, can be developed to mitigate its effect (Ruegg, 2017; Tommasoni et al., 2023). Furthermore, quantifying the economic effect, including milk production losses and discarded milk, culling, labor, veterinary, and antibiotic costs, enables the formulation of cost-efficient control strategies (Seegers et al., 2003; Halasa et al., 2007; Hogeveen et al., 2011). However, the epidemiology and economic effects of mastitis and mastitis control strategies in the context of smallholder dairy farms are not well understood. Existing literature often focuses on the prevalence of mastitis and its risk factors, neglecting the specific challenges faced by smallholder farmers, such as insufficient education about mastitis management and limited access to efficient diagnosis and antibiotic treatment for subclinical mastitis (Setianingrum et al., 2019; Khasanah et al., 2021; Nuraini et al., 2023). Consequently, there is a lack of evidence-based recommendations tailored to support smallholder dairy farmers regarding mastitis management decision making (Romero et al., 2018; Mekonnen et al., 2019). The objectives of this study were to estimate the costs of mastitis on Indonesian smallholder dairy farms and provide insights into the costs and benefits of different control strategies aimed at mitigating the burden of mastitis. By employing a stochastic bio-economic modeling approach, this study endeavored to generate recommendations for improved mastitis management on smallholder dairy farms (Getaneh et al., 2017; Ferchiou et al., 2021).

MATERIALS AND METHODS

Dynamic Modeling of Herd Demographics and Mastitis Incidence

The basis for the current study was a previously developed stochastic dynamic simulation model aimed at estimating the annual farm-level costs of mastitis on Ethiopian dairy farms (Getaneh et al., 2017). With this model, we simulated the incidence of clinical and subclinical mastitis, which are dependent on the lactation stage and parity of the cows, in 26 time periods of 2 wk, representing a full year. At the start of each iteration, individual cows on the farm were assigned a specific parity, lactation stage, and calving interval. Mastitis dynamics were then modeled, with transition probabilities for each time period determined according to the cow's prior health status. The probability of clinical mastitis was adjusted by considering the previous number of clinical cases during the current lactation. Subclinical mastitis was simulated based on California Mastitis Test (**CMT**) scores. It was assumed that cows with subclinical mastitis exhibited 2 infected quarters with CMT scores of 1, 2, or 3, whereas the remaining 2 quarters remained healthy (i.e., had a CMT score of zero; Getaneh et al., 2017). The CMT score distribution was only applied to cows whose teats were identified as being infected with subclinical mastitis. Milk losses, including those from

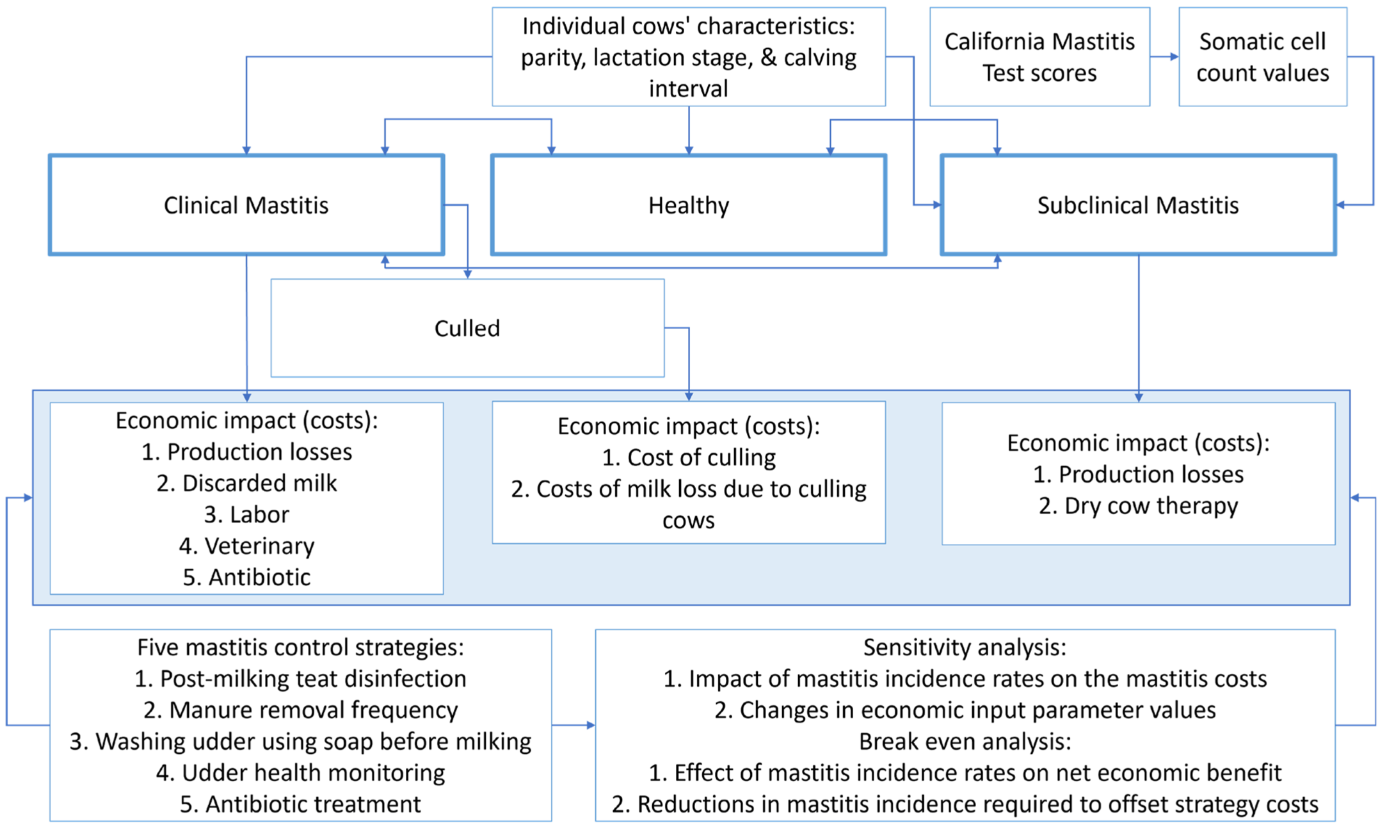

Figure 1. The dynamics of mastitis, its economic consequences, control strategies, sensitivity and break-even analyses as modeled on a typical Indonesian smallholder dairy farm containing 4 lactating cows.

milk withdrawal, attributable to clinical and subclinical mastitis were incorporated into the model, accounting for basic milk yield, the effect of clinical mastitis occurrence in the previous time step, and CMT scores.

The incidence of clinical and subclinical mastitis was subsequently used to assess the economic effect of mastitis on dairy farms, including production losses and discarded milk, antibiotics, veterinarian, culling, and labor costs. We refer to Getaneh et al. (2017) for a comprehensive description of the modeling process encompassing farm dynamics, mastitis dynamics, and economic consequences.

Refining Mastitis Dynamics Modeling

In the context of Indonesian dairy farming, several adjustments were made to the model (Table 1; Figure 1). First, SCC values were added to the model to monitor udder health and milk quality per time period. Based on the simulated CMT scores in each time step, quarter-level SCC was simulated following a program evaluation and review technique (**PERT**) distribution associated with each CMT score. These distributions are based on the work of Ruegg and Reinemann (2002), who provided the SCC values (cells/mL of milk) corresponding with the CMT. These quarter-level SCC values are then aggregated to cow-level SCC values by calculating the arithmetic mean of the SCC values from all 4 quarters of each cow, ensuring simplicity and consistency in the model. The cow-level SCC values subsequently serve as the basis for estimating bulk milk SCC values by taking the arithmetic mean from the combined milk of all cows on the farm.

In the previous bio-economic mastitis model (Getaneh et al., 2017), modeling started with all quarters being healthy, which does not mimic the udder health status of dairy farms (Fadillah et al., 2023a). To rectify this, the current model incorporated 4 additional initial time periods to ensure a stable subclinical mastitis prevalence, as evidenced by predicted bulk milk SCC levels. Extraction of model output started only after those 4 initial time periods for a period of 1 yr.

Furthermore, the original model did not include blanket dry cow therapy, whereas this is commonly practiced on Indonesian dairy farms. Therefore, blanket dry cow therapy was included in the current model. This is achieved by increasing the cure rate of subclinical mas-

Table 2. Input parameter values for modeling the mastitis dynamics on a typical Indonesian smallholder dairy farm containing 4 lactating cows

Parameter	Probability	Distribution	Referent
Incidence of clinical mastitis (cases per cow-year at risk)			
Default	0.17	Constant	Zalizar et al., 2023
Postmilking teat disinfection	0.09	Constant	Calculated
Manure removal frequency	0.16	Constant	Calculated
Washing udder using soap before milking	0.16	Constant	Calculated
Prevalence of subclinical mastitis	0.62	Constant	Nuraini et al., 2023
Incidence of subclinical mastitis (cases per cow-year at risk)			
Default	3	Constant	Authors' expertise
Postmilking teat disinfection	1.62	Constant	Calculated
Manure removal frequency	2.83	Constant	Calculated
Washing udder using soap before milking	2.9	Constant	Calculated
Probabilities of occurrence at t = 1:		Constant	
Clinical mastitis	0.01		Calculated
Subclinical mastitis	0.12		Calculated
Transition probabilities per 2 wk		Constant	
Healthy to clinical mastitis	0.01		Calculated
Healthy to subclinical mastitis	0.12		Calculated
Cure rate of subclinical mastitis (spontaneous cure)	0.25		van den Borne et al., 2010
Cure rate of subclinical mastitis (dry cow therapy)	0.71		Shephard et al., 2004
Cure rate of subclinical mastitis (lactational antibiotic treatment)	0.55		van den Borne et al., 2010
Cure rate of clinical mastitis	0.85		Getaneh et al., 2017
Subclinical to clinical mastitis	0.03		Getaneh et al., 2017
Clinical to subclinical mastitis	0.14		Getaneh et al., 2017
Subclinical mastitis stays subclinical for more than one time period	0.72		Calculated
Adjustment factors of lactation stages for incidence of clinical mastitis		Constant	Biffa et al., 2005
Early lactation	1.67		
Mid lactation	0.81		
Late lactation	0.52		
Adjustment factors of lactation stages on for incidence of subclinical mastitis		Constant	Biffa et al., 2005
Early (<120 DIM)	0.45		
Mid (120–240 DIM)	0.97		
Late (>240 DIM)	1.01		
Adjustment factors of parity for the incidence of mastitis		Constant	Zalizar et al., 2023
Parity 1	0.75		
Parity 2	0.90		
Parity 3	1.06		
Parity 4	1.30		
Increased risk of clinical mastitis based on previous clinical mastitis		Constant	Steeneveld et al., 2008
Zero cases in the last month	1.00		
One case in the last month	2.49		
Two cases in the last month	3.45		
General culling/year	0.18	Constant	Rahayu et al., 2015
Odds ratio of culling when there is clinical mastitis	2	Constant	Getaneh et al., 2017
Maximum duration of subclinical mastitis (time period)	12	Constant	Authors' expertise
Distribution of California Mastitis Test scores		Discrete	Khasanah et al., 2021
California Mastitis Test = 1	0.42		
California Mastitis Test = 2	0.32		
California Mastitis Test = 3	0.26		

titis to 71% (Shephard et al., 2004) during the first time period of the dry cow period, a result of all cows receiving antibiotic treatment, including those with subclinical mastitis. To further reflect mastitis dynamics during the dry period, the incidence of clinical and subclinical mastitis was set to zero during the second and third periods of the dry period. In the fourth period, the probability of clinical and subclinical mastitis was doubled compared with the incidences observed during lactating periods. This adjustment accounts for the higher likelihood of cows becoming infected during this time period (Green et al., 2002). The cost of blanket dry cow treatment was attributed fully to subclinical mastitis in our model as a simplification for assigning costs and benefits within the bio-economic framework.

Model Parameterization

The current model was reparametrized for a typical smallholder dairy farm in West Java, Indonesia, with 4 lactating cows (Fadillah et al., 2023b). Input parameter values (Tables 1, 2, and 3) were gathered from various

Table 3. Input parameter values for estimating the costs due to mastitis on a typical Indonesian smallholder dairy farm containing 4 lactating cows

Parameter	Value	Distribution	Referent
Milk production losses (in %):			
Clinical mastitis	5	Constant	Huijps et al., 2008
Subclinical mastitis:		Constant	Mungube et al., 2005
California Mastitis Test = 1	1.2		
California Mastitis Test = 2	6.3		
California Mastitis Test = 3	33		
Probability of a clinical mastitis case being treated by a veterinarian	0.5	Constant	Getaneh et al., 2017
Total time to treat clinical mastitis (h)	2	Constant	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data
Total time to treat subclinical mastitis (h)	2	Constant	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data
Age of old cow after first calving (yr)	6	Constant	Getaneh et al., 2017
Costs for milk production losses (€/kg)		PERT	Hetherington et al., 2023
Minimum	0.28		
Most likely	0.29		
Maximum	0.30		
Costs for discarded milk (€/kg)		PERT	Hetherington et al., 2023
Minimum	0.43		
Most likely	0.44		
Maximum	0.45		
Labor wage (€/h)	0.36	Constant	Hetherington et al., 2023
Veterinary service (€/case)	1.60	Constant	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data
Antibiotics price (€/case)		PERT	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data
Minimum	1.92		
Most likely	2.24		
Maximum	2.56		
Replacement costs (€/culled cow)		PERT	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data
Minimum	449		
Most likely	513		
Maximum	577		
Average slaughter value (€)	160	Constant	A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data

sources including literature, fieldwork data collection (Fadillah et al., 2023a), local research reports, and expert insights obtained from staff of a local cooperative, veterinarians, local university experts, and authors' expertise. For the current model, adjustment factors for lactation stages influencing mastitis occurrence were differentiated based on the type of mastitis. The probabilities of clinical mastitis occurrence decrease with an increasing DIM, whereas those for subclinical mastitis increase from early to late lactation (Biffa et al., 2005). Tables 1 and 2 provide input data for farm and mastitis dynamics, respectively. Table 3 presents economic input data. All economic values were calculated in Indonesian Rupiah and converted to Euro using an average exchange rate of 15,600 IDR/€ (Exchange Rates UK, 2022). This exchange rate is used for consistency, as input parameter values for estimating the costs of mastitis are primarily based on fieldwork conducted in 2022 (Fadillah et al., 2023a).

Effect Mastitis Control Strategies

Five mastitis control strategies were evaluated and compared with a default strategy without those control strategies.

Postmilking Teat Disinfection. Postmilking teat disinfection (**PMTD**), as recommended by the National Mastitis Council (2016), reduces the incidence of both clinical and subclinical mastitis. However, this practice remains largely unimplemented on many smallholder dairy farms across Indonesia despite its demonstrated effect (Khasanah and Widianingrum, 2021). Iodine has been found to be 46% effective in preventing naturally occurring intramammary infections and clinical masti-

Table 4. The average annual cumulative incidence of clinical and subclinical mastitis (including 5th, 50th, and 95th percentiles) across lactation stages and parity, alongside the number of culled cows due to mastitis on a typical Indonesian smallholder dairy farm based on the simulation model

	Clinical				Subclinical			
Annual mastitis incidence[1]	Mean	5th	50th	95th	Mean	5th	50th	95th
Total	1.19	0	1	3	7.33	4	7	11
Per lactation stage								
Early (<120 DIM)	0.52	0	0	2	1.54	0	1	4
Mid (120–240 DIM)	0.35	0	0	1	2.64	1	3	5
Late (>240 DIM)	0.32	0	0	1	3.15	1	3	6
Per parity								
Parity 1	0.15	0	0	1	1.53	0	1	5
Parity 2	0.19	0	0	1	1.57	0	1	5
Parity 3	0.21	0	0	1	1.49	0	1	4
Parity 4 and higher	0.64	0	0	2	2.74	0	2	6
Number of culled cows due to mastitis	0.55	0	0	2				

[1]Number of cow-level cases per year per farm of 4 lactating cows.

tis in dairy cows (Martins et al., 2017). Following the application of PMTD, the incidence rates of clinical mastitis (**IRCM**) and subclinical mastitis (**IRSCM**) were, therefore, lowered to 0.09 and 1.62/cow per year, respectively. We also simulated PMTD implementation under alternative effectiveness scenarios of 20% and 30% to assess its economic effect at varying levels of efficacy. Implementing PMTD incurs additional costs for purchasing iodine, increased labor, and the acquisition of some equipment such as dippers. The time required to conduct PMTD is estimated at 30 s/cow, with labor costs set at €0.36/h (Hetherington et al., 2023). Additionally, the costs of the dipper and iodine were recorded at €3.21/yr and €1.02 per time period, respectively (Sudarnika et al., 2019).

Manure Removal Frequency. Hygiene practices such as the regular removal of manure have been linked to a reduction in the incidence of mastitis and the prevalence of high SCC in milk (Khasanah et al., 2021; Fadillah et al., 2023a). According to our previous work (Fadillah et al., 2023a), increasing the frequency of manure removal from 2 to 3 times per day was associated with a 5.74% decrease in the bulk milk SCC of smallholders. This value was used to model the same reduction in the incidence rates of mastitis, assuming IRCM and IRSCM to be 0.16 and 2.83/cow per year, respectively. Removing manure was assumed to take ~35 s/cow, referring specifically to the removal of manure from the cow's lying area using a shovel and water splashing. The additional labor costs incurred for increasing the frequency of manure removal from 2 to 3 times per day was estimated at €0.05 per time period (Hetherington et al., 2023). Farmers were required to invest more in tools such as buckets and shovels, knowing that more frequent use reduces their life span (~3 yr), thereby leading to increased replacement costs totaling €12.82/yr.

Washing Udder Using Soap Before Milking. Washing the udder with soap before milking has been associated with a 3.36% lower bulk milk SCC (Fadillah et al., 2023a). This value was used to model a 3.36% reduction in the incidence rates of mastitis, assuming IRCM and IRSCM to be 0.16 and 2.9/cow per year, respectively. Washing the udder with soap before milking was assumed to require ~30 s/cow. The additional costs incurred for soap and labor were estimated at €0.16 and €0.04/cow per time period, respectively (Hetherington et al., 2023). Implementing this practice requires farmers to invest in buckets and sponges. These tools are assumed to last 3 yr for buckets and 1 yr for sponges, with total costs of €8.46/yr, accounting for their life span and depreciation.

Udder Health Monitoring. The CMT serves as a monitoring tool to detect subclinical mastitis (Ashraf and Imran, 2018; Ferronatto et al., 2018). In the current model, monthly udder health monitoring using CMT was considered. Each monthly udder health monitoring event using CMT was assumed to require ~3 min/cow. Consequently, the additional labor costs for conducting udder health monitoring using CMT was estimated at €0.01 per time period. Furthermore, a total of 2 mL of reagent per sample or quarter is necessary (Perrin et al., 1997; Kandeel et al., 2018), with the cost of the reagent being €0.03/mL. Accordingly, farmers need to allocate ~€0.12 per time period for reagents. Additionally, farmers are required to invest in paddles, priced at €1.47 each and used for 4 cows. The paddles are assumed to last for 3 yr, with an estimated costs of €0.37/cow per year, accounting for the life span and depreciation.

Antibiotic Treatment for Subclinical Mastitis During Lactation. The use of intramammary antibiotics for subclinical cases during lactation is not common on Indonesian smallholder dairy farms, and neither do we

Table 5. Comparison of average annual farm-level mastitis incidence, milk production losses, and bulk milk SCC values on a typical Indonesian smallholder dairy farm: default and control strategies

	Clinical mastitis		Subclinical mastitis		
Control strategy	Incidence (cases)	Milk production losses (kg)	Incidence (cases)	Milk production losses (kg)	SCC farm level (cells/mL)
Default	1.19	42.45	7.33	129.70	521,000
Postmilking teat disinfection	0.72	27.09	4.52	79.32	412,000
Manure removal frequency	1.14	40.58	7.03	122.79	508,000
Washing udder using soap	1.18	42.58	7.15	125.21	513,000
Udder health monitoring	1.18	41.91	7.32	129.05	522,000
Udder health monitoring and treatment	1.16	42.73	7.59	119.68	489,000

advocate it from a prudent use perspective. However, this mastitis control strategy was evaluated as a measure to reduce the prevalence and transmission of contagious pathogens (van den Borne et al., 2010a; Barlow et al., 2013) on smallholder dairy farms. Following the udder health monitoring using CMT strategy, cows that had a positive CMT score (scores 1, 2, and 3) for 2 consecutive months (4 periods) received antibiotic treatment for subclinical mastitis for 3 consecutive milking sessions. This was assumed to increase the cure probability of subclinical mastitis to 0.55 (van den Borne et al., 2010b). We also simulated antibiotic treatment for subclinical mastitis under alternative cure probability scenarios of 0.4, 0.5, 0.6, and 0.7 to assess its economic effect at varying levels of treatment efficacy. The additional costs associated with antibiotic treatment for subclinical mastitis included labor (€0.72/treatment) and veterinary service (€0.8/treatment; including the call-out fee and the cost of time spent on the farm), and antibiotic costs (ranging from €1.92 to €2.56, with the most likely value being €2.24/tube, according to a PERT distribution). The antibiotic treatment for subclinical mastitis required 3 tubes per infected quarter for every 3 consecutive milking sessions.

Assessing the Economic Consequences of Mastitis

The output of the bio-economic model consists of the annual total costs of mastitis, which encompass various components. The costs of clinical mastitis consist of milk production losses, discarded milk (including additional milk withdrawal due to antibiotic treatment), culling (calculated based on the replacement cow costs and the average slaughter value), labor, veterinary, antibiotic, and milk loss due to culling (until the replacement cow arrives and starts producing milk). In contrast, the costs of subclinical mastitis include milk production losses and the costs of blanket dry cow therapy. The annual total costs of mastitis consist of the costs of clinical mastitis, subclinical mastitis, and control strategies, which are assessed for both the default and the 5 control strategies. The net economic benefit was based on the difference in the annual total costs of mastitis between the default strategy and the control strategies.

Model Implementation and Validation

The bio-economic Monte Carlo simulation model was formulated using @Risk 7.5 software (Palisade Corporation, Ithaca, NY) to compute the annual total mastitis costs for a typical Indonesian smallholder dairy farm. The model was executed for 30 time periods and ran for 10,000 iterations. All simulation outcomes were presented per year at farm-level, based upon the last twenty-six 2-wk time periods.

To validate the default strategy externally, we compared the SCC model output with SCC values obtained from field data collected from a cross-sectional study in which the average geometric bulk milk SCC was 529,665 cells/mL (Fadillah et al., 2023a). Internally, the model was validated through the rationalism method and the face validity method (Law, 2015). The rationalism method involved altering input values to verify the consistency of the model output. Additionally, 2 veterinarians working in academia and 2 paramedics of a dairy cooperative were consulted regarding model assumptions and credibility, employing the face validity method. The experts reviewed and provided their feedback on the input parameters, model outputs, and control strategies during the face validity assessment.

Sensitivity Analysis

In this study, a total of 2 sensitivity analyses were conducted. First, a sensitivity analysis was performed to estimate the effects in €/farm/year of decreased and increased (±10% and ± 20%) incidence rates of subclinical and clinical mastitis. This analysis aimed to evaluate the economic burden of mastitis, considering changes in incidence rates under the default control strategy.

Table 6. The economic consequences of clinical and subclinical mastitis at the farm-level per year (€), including 5th, 50th, and 95th percentiles on a typical Indonesian smallholder dairy farm under the default strategy

Costs factors	Mean (€)	5th (€)	50th (€)	95th (€)
Clinical mastitis				
Costs of milk production losses	12.41	0	6.44	39.34
Costs of discarded milk	27.45	0	14.39	87.31
Costs of culling	45.42	0	0.00	261.70
Costs of labor	0.79	0	0.72	2.15
Veterinary costs	0.88	0	0.00	2.40
Antibiotic costs	2.46	0	0.00	6.95
Costs of milk loss due to culling cows	12.58	0	0.00	65.66
Subtotal clinical mastitis costs	101.98	0	38.53	388.33
Subclinical mastitis				
Costs of production loss	38.04	9.91	25.45	79.11
Costs of blanket dry cow therapy	35.18	20.50	34.70	44.62
Subtotal costs of subclinical mastitis	73.22	41.54	61.66	115.30
Total costs of mastitis	175.20	52.77	104.76	460.67

Second, a sensitivity analysis was conducted to evaluate the effects of increased or decreased (±10%) economic input parameter values, including milk prices and antibiotic, culling, teat dipping, veterinary service, and labor costs, on the net economic benefit in €/farm/year between the default and the most cost-efficient control strategy. This analysis was conducted to evaluate the importance of input parameter values on the net economic benefit.

Break-Even Analysis

Two analyses were conducted to assess how much incidence rates of clinical and subclinical mastitis should change for control strategies to become cost-efficient. First, a break-even analysis was performed to estimate the effects of decreased and increased (±10% and ± 20%) incidence rates of subclinical and clinical mastitis on the net economic benefit in €/farm/year between the default and other control strategies, such as manure removal frequency and washing udder using soap before milking. This analysis was conducted to evaluate the effectiveness of these strategies.

Second, a break-even analysis was conducted to estimate the reductions in mastitis incidence necessary to offset the additional costs of udder health monitoring using CMT alone or combined with antibiotic treatment for subclinical mastitis. The costs of clinical and subclinical mastitis through udder health monitoring using CMT, both with and without subsequent antibiotic treatment for subclinical mastitis, were also assessed under scenarios of decreasing annual IRCM and IRSCM. We modeled different scenarios where the IRCM and IRSCM were hypothetically reduced by 5% and 10% related to udder health monitoring using CMT only, as well as a reduction of 20% and 40% related to udder health monitoring using CMT with antibiotic treatment for subclinical mastitis, all compared with the default values. Figure 1 illustrates the dynamics of mastitis, its economic consequences, the control strategies, the sensitivity, and break-even analyses as modeled.

RESULTS

Default Mastitis Incidence, Economic Effect, and SCC

Table 4 presents the average annual incidences of mastitis across lactation stages and parity, alongside the number of culled cows due to mastitis on a typical Indonesian smallholder dairy farm containing 4 lactating cows based on the simulation model. The average annual number of clinical mastitis cases per farm was 1.19 (5th percentile: 0; 95th percentile: 3 cases). The average annual number of subclinical mastitis cases per farm was 7.33 cases (5th percentile: 4; 95th percentile: 11 cases). Incidences of both clinical and subclinical mastitis varied across lactation stages, with clinical mastitis rates of 0.52, 0.35, and 0.32/farm per year during early, mid, and late lactation, respectively, and subclinical mastitis incidences of 1.54, 2.64, and 3.15 cases per farm per year during the same lactation stages. Mastitis incidences also varied with parity (Table 4). The number of culled cows due to mastitis was 0.55/farm per year (5th percentile: 0; 95th percentile: 2 cows).

The average annual farm-level mastitis incidence, milk production losses, and bulk milk SCC values under default and control strategies on a typical Indonesian smallholder dairy farm are presented in Table 5. Milk losses attributed to clinical mastitis averaged 42.45 kg/farm annually (5th percentile: 0; 95th percentile: 133.33 kg), whereas losses due to subclinical mastitis averaged 129.70 kg/farm annually (5th percentile: 34.03; 95th percentile: 266.15 kg). The average farm-level arithme-

Table 7. Comparison of average economic consequences of mastitis between default and control strategies on a typical Indonesian smallholder dairy farm (€/farm/yr)

Control strategy	Clinical mastitis cost (€)	Subclinical mastitis cost (€)	Control strategy cost (€)	Total costs of mastitis (€)	5th percentile (€)	95th percentile (€)	Net economic benefit (€)
Default	101.98	73.22	—	175.2	52.77	460.67	0
Postmilking teat disinfection	59.94	59.16	30.05	149.15	68.76	383.65	26.05
Manure removal frequency	98.83	71.63	17.9	188.36	69.05	460.89	−13.16
Washing udder using soap	99.47	72.64	26.91	199.02	79.04	478.8	−23.82
Udder health monitoring	102.66	73.26	12.75	188.67	66	463.1	−13.47
Udder health monitoring and treatment	101.57	70.81	63.3	235.68	89.66	519.2	−60.48

tic SCC was 521,000 cells/mL (5th percentile: 309,000; 95th percentile: 821,000 cells/mL of milk).

Table 6 presents the average total mastitis-related costs which amounted to €175.20 per farm per year under the default strategy based on the simulation model. These costs exhibited substantial variation, with the 5th and 95th percentiles ranging from €52.77 to €460.67, respectively. This highlights the diverse range of total mastitis costs across iterations. The total cost of mastitis represented 14% of the annual gross margin (€1,271.27; A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data). At the 95th percentile, mastitis costs reached €460.67 per farm per year, equivalent to 36% of the annual gross margin. On average, the annual costs attributed to clinical mastitis totaled €101.98 per farm (Table 6), with the 5th and 95th percentiles ranging from €0 to €388.33. Within these costs, culling costs accounted for the largest share at €45.42, followed by discarded milk (€27.45), milk loss due to culling cows with clinical mastitis (€12.58), and milk production losses (€12.41). The average annual costs associated with subclinical mastitis amounted to €73.22 per farm, with the 5th and 95th percentiles ranging from €41.54 to €115.30. These costs were relatively equally shared between milk production losses (€38.04) and costs related to blanket dry cow therapy (€35.18).

Effect of Mastitis Control Strategies

Annual farm-level mastitis incidence, milk production losses, and SCC values under different control strategies are compared in Table 6. Postmilking teat disinfection resulted in the strongest reduction in incidences of clinical and subclinical mastitis of 0.72 and 4.52 cases/farm per year, respectively. Corresponding milk production losses were 27.09 and 79.32 kg/yr, whereas the median bulk milk SCC was 412,000 cells/mL. The other control strategies demonstrated relatively similar median mastitis incidences, milk production losses, and bulk milk SCC values compared with the default strategy.

The economic consequences of mastitis were compared between the default situation and control strategies, as shown in Table 7. Postmilking teat disinfection had the lowest total mastitis costs per farm per year (€149.15). As a result, PMTD emerged as the only cost-efficient control strategy with a positive net economic benefit of €26.05. In contrast, the other control strategies resulted in a negative net economic benefit, primarily driven by increased control costs which were not sufficiently compensated by reduced costs of clinical and subclinical mastitis. The combination of udder health monitoring using CMT and antibiotic treatment for subclinical mastitis resulted in the strongest negative net economic benefit of −€60.48. Notably, the 5th and 95th percentiles (Table 7) illustrate the variability in total costs among different control strategies. The PMTD strategy showed the narrowest distribution of the annual total cost of mastitis among control strategies (Figure 2).

Simulated lower reductions in mastitis incidence of 30% and 20% in implementing PMTD resulted in higher costs (€169.29 and €181.11, respectively) and lower net economic benefits (€5.91 and −€5.91, respectively). Changing the cure probability of subclinical mastitis after treatment in the udder health monitoring with CMT

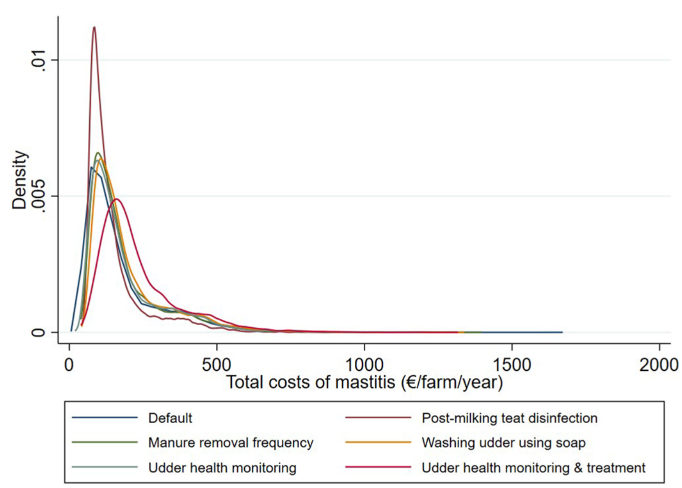

Figure 2. Distribution of the annual total costs of mastitis according to the default and control strategies on a typical Indonesian smallholder dairy farm containing 4 lactating cows.

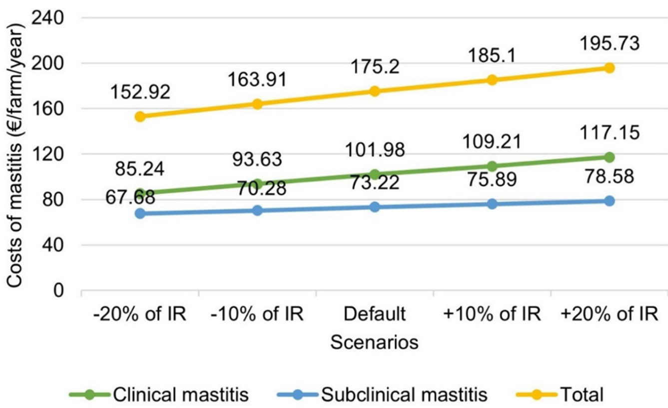

Figure 3. The effects of decreased and increased (±10% and ± 20%) mastitis incidence rates (IR) on costs of mastitis in the default control strategy.

and treatment scenario resulted in similar net economic benefits compared with the base cure probability. The net economic benefit of udder health monitoring with CMT and treatment was −€60.03, −€60.22, −€58.61, and −€55.81, respectively, for cure probabilities of 0.4, 0.5, 0.6, and 0.7.

Sensitivity Analysis

The first sensitivity analysis of the effect of decreasing and increasing mastitis incidence rates revealed the economic effect on farms in terms of the costs of subclinical and clinical mastitis in the default control strategy (Figure 3). When the incidence rates decreased by 20%, the total cost was €152.92/farm per year, whereas a 10% decrease resulted in total costs of €163.91/farm per year all compared with the default strategy. Conversely, increasing the incidence rates by 10% and 20% resulted in total costs of €185.10 and €195.73/farm per year, respectively, compared with the default strategy costs of €175.20/farm per year. These higher mastitis incidence rates also increase the proportion of total mastitis costs (15%) relative to the gross margin.

The results of the second sensitivity analysis on modifying economic input parameter values that affected the net economic benefit of implementing PMTD as the most cost-efficient strategy compared with the default control strategy are presented in Figure 4. The net economic benefit of implementing the PMTD control strategy compared with the default control strategy, €26.05/farm per year (Table 7), was set as the reference line. The net economic benefit on the farm was most sensitive to variations in the milk prices and teat dipping costs, both of which had the largest changes in net economic benefit. Increasing milk prices by 10% resulted in an increase in the net economic benefit to €29.08/farm per year, and decreasing milk prices by 10% decreased the net economic benefit to €22.42/farm per year. Similar effects on the net economic benefit, such as those from changing milk prices, were found when increasing or decreasing the costs of antibiotics, veterinary services, and culling by 10%. Conversely, increasing teat dipping costs by 10% resulted in a decrease in the net economic benefit to €23.43/farm per year, whereas decreasing teat dipping costs by 10% increased the net economic benefit to €29.48/farm per year. Similar effects on the net economic benefit, compared with those from changing teat dipping costs, were found when increasing or decreasing the costs of labor by 10%.

Break-Even Analysis

The results of the first break-even analysis on the effect of increasing and decreasing baseline mastitis incidence rates on the net economic benefit of implementing the control strategies regarding the manure removal frequency and washing udder using soap before milking, compared with the default strategy, are presented in Figure 5. When the incidence rates increased by 20%, the net economic benefits for the manure removal frequency and washing udder using soap before milking control strategies were −€32.41 and −€43.30/farm per year, respectively. A 10% increase in the incidence rates resulted in net economic benefits of −€21.67 and −€30.50/farm per year, respectively. Moreover, decreasing the incidence rates by 10% and 20% resulted in net economic benefits of almost zero (−€0.76) and being positive (€12.32), respectively, for the manure removal frequency strategy. For the washing udder using soap before milking strategy, decreasing the incidence rates by 10% and 20% resulted in net economic benefits of −€11.52 and almost zero (−€0.11), respectively.

The second break-even analysis results of the economic effect of mastitis, assessed through udder health monitoring using CMT (with and without antibiotic treatment for subclinical mastitis) under scenarios of decreasing IRCM and IRSCM annually, are summarized in Table 8. Compared with the default scenario, implementing udder health monitoring using CMT with a 5% reduction in IRCM and IRSCM showed only slight reductions in the costs associated with clinical mastitis, amounting to €97.79/farm per year. Additionally, the costs related to subclinical mastitis were also slightly decreased at €71.81/farm per year. Consequently, a 5% reduction in IRCM and IRSCM was not sufficient to outweigh the costs of monitoring, as this control strategy was still more expensive compared with the default scenario. A similar observation was made when IRCM and IRSCM were reduced by another 5%. Then, the total costs of

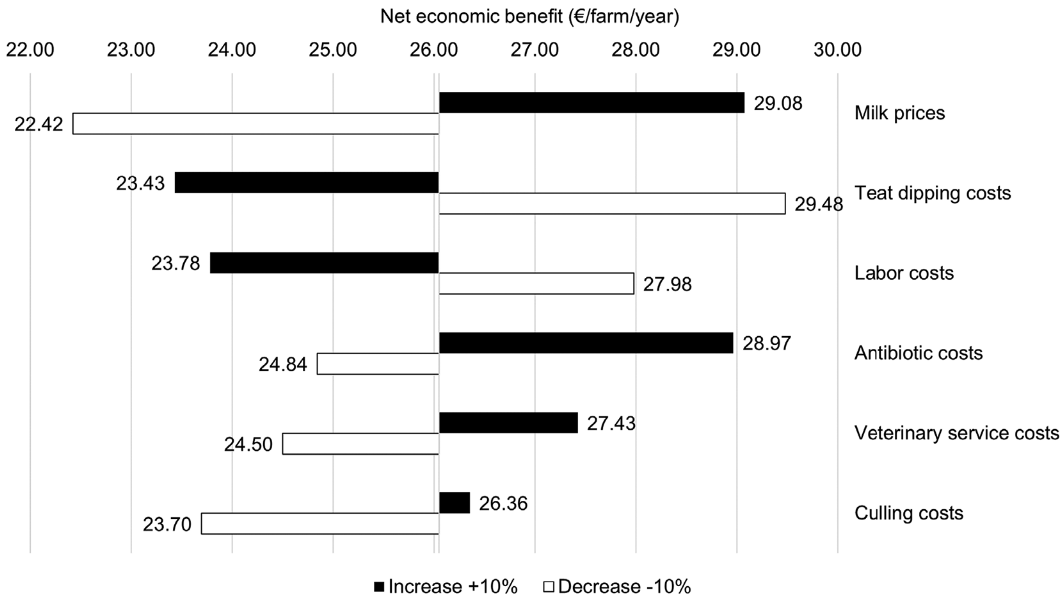

Figure 4. The effects of increased or decreased (±10%) economic input parameter values on the net economic benefit of implementing the postmilking teat disinfection control strategy compared with the default control strategy. The bars represent the difference between the default net economic benefit of postmilking teat disinfection and a situation with a changed economic input value.

mastitis (€178.40/farm per year) was almost similar to that of the default strategy.

Compared with the default scenario, implementing udder health monitoring using CMT and antibiotic treatment for subclinical mastitis with a 20% reduction in IRCM and IRSCM led to a decrease in clinical mastitis costs, amounting to €82.95/farm per year. Similarly, costs associated with subclinical mastitis decreased to €65.13/farm per year. However, due to the additional costs of udder health monitoring using CMT and antibiotic treatment for subclinical mastitis, the total mastitis costs was €203.66/farm per year. When IRCM and IRSCM were reduced by 40% due to this control strategy, total mastitis costs decreased further to €169.71/farm per year, demonstrating greater savings compared with the default strategy.

DISCUSSION

This study aimed to estimate the costs associated with mastitis and evaluate the economic effect of various control strategies aimed at mitigating mastitis on smallholder dairy farms in Indonesia. The default strategy, without specific control strategies, illustrates the current economic burden of mastitis on smallholder dairy farms in Indonesia with 4 dairy cows. The total cost of mastitis was €175.20/farm per year, which is 14% of the annual gross margin (€1,271.27; A. Fadillah, B. H. P. van den Borne, Y. H. Schukken, O. N. Poetri, and H. Hogeveen, unpublished data). This percentage increases to 36% when considering the 95th percentile of mastitis costs (€460.67), indicating that these losses are substantial on smallholder dairy farms. This finding emphasizes the need for efficient control strategies to improve the profitability and sustainability of smallholder dairy farms, which are crucial for farmers' livelihoods and economic stability.

Clinical and subclinical mastitis incurred costs of €101.98 and €73.22/farm per year, respectively. When expressing those losses per cow per year, the total costs of mastitis in Indonesia (€43.80) was higher than on Ethiopian smallholder dairy farms (€31.26) but lower than in Dutch and Swedish dairy farms (€78 and €97, respectively; Huijps et al., 2008; Hagnestam-Nielsen and Stergaard, 2009; Getaneh et al., 2017). These differences were mainly attributed to differences in labor costs on the dairy farms, which were relatively high in Sweden (€17.5/h) and the Netherlands (€18/h) compared with Ethiopia (€0.30/h) and Indonesia (€0.36/h; Huijps et al., 2008; Hagnestam-Nielsen and Stergaard, 2009; Getaneh et al., 2017; Hetherington et al., 2023). The substantial economic burden of clinical mastitis is primarily driven by culling costs (45%) and discarded milk (27%). In contrast, subclinical mastitis costs were split between blanket dry cow therapy (48%) and milk production losses (52%). The costs of culling on smallholder farms in Indonesia and Ethiopia comprise a higher portion of mastitis costs (52% and 64%, respec-

Table 8. The economic effect of mastitis through udder health monitoring using California Mastitis Test (CMT; with and without antibiotic treatment for subclinical mastitis) under scenarios of decreasing incidence rates of clinical mastitis (IRCM) and incidence rates of subclinical mastitis (IRSCM; €/farm/yr)

		Udder health monitoring			Udder health monitoring and treatment		
Cost factor	Default	No reduction	5% reduction	10% reduction	No reduction	20% reduction	40% reduction
Subtotal clinical mastitis costs	101.98	102.66	97.79	95.27	101.57	82.95	62.96
Subtotal subclinical mastitis costs	73.22	73.26	71.81	70.40	70.81	65.13	58.96
Control strategy costs	—	12.75	12.74	12.73	63.3	55.58	47.79
Total costs of mastitis	175.20	188.67	182.34	178.40	235.68	203.66	169.71
5th percentile	52.77	66.00	64.07	62.06	89.66	75.51	61.03
95th percentile	460.67	463.10	452.72	455.37	519.20	464.29	402.79

tively) compared with Dutch dairy farms (17%–28%; Hogeveen et al., 2011; Getaneh et al., 2017). These findings indicated that culling had a much larger effect on smallholder farms, and labor costs had a lower effect on smallholder farms. The sensitivity analysis indicated that mastitis incidence rates were positively correlated with the costs associated with mastitis. These findings emphasize the potential for mastitis control strategies to reduce the occurrence of mastitis. Such control will not only lead to reduced economic losses due to mastitis but will also have a positive effect on dairy cow welfare and the environment (Steeneveld et al., 2024).

This study evaluated several mastitis management control strategies, including PMTD, increased manure removal frequency, washing udders using soap, and udder health monitoring using CMT with and without antibiotic treatment for subclinical mastitis. Among the control strategies evaluated, PMTD stood out as the only cost-efficient strategy. Furthermore, PMTD proved to be a robust control strategy for mitigating costs associated with mastitis, consistently resulting in a positive net economic benefit compared with the default control strategy for all economic input parameter values. This benefit persisted whether efficacy increased or decreased by 10%. The PMTD is expected to reduce the incidence of mastitis and associated economic losses substantially, which outweighs the costs associated with this control strategy. As this also improved milk quality by reducing bulk tank SCC levels, this finding emphasizes that PMTD should be a priority program for improving udder health, milk quality, and economic benefit of smallholder farms (Huijps et al., 2010; Martins et al., 2017).

Increased manure removal frequency and the washing of udders using soap before milking only slightly reduced the incidence of mastitis, milk production losses, and bulk tank SCC levels. The association between some hygiene strategies and SCC has been studied by Fadillah et al. (2023a) and Khasanah et al. (2021). However, implementing both control strategies resulted in negative net economic benefits due to additional control costs. The findings aligned with Hogeveen et al. (2011), who found that some control strategies related to hygiene practices, such as maintaining clean yards and cubicles, resulted in a negative net economic benefit. However, in estimating the effect of interventions, such as improved hygiene, it was difficult to estimate the effect of these interventions on the incidence of mastitis. Almost all intervention studies were aimed at dairy farms in high-income countries and not at smallholder dairy farms in low and middle-income countries under tropical circumstances. Given the specific farming circumstances, a set of interventions, tailormade for these circumstances should be developed and evaluated. The manure removal frequency and washing udder using soap before milking control strategies had a more favorable economic effect when the incidence rates of mastitis decreased. Specifically, a 20% reduction in incidence rates resulted in ~0 (break-even point) and positive net economic benefits compared with the default control strategy for washing udder using soap before milking and manure removal frequency control strategies, respectively. However, when the incidence rate increases, these strategies become more unfavorable, resulting in higher negative net economic benefits compared with the default control strategy. The effectiveness of manure removal and washing udders depends on mastitis incidence; at low levels, it helps maintain a low infection rate, whereas at high levels, additional interventions are needed to control transmission and reduce new infections. These findings suggest that these control strategies can effectively mitigate the costs associated with mastitis when incidence rates are lowered due to the implementation of interventions, including beyond those investigated here, thus making them potentially viable and cost-efficient (Hogeveen et al., 2011; Lam et al., 2013).

Implementing udder health monitoring using CMT alone demonstrated relatively similar mastitis incidences, milk production losses, and bulk tank SCC levels compared with the default strategy. Because manage-

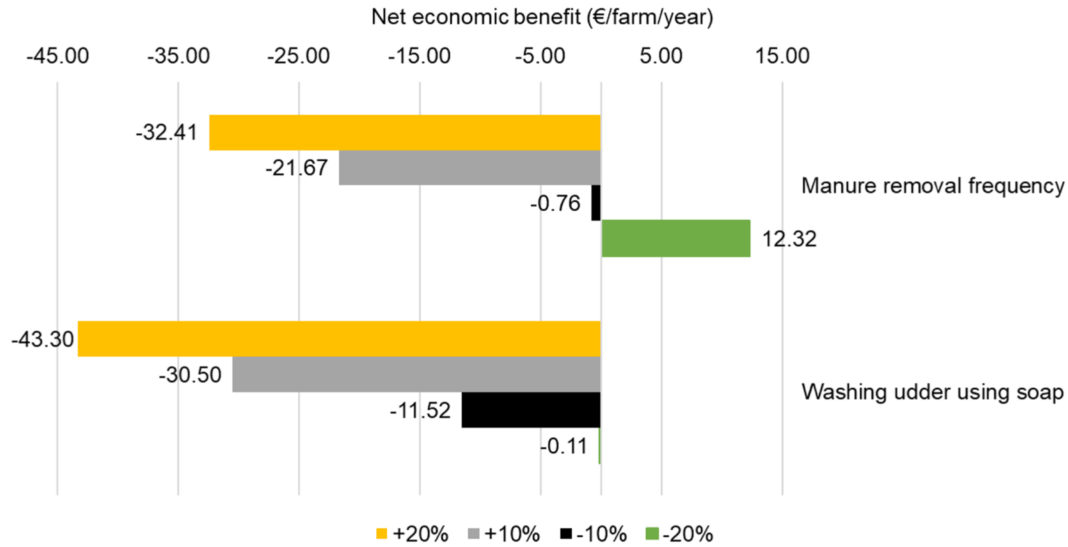

Figure 5. The effects of increased or decreased (±10% and ± 20%) baseline incidence rates of mastitis on the net economic benefit of the control strategies of implementing manure removal frequency and washing udder using soap before milking, compared with the default control strategy.

ment does not change when one is only monitoring udder health, one cannot expect the incidence of mastitis to decrease. The overall mastitis costs per farm per year increased though due to the additional costs of udder health monitoring. Implementing udder health monitoring using CMT combined with antibiotic treatment for subclinical mastitis showed more promising results, particularly regarding reductions in milk production losses and bulk tank SCC levels. However, the net economic benefit of this control strategy was lower compared with udder health monitoring using CMT alone strategy due to the additional costs of antibiotic treatment for subclinical mastitis. Furthermore, implementing udder health monitoring using CMT (with and without antibiotic treatment for subclinical mastitis) under various scenarios of decreasing IRCM and IRSCM showed the importance of achieving substantial reductions in mastitis incidence to offset additional costs. The second break-even analysis showed that the costs of udder health monitoring using CMT alone can almost be entirely compensated when IRCM and IRSCM are reduced by 10% at no additional costs (break-even point). Implementing a milking order, which can be easily implemented on smallholder dairy farms, would be one of the options to achieve this. Meanwhile, reducing IRCM and IRSCM by 40% in the simulation scenario can lower the costs of udder health monitoring using CMT with antibiotic treatment by 35% compared with no reduction and reduce mastitis costs by 12% compared with the default strategy. This indicates that whereas udder health monitoring using CMT and antibiotic treatment for subclinical mastitis can be beneficial, their cost-efficiency is highly dependent on achieving substantial reductions in mastitis incidence. Antibiotic treatment alone may not be sufficient to control mastitis transmission, particularly in herds with a relatively high risk of infection, as observed by Barlow et al. (2013). These findings can be used to encourage farmers to implement control strategies for reducing IRCM and IRSCM to achieve greater savings to compensate for the additional costs of udder health monitoring using CMT and antibiotic treatment for subclinical mastitis programs. Studies have shown that udder health monitoring, coupled with appropriate antibiotic treatment for subclinical mastitis, can significantly reduce the incidence of mastitis and improve economic outcomes for dairy farms that have mostly contagious pathogens as the cause of mastitis (Ruegg and Reinemann, 2002; Halasa et al., 2007; van den Borne et al., 2010a). However, this control strategy needs to be combined with cost-efficient measures to offset its implementation costs.

It is acknowledged that this study does not include the transmission of mastitis pathogens within the herd, and this may result in an underestimation of the benefits of control strategies. Including a disease transmission model would probably have an effect on the findings, as treatment may only be economically feasible on farms when decreased transmission of contagious pathogens is observed (van den Borne et al., 2010b; Gussmann et al., 2019b). In this study, the inclusion of subclinical mastitis treatment during lactation was not intended to promote antibiotic use but rather to simulate and evaluate the potential economic effects of such an intervention under varying cure probabilities. This approach allows for a more comprehensive understanding of the cost-benefit dynamics under different treatment efficacy scenarios in the smallholder context. The interventions considered in this study were based on a previously conducted risk factor analysis (Fadillah et al., 2023a). Further research is necessary to develop cost-efficient preventive measures tailored to the circumstances studied here. Despite these limitations, the current study provides valuable insights into cost-efficient mastitis control strategies that can be particularly adapted to smallholder farms. We acknowledge that smallholder farmers' ability to implement control strategies varies depending on their current knowledge of mastitis management and the resources available on their dairy farms. Additionally, there are potential risks associated with their implementation. For example, the use of a sponge in the udder washing with soap control strategy may increase the risk of bacterial contamination if not managed properly. These potential risks highlight the need for proper training of smallholder farmers to ensure effective implementation. Socio-economic considerations, such as availability, social acceptance, and local community involvement, are also crucial in designing and implementing control strategies. Smallholder farmers should prioritize implementing PMTD, which has been shown in this study to be the most cost-efficient control strategy. Additionally, variations in milk prices and teat dipping costs need the attention of dairy cooperatives and industries due to the importance of this value in determining the costs of mastitis and its significant effect on the net economic benefit of its control strategies on smallholder dairy farms.

CONCLUSIONS

This study underscores the significant economic burden of mastitis on smallholder dairy farms and the need for efficient control strategies. The total costs of mastitis were 14% of the annual gross margin; this rises to 36% when considering the 95th percentile of mastitis costs. Interventions can reduce the economic burden of mastitis and may also be cost-efficient. Among the evaluated strategies, PMTD emerged as the only cost-efficient strategy to reduce the incidence and associated costs of mastitis, as it was the only control strategy with a positive net economic benefit. Smallholder farmers in Indonesia, therefore, should prioritize this control strategy. Implementing udder health monitoring using CMT, combined with antibiotic treatment for subclinical mastitis, is a feasible control strategy when there is a substantial reduction in mastitis incidence rates. The modeling approach and findings may also be applicable to other regions of the world where milk production is dominated by smallholder dairy farmers.

NOTES

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Nonstandard abbreviations used: CMT = California Mastitis Test; IRCM = incidence rates of clinical mastitis; IRSCM = incidence rates of subclinical mastitis; PMTD = postmilking teat disinfection.

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