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Economic values for production, fertility and mastitis traits for temperate dairy cattle breeds in tropical Sri Lanka

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Abstract

Economic values for annual milk yield (MY, kg), annual fat yield (FY, kg), annual protein yield (PY, kg), age at first calving (AFC, days), number of services per conception (NSC), calving interval (CI, days) and mastitis episodes (MS) were derived for temperate dairy cattle breeds in tropical Sri Lanka using a bio-economic model. Economic values were calculated on a per cow per year basis. Derived economic values in rupees (LKR) for MY, FY and PY were 107, −162 and −15, while for AFC, NSC, CI and MS, economic values were −59, −270, −84 and −8,303. Economic values for FY and PY further decreased with higher feed prices, and a less negative economic value for FY was obtained with increased price for fat. Negative economic values for FY and PY show that genetic improvement for these traits is not economical due to the high feed costs and/or the insufficient payment for fat and protein. Therefore, revision of milk fat and protein payments is recommended. Furthermore, the breeding objective developed in this study was dominated by milk production and fertility traits. Adaptability and functional traits that are important in a temperate dairy cattle breeding programme in tropical Sri Lanka, such as longevity, feed efficiency, disease resistance and heat tolerance should be recorded to incorporate them in the breeding objective. Continued trait recording of all traits is recommended to ensure dairy cows can be selected more effectively in a tropical environment based on a breeding objective that also includes adaptability and functional traits.

KEYWORDS

economic value, sensitivity analyses, temperate dairy cattle, tropical climate

1 | INTRODUCTION

In Sri Lanka, dairy farming is widespread across the low, intermediate and high elevation zones and consists of enterprises varying from small-scale subsistence-level farming to large-scale commercial farms. The main objectives of large-scale farms were to get cows in calf and produce milk. Large-scale dairy farms also provide breeding animals from temperate breeds to other farms with a similar management system. Objectives of smallholder production systems were often complex with emphasis on numerous non-market value traits that have social, cultural or environmental importance

other than milk production. Hence, smallholder production systems offer fewer opportunities for genetic improvement than large-scale dairy farms in Sri Lanka, and therefore, the focus of this paper is on large-scale dairy farms.

Over the past decades, the improvement in dairy cow milk production in Sri Lanka was mainly achieved via improving management conditions on-farm and importing germplasm from other countries. There were numerous occasions where live animals were imported from temperate countries (Samaraweera et al., 2018; Vernooij et al., 2015). Studies showed a large genotype by environment interaction (Buvanendran & Petersen, 1980; Samaraweera et al., 2020), suggesting that genetic improvement of cows for the production systems in Sri Lanka should be identified via a local breeding programme rather than relying on selection in other countries.

The first step in implementing a local breeding programme in Sri Lanka for genetic improvement of dairy cattle is the definition of a breeding objective. The breeding objective defines the traits that have an effect on farm profit, and it defines the relative weight that each trait should receive during selection. This weighting is proportional to the economic importance of the trait and is derived as an economic value (EV), which is the marginal change in profit obtained through one unit of change in the trait, while all other traits are held constant (Fewson, 1993). Once economic values have been defined, the genetically superior animals can be identified and potentially selected using the selection index methodology (Hazel, 1943). Bio-economic models, which combine the characteristics of production, reproduction, nutrition and economics at the animal and farm level, have been used commonly to derive the EVs in dairy breeding programmes (Kahi & Nitter, 2004; Vargas et al., 2002).

The literature related to economic benefits arising from genetic improvement of traits relevant for the dairy cattle industry in Sri Lanka is scarce. Such attempts must have been hampered by the complexity of bio-economic modelling, due to the difficulties in finding the specific information required for the analyses and due to an absence of functioning dairy cattle breeding programmes in Sri Lanka. Milk production, fertility traits and mastitis are important determinants of a successful dairy enterprise (Kadarmideen et al., 2003; Windig et al., 2006). The genetic parameters of milk production, udder health and fertility traits in temperate dairy cows in Sri Lanka have been previously estimated (Samaraweera, 2020; Samaraweera et al., 2020). In order to establish dairy cattle breeding programmes in Sri Lanka, it is important to estimate the economic benefits arising from genetic improvement of these important traits.

The objective of this study was to estimate economic values for the breeding objective traits relevant for intensive large-scale dairy cattle farms with temperate breeds in Sri Lanka. Profit functions were derived on a per cow per year basis using bio-economic models. Sensitivity of the economic values to changes in the price of milk yield, fat yield and feed was investigated.

2 | MATERIALS AND METHODS

2.1 | Derivation of economic values

The economic values (EVs) were calculated for the main traits of interest in a breeding objective for large-scale dairy farms in Sri Lanka, that is annual milk yield (MY, kg per cow per year), annual fat yield (FY, kg per cow per year), annual protein yield (PY, kg per cow per year), age at first calving (AFC, days/cow), number of services per conception (NSC, counts per cow per conception), calving interval (CI, days/cow) and number of episodes of mastitis (MS, counts per cow per lactation). A breeding programme for temperate pure breeds was assumed, and all input parameters for EV calculation were obtained from the large-scale dairy farms owned by the National Livestock Development Board (NLDB) in Sri Lanka, which rearing only the temperate dairy breeds. Currently, Friesian and Jersey are the two temperate dairy breeds reared by NLDB farms.

The EV of a trait was defined as the change in profit per average lactating cow per year arising from a one-unit increase in the genetic expression of the cow for a particular trait, while all other traits are held constant. The profit per cow per year was derived as the difference between the revenue per cow per year and the cost per cow per year.

The costs, which are influenced by the level of production of the cow, are the variable costs and those costs attributed to farm structures, and machinery, which are fixed costs. Breeding objective traits that were assumed to influence revenues and variable costs are listed in Table 1. Since milk payment is based on fat and protein in milk, the revenue from milk depends on the milk, fat and protein yields. Feed costs of cows vary based on the level of milk, fat and protein yields. Milk yield is often standardized to a lactation length of 305 days, while the actual lactation length can be longer, depending on calving interval (CI). This study looked at annual milk yield calculated from lactation yield and CI. With CI longer than 365 days, the milk yield on an annual basis is likely lower than the 305-day milk yield, and the daily average production of extended lactation will be lower than the 305-day average. A delayed AFC increases the non-productive period of the cow, therefore, increasing feed and non-feed costs. Non-feed costs are mainly health and labour costs. The increased interval between two calvings also reduces the chances of cows having a calf per year, which ultimately reduces the income from selling calves and increases the cost of

rebreeding. The cost of rebreeding was expressed as NSC to account for only the mating costs. Mastitis increases the treatment costs. The revenue from milk is decreased due to discarded milk when cows are infected with mastitis.

The revenues and costs per cow per year were included in the profit equation in Sri Lankan rupees (LKR). The profit was derived using the following equation:

$$P = R_{\text{milk}} + R_{\text{cl}} - C_{\text{fc}} - C_{\text{nf}} - C_{\text{mt}} - C_{\text{ms}} \quad (1)$$

where P = profit (LKR per cow per year), R_{milk} = revenue from milk, R_{cl} = revenue from selling male calves and excess female calves, C_{fc}= feed costs, C_{nf}= non-feed costs, C_{mt} = mating costs and C_{ms} = costs of mastitis.

The profit was calculated for the base (present) scenario assuming mean performance and compared with the profit after one-unit increase in the mean of the trait of interest. The difference between the two scenarios is the marginal profit arising from changing a trait by one unit, which was taken as the EV. The average performance levels, relevant price information and production variables used in the profit function are presented in Table 2, Table 3 and Table 4 respectively. Calculations and key assumptions to derive revenue and costs used for the derivation of this profit function are described in the following sections.

TABLE 1 Breeding objective traits that affect revenues and costs

Profit component	Group of cattle	Trait[a]
Revenues		
Selling milk	Cows	MY, FY, PY, CI, MS
Selling calves	Male calves	CI
Variable costs		
Feed	Calves, heifers, cows	MY, FY, PY, CI, AFC
Non-feed	Calves, heifers, cows	AFC, CI
Mating	Cows	NSC
Mastitis	Cows	MS

[a]Traits are MY: annual milk yield (kg); FY: annual fat yield (kg); PY: annual protein yield (kg); AFC: age at first calving (days); NSC: number of services per conception; CI: calving interval (days); MS: number of episodes of clinical mastitis.

2.2 | Calculation of revenues

2.2.1 | Revenue from selling milk, milk fat and milk protein

Lactation milk, fat and protein yields vary based on lactation length and lactation length depends on calving interval. In this study, average calving interval was longer than a year (516 days). For these longer calving intervals, an extended lactation was assumed. To calculate the effect of a longer calving interval on the total lactation yield (LY), the Wood's function (Wood, 1967) was used to calculate the milk yield at day t of lactation (LY_t) as follows:

$$\text{LY}_t = at^b \exp(-ct), \quad (2)$$

where values for initial milk yield (a), increasing slope (b) and decreasing slope (c) were assumed to be as 12.5 kg, 0.1465 and 0.003 respectively. The values for lactation curve parameters were derived from the curve parameters of 305-day milk yield described in the study by Samaraweera et al. (2020). For a given calving interval (CI, days), a lactation length (LL, days) of CI − 60 was assumed, with 60 days being the dry period. The total lactation yield (LY) is then:

$$\text{LY} = \sum_{1}^{\text{LL}} \text{LY}_t. \quad (3)$$

Annual milk yield (MY) was calculated for a standard calving interval of 365 days, and MY was calculated as LY*(365/CI). The price of 1 kg of milk was based on 38 g of fat, 33 g of protein and 46 g of lactose per kg milk. Revenue from 1 kg increase in fat and protein was taken as

TABLE 2 Average performance for each breeding objective trait

Breeding objective traits	Abbreviations	Unit	Average
Annual milk yield[a]	MY	kg per cow per year	4,471
Annual fat yield[b]	FY	kg per cow per year	170
Annual protein yield[b]	PY	kg per cow per year	148
Age at first calving[a]	AFC	days per cow	1,095
Number of services per conception[a]	NSC	counts per cow per conception	6
Calving interval[a]	CI	days per cow	516
Mastitis episodes[a]	MS	counts per cow per lactation	0.29

[a]Samaraweera (2020) and Samaraweera et al. (2020).

[b]National Livestock Development Board (NLDB).

TABLE 3 Prices and costs used for the calculation of the economic values of each trait

Variable[a]	Abbreviations	Unit	LKR[b]
Price of milk with 3.8% fat and 3.3% protein per kg	P_{MY}	LKR/kg	115
Extra payment for 1 kg increase in fat	P_{FAT}	LKR/kg	250
Extra payment for 1 kg increase in protein	P_{PRT}	LKR/kg	250
Imported conventional semen		LKR/straw	900
Local conventional semen		LKR/ straw	50
Price per kg of live male calf weighing 80 kg	P_{MCALF}	LKR/male calf	12,000
Price per kg of live female calf weighing 80 kg	P_{FCALF}	LKR/female calf	16,000
Price per kg of culled cow per live weight basis	PLWc	LKR/kg	228
Mastitis treatment cost per dose	C_d	LKR/dose	250
Price of antibiotics for dry cows with mastitis	P_A	LKR/treatment	1000
Daily feed cost for heifers (weaning to first calving)	P_{df1}	LKR/day	240
Daily feed cost for pregnant heifers	P_{df2}	LKR/day	252
Daily feed cost for lactating cows for maintenance	P_{df3}	LKR/day	378
Daily feed cost for dry cows	P_{df4}	LKR/day	380
Daily health cost for heifers and cows	C_H	LKR/day	10
Daily labour cost for heifers and cows	C_L	LKR/day	150
Daily fixed costs		LKR/day	400
Price per one MJ of net energy of milking cow diet	FC_{NE}	LKR per MJ NE	10.8

[a]Prices were obtained from National Livestock Development Board (NLDB) except for FC_{NE}. Derivation of FC_{NE} given in the Appendix 2.
[b]1 US dollar = 186 LKR, May 2020.

the mean difference in fat and protein yields between the base and after one-unit increase. The annual milk revenue (R_{milk}, LKR per cow per year) was calculated as follows:

$$R_{milk} = \left[(MY \times P_{MY}) + (FY - (MY \times 0.038)) \times P_{FAT} + (PY - (MY \times 0.033)) \times P_{PRT}\right] \quad (4)$$

where MY = annual milk yield (kg per cow per year), FY= annual fat yield (kg per cow per year), PY = annual protein yield (kg per cow per year), P_{MY} = price per 1 kg of milk with 38 g of fat and 33 g of protein (115 LKR per kg), P_{FAT} = payment for 1 kg increase in milk fat (250 LKR per kg) and P_{PRT} = payment for 1 kg increase in milk protein (250 LKR per kg). Total lactation milk yield changes with the length of the calving interval; therefore, to derive the EVs for CI, the terms MY, FY and PY in Equation (4) were replaced with LY, lactation fat and lactation protein yields, respectively, and multiplied by (365/CI).

2.2.2 | Revenue from selling calves

The number of calves born per cow per year varied based on calving interval. The number of calvings per year is equal to (365/CI). The number of male calves born and alive at 24 hr after birth per cow per year (n_m) was calculated as follows:

$$n_m = 0.5 \times SRB \times (365/CI) \quad (5)$$

where SRB = survival rate at birth, which was assumed as 0.94. The sex ratio was taken as 0.5. The average weight of calves when sold after weaning was 80 kg. The income from selling male calves (R_{mc}, LKR per cow per year) was calculated as follows:

$$R_{mc} = n_m \times SRW \times P_{MCALF} \quad (6)$$

where n_m= number of male calves born per cow per year, SRW = survival rate from birth to weaning (0.88) and P_{MCALF} = price of live male calf weighing 80 kg (12,000 LKR/male calf).

The number of female calves born and alive at 24 hr after birth per cow per year (n_f) was equal to the number of male calves (n_m). The number of replacement heifers was calculated as 1/PL, where PL = productive lifespan. The income from selling female calves (R_{fc}, LKR per cow per year) was calculated as follows:

$$R_{fc} = \left[(n_f \times SRW) - (1/PL)\right] \times P_{FCALF} \quad (7)$$

TABLE 4 Production variables used for the calculation of the economic values of each trait

Variable[a]	Abbreviations	Unit	Average
Lactation yield for calving interval of 516 days	LY	kg per cow per lactation	6,321
Lactation fat yield		kg per cow per lactation	240
Lactation protein yield		kg per cow per lactation	209
Fat concentration	*F*	g/kg of milk	38
Protein concentration	*P*	g/kg of milk	33
Lactose concentration	*L*	g/kg of milk	46
Percentage of calves survived at birth	SRB	%	94
Percentage of calves survived from birth to weaning	SRW	%	88
Average number of calves produced during the lifetime of a cow		count	5
Productive life time[b]	PL	years	7
Age at weaning	wn	days	90
Age at first service	AFS	days	548
Dry period		days	60
Quantity of milk fed from birth to weaning	Q_{milk}	kg/day	4
Local semen		% of use	90
Imported semen		% of use	10
Number of straws used per insemination	n_s	count	2
Percentage of cows with mastitis during a lactation	$\%_{ms}$	%	24
Average number of mastitis episodes per cow per lactation	n_{ms}	episodes/lactation	1.2
Average number of days treated per mastitis episode	D_{tp}	days	10
Milk withdrawal period after treatment for mastitis	mw	days	14
Number of drug doses used per mastitis treatment	nd	doses/episode	6

[a]National Livestock Development Board (NLDB).

[b]From first calving to death or removal from herd.

where n_f = number of female calves born per cow per year and P_{FCALF} = price of live female calf weighing 80 kg (16,000 LKR/female calf).

2.3 | Calculation of variable costs

2.3.1 | Calculation of feed costs

Older ages at first calving increase feed costs. Longer calving intervals also increase per lactation feed costs. Since feed costs are determined by the level of production, feed cost also varies relative to the level of milk, fat and protein yields. Total feed cost per cow per year (C_{fc}) is equal to the cost of feeding calves from birth to first calving (FC_{b-c}, LKR per cow per year) as affected by the age at first calving and the cost of feeding milking and dry cows from one calving to the next (FC_{mdc}, LKR per cow per year). The first part of the Equation (8) (FC_{b-c}) is based on the number of calves and heifers kept in the replacement herd, and calculation of these numbers are described below:

$$C_{fc} = FC_{b-c} + FC_{mdc} \quad (8)$$

The derivation of feed costs for each period, that is (i) from birth to first calving and (ii) during the calving interval as well as (iii) due to increased milk, fat and protein yields, is presented in the following sections.

(i) *Feed costs from birth to first calving*: Feed costs from birth to first calving are the sum of costs for feeding calves, heifers and pregnant heifers. The number of calves and heifers per cow is accounted for in the feed cost calculation. The feed cost from birth to first calving (FC_{b-c}) was expressed per cow per year as follows:

$$FC_{b-c} = \left[90 \times n_c \times Q_{milk} \times P_{MY}\right] + \left[(548 - 90) \times n_{wf} \times P_{df1}\right] + \left[(AFC - 548) \times n_{rf} \times P_{df2}\right]. \quad (9)$$

The first, second and third parts of Equation (9) refer to feed costs from birth to weaning (90 days), from weaning to first service at 18 months of age (548 days) and from 18 months of age to first calving respectively. The number of calves born and alive at 24 hr postcalving per cow per year is equal to the sum of both male (n_m) and female (n_f) calves, that is $n_c = n_m + n_f$, where $n_f = n_m$. The number of females after weaning (n_{wf}) is equal to n_f multiplied by SRW. The number of replacement heifers (n_{rf}) was calculated as 1/PL. Values for quantity of milk fed on each day (Q_{milk}), daily feed cost for heifers (P_{df1}), daily feed cost for pregnant heifers (P_{df2}) and PL are 4 kg per day per calf, 240 LKR per cow per day, 252 LKR per cow per day and 7 years respectively.

(ii) *Feed costs during calving interval*: Feed cost during the calving interval varies based on the length of the calving interval and the energy requirement for daily production of milk, fat and protein yields of the cow. Feed costs for daily production of milk, fat and protein were calculated as the price per one MJ of net energy of milking cow diet (FC_{NE}) multiplied by the energy requirement to produce milk daily. The daily feed cost for daily fat, protein and lactose yields ($FC_{dailymilk}$, LKR per cow per day) was predicted using the following equation:

$$FC_{dailymilk} = (0.0381F + 0.0245P + 0.0165L) \times LY_t \times FC_{NE} \quad (10)$$

where F = fat concentration (g per kg of milk), P = protein concentration (g per kg of milk), L = lactose concentration (g per kg of milk), and the constants were as given in CSIRO (2007), FC_{NE}= feed cost to produce one MJ of net energy (10.8 LKR per MJ NE). Feed costs for the production of a kg of milk, fat and protein were calculated using the same equation used to derive the daily feed cost (Equation 10). The derivation of FC_{NE} is described in the Appendices 1 and 2.

Annual feed costs for milking and dry cows (FC_{mdc}, LKR per cow per year) were calculated as the sum of daily feed cost for milk yield ($FC_{dailymilk}$) and daily feed cost for maintenance as follows:

$$FC_{mdc} = \left[\sum_{t=1}^{t=CI-60} FC_{dailymilk} + t \times P_{df3}\right] + \left[60 \times P_{df4}\right] \times (365/CI) \quad (11)$$

where P_{df3} = daily feed cost for maintenance in milking cows (378 LKR per cow per day), P_{df4} = daily feed cost of dry cows (380 LKR per cow per day) and t = number of days in the CI, with the dry period taken as 60 days and $FC_{dailymilk}$ was derived for each day using Equation (10).

2.3.2 | Calculation of non-feed costs

Non-feed costs affect the economic values for AFC and CI, and they mainly consist of health and labour costs. Similar to feed costs, non-feed costs were calculated separately for two periods, that is from birth to AFC and for the duration of the CI. The sum of the non-feed costs for the two periods adjusted per cow per year was taken as the non-feed costs. Non-feed cost (C_{nf}, LKR per cow per year) was derived as follows:

$$C_{nf} = \left[90 \times n_c \times (C_H + C_L) + (548 - 90) \times n_{wf} \times (C_H + C_L) + n_{rf} \times (AFC - 548) \times (C_H + C_L)\right] + \left[CI \times (C_H + C_L)\right] \quad (12)$$

The first and second parts of Equation (12) refer to the annual non-feed costs from birth to age at first calving (LKR per cow per year) and the annual non-feed costs for the duration of the CI (LKR per cow per year) respectively. Symbols, C_H and C_L refer to daily health cost (10 LKR per cow per day) and daily labour cost (150 LKR per cow per day) respectively. Age at first service was 548 days.

2.3.3 | Cost of mating

Mating costs (C_{mt}) were based on the number of services per conception (NSC). Since labour cost is independent of the number of services in the large-scale dairy farms in Sri Lanka, artificial insemination rebreeding cost was assumed to include only the cost for semen straws.

$$C_{mt} = NSC \times C_i \times n_s \quad (13)$$

where NSC = number of services per conception, C_i = the average cost of a semen straw (135 LKR per straw) and n_s = number of straws used per insemination (2 straws). The average cost of a semen straw was calculated as the cost of each semen type (imported or local semen) multiplied by the frequency of use of each semen type. Most artificial inseminations were carried out with local semen (90%) rather than with the imported semen (10%). High NSC indicates the poor rebreeding success in large-scale dairy farms in Sri Lanka. Cows that can successfully rebreed stay in the herd for

as long as they reproduce, increasing the length of PL (Samaraweera, 2020).

2.3.4 | Costs of mastitis

A sequence of treated and non-treated days for mastitis was considered as a single episode if the non-treated days between two treatments were less than 14 days. This avoids counting the same case of mastitis as two distinct mastitis episodes. The average clinical mastitis episode per cow per year (MS) was derived by multiplying the percentage of cows with mastitis during a year ($\%_{ms}$) by the average number of mastitis episodes per cow per lactation (n_{ms}). The main costs of clinical mastitis (C_{ms}, LKR per cow per year) are the costs of drugs (CM_{dr}, LKR per cow per year) and cost of discarded milk (C_{dm}, LKR per cow per year) due to mastitis infection:

$$C_{ms} = CM_{dr} + CM_{dm}. \quad (14)$$

The cost of drugs was calculated as follows:

$$CM_{dr} = MS \times \left(C_d \times nd + P_A\right) \quad (15)$$

where MS = number of mastitis episodes per cow per lactation, C_d = cost per dose (250 LKR/dose), nd = number of doses per episode (6 doses) and, P_A = price of antibiotics for dry cows (1000 LKR/treatment) that have mastitis. The number of days the milk was discarded is equal to the number of episodes per lactation times the number of days per episode plus 14 days of milk withdrawal period after each mastitis episode. During this period, milk was discarded due to antibiotic residues in the milk. Therefore, the cost of discarded milk per episode (CM_{dm}) was calculated as follows:

$$CM_{dm} = MS\left[\left(D_{tp} + mw\right) \times \left(md \times P_{MILK}\right)\right] \quad (16)$$

where D_{tp} = the average number of days treated per episode of mastitis (10 days), mw = number of days of milk withdrawal after treatment for mastitis (14 days) and md = average milk production per day, which was taken as 13.9 kg per cow per day. Higher mastitis incidences were reported during the first 10 days of lactation in temperate dairy cows in Sri Lanka, but the incidences were not restricted to the first 10 days (Samaraweera, 2020). Therefore, an average milk yield was assumed as the amount of daily discarded milk due to mastitis. Mastitis incidences in all lactations were assumed to be the same.

2.4 | Sensitivity analyses

The sensitivity of EVs to changes in the price of milk, fat, feed, and cost of treatments for mastitis by 20% was calculated sequentially, keeping all other parameters constant.

3 | RESULTS

3.1 | Economic values

The revenue from milk, including payments for fat and protein, accounted for 97% of total income (Table 5). The feed cost was 58%, and health and labour costs were 16.5%

TABLE 5 Percentage contribution of revenue and costs per cow per year, the marginal change after one unit increase in genetic merit of each trait from the base situation, discounted genetic expression coefficients, economic weights and relative emphasis of each trait

		Marginal change after one unit change in the genetic merit of the traits[a]						
Parameter	**%**	**MY**	**FY**	**PY**	**AFC**	**NSC**	**CI**	**MS**
(1) Income (LKR per cow per year)								
Milk	97	115	250	250	0	0	−347.6	−7,794
Male calves	0.5	0	0	0	0	0	−6.8	0
Culled cows and excess heifers	2.8	0	0	0	0	0	−9.1	0
(2) Costs (LKR per cow per year)								
Feed	58	8	412	265	36	0	−218.6	0
Health & labour	16.5	0	0	0	23	0	−61.0	509
Rebreeding	0.5	0	0	0	0	270	0	0
Fixed	25	0	0	0	0	0	0	0
EV[b] = *Profit (1–2, LKR per cow per year)*		107	−162	−15	−59	−270	−84	−8,303

[a]Traits are MY: annual milk yield (kg); FY: annual fat yield (kg); PY: annual protein yield (kg); AFC: age at first calving (days); NSC: number of services per conception; CI: calving interval (days); MS: number of episodes of clinical mastitis.

[b]EV, the profit under the marginal change after one unit increase in the genetic merit of the traits is equal to economic value per trait basis.

of total costs. The marginal changes in costs and revenues after one-unit increase in genetic merit of each trait are shown in Table 5. The EVs per unit change in the trait were positive only for MY. Economic values for FY and PY were negative due to feed costs, which were higher than the revenue for selling a kg of FY and PY. For the current payment and cost system, selection for higher MY and lower FY and PY is profitable.

For age at first calving, the number of services per conception and calving interval, the EVs (LKR) were −59, −270 and −84 respectively. Therefore, selection targeting a reduction in these traits will increase farm profit. Increased CI reduced revenue from milk sales and decreased the cost of discarded milk due to mastitis by 363 and 15 LKR per cow per year respectively. Therefore, annual milk revenue was decreased by 348 LKR per cow per year (i.e. −363 LKR per cow per year +15 LKR per cow per year), indicating that selection for reduced calving interval would increase the annual revenue from milk sales. Selection for reduced calving interval would decrease feed costs for milking and dry cows by 103 LKR per cow per year since the low production period of a cow's lactation would be shortened giving more productivity on an annual basis. However, selection for a shorter CI would increase feed costs for calves and heifers by 115 LKR per cow per year (53 LKR from birth to weaning and 62 LKR from weaning to AFS), due to increased number of calves born. Feed intake had no impact on NSC and MS. The EV for increasing the average mastitis episodes by one episode per cow per year was (−8303) LKR. Milk losses accounted for the majority (94%) of economic losses caused by clinical mastitis.

3.2 | Sensitivity analyses

The effects of a 20% change in price of milk yield, fat yield, feed and treatment cost for mastitis on EVs of these traits were evaluated (Table 6). Increasing the price of milk increased the EV for MY and further decreased the EVs of CI and MS. With the increased milk price, EV for CI became more negative because the extended CIs decrease MY. The sensitivity of MS to changes in the milk price is due to the cost of discarded milk during treated periods and milk withdrawal periods after treatment for mastitis. The increased payment for fat reduced the negative EV for FY. Sensitivities of the EVs to changes in feed price were highest for FY followed by PY. Reduction in feed prices by 20% results in positive EVs for FY, PY and AFC. Change in feed price had no effects on the EVs of NSC and MS. Any of the price changes does not influence NSC.

4 | DISCUSSION

Economic values (EVs) on a per cow per year basis were estimated for milk production traits, reproductive traits and mastitis, which have the potential to be included in a dairy cattle breeding programme for large-scale intensive dairy farms in Sri Lanka. The EVs were derived by taking the marginal change in profit of a single trait at a time, when all other traits were held constant. Fixed costs and other costs that were not directly affected by the change of the genetic merit in a trait remained constant when the herd size was fixed. Therefore, the EVs for traits were the same as the marginal profit per cow after a trait change.

TABLE 6 Changes in the economic values per cow per year in response to ±20% changes in the price of milk, milk fat, feed and mastitis treatment costs relative to the current average economic values

Variable	Change	MY[a]	FY	PY	AFC	NSC	CI	MS
Base economic value		107	−162	−15	−59	−270	−84	−8,303
Changes in prices								
Milk (LKR/kg)	+20%	23	0	0	0	0	−59	−1,558
	−20%	−23	0	0	0	0	59	1,558
Milk fat (LKR/kg)	+20%	0	50	0	0	0	0	0
	−20%	0	−50	0	0	0	0	0
Feed (LKR per kg per day)	+20%	−2	−83	−53	−7	0	33	0
	−20%	2	82	53	7	0	−33	0
Mastitis treatment cost (LKR/dose)	+20%	0	0	0	0	0	0	−100
	−20%	0	0	0	0	0	0	100

[a]Traits are MY: annual milk yield; FY: annual fat yield; PY: annual protein yield; AFC: age at first calving; NSC: number of services per conception; CI: calving interval; MS: number of episodes of clinical mastitis.

In this study, the price of milk was based on milk with 3.8% of fat (38 g) and 3.3% of protein (33 g). Therefore, a positive EV was observed in this study for MY similar to milk volume-based payment systems in the literature. Positive EVs per cow per year for milk yield were also reported in tropical production systems in Kenya (18.93 KES) (Kahi & Nitter, 2004), Chinese Holstein production systems (1.99 RMB) (Chen et al., 2009) and Iranian production systems for Holstein cows (0.192 USD) (Ghiasi et al., 2016) where the price of milk was determined by milk volume. The EVs for milk yield are negative when the payment system is based on milk solids rather than volume, such as in the Australian dairy industry (−0.09) (Byrne et al., 2016). Therefore, the payment scheme for milk affects the EV of milk and its components.

The current payment system in Sri Lanka rewards both fat and protein due to their usefulness in product quality. Payment for 1 kg increase in fat or protein was 250 LKR, whereas the feed costs for 1 kg increase in fat and protein were 412 LKR and 265 LKR, respectively, resulting in negative EVs for FY and PY given the high feed costs and/or the insufficient payment for fat and protein in this study. Therefore, the current payment system does not encourage the genetic improvement of fat or protein content and if index selection is implemented, it will lead to reduction in protein and fat content (i.e. as percentages) of milk. This needs further investigation as to see whether the dairy industry in Sri Lanka would benefit from increased lactation milk yield or increased fat and protein yields since benefits from genetic improvement largely depend on the dairy products manufactured in Sri Lanka. Currently, consumption of liquid milk is promoted; however, the demand is highest for powdered milk in Sri Lanka. Milk fat, milk protein and lactose are the major constituents in milk powder. Due to lowered fat and protein content and increased milk yield, there could be negative consequences such as decreased nutritive value of milk, higher energy requirements to evaporate the liquid portion of the milk in producing milk powder, and increased storage and transport costs while handling milk. Therefore, an increased emphasis on fat and protein in a selection index could be beneficial, despite the current negative EVs.

In this study, all fertility traits AFC, NSC and CI had negative EVs. Increases in CI in lactating cows allow lactations to continue; however, low daily milk production at the end of lactations reduces the annual income from MY. In this study, the annual milk yield was used as the breeding objective trait and lactation milk yield was used to account for the loss in milk income due to extended CI. Increased CI also increased the annual feed cost. Furthermore, a minor reduction in revenue from selling male and female calves was also observed in this study. In contrast to the current study, a positive EV for CI was reported in tropical pasture-based production systems in Kenya (Kahi & Nitter, 2004). The positive EV in the study by Kahi and Nitter (2004) could be due to not changing the milk yield based on CI and not accounting for the feed costs during the extended calving interval. In Sri Lanka, commercial dairy producers aim to produce a calf per cow each year to ensure a lactation yield every year and to increase the number of replacement heifers available. Therefore, genetic selection for shorter CIs benefits dairy farms in Sri Lanka.

The negative EV for AFC reflects the increase in farm profit due to shortened age at first calving that would shorten the unproductive period of a cow's life. The negative EV was also reported for AFC in Kenyan production systems (Kahi & Nitter, 2004). A reduction in AFC increases overall farm profit.

A negative EV was reported in this study for mastitis. Comparisons of the EV for mastitis in this study with other studies shows that the EV in this study was less than the EV estimated for Holstein dairy cattle production systems in Iran (44 USD vs. 80 USD) (Sadeghi-Sefidmazgi et al., 2011). The difference in EV between this study and the study by Sadeghi-Sefidmazgi et al. (2011) could be due to differences in the cost of the treatments used. At present, only the clinical mastitis incidences are recorded on farms on a per cow basis; however, milk acceptance or rejection is based on the cell counts in milk samples. Cows with sub-clinical mastitis are usually not recorded due to an absence of clinical signs, but still, the cell counts in their milk could be high. Therefore, traits accounting for milk hygiene, such as somatic cell counts, could be considered for incorporation into the selection index given cell counts on a per cow basis are available.

The bio-economic model used in this study assumed a fixed herd size, and feed supply was altered based on the level of production. In Sri Lanka, Jersey-Friesian crossbred cows produced a higher milk production than Jersey cows (Samaraweera et al., 2020). Jersey cows produced more milk fat than Holstein-Friesian cows, and a higher body size is expected in Holstein-Friesian cows than in Jersey cows (Prendiville et al., 2010). The differences in milk, fat and protein production were accounted for in the feed cost calculations in this study. The feed cost calculations for milking cows were based on energy requirement for milk production and maintenance, while for heifers and dry cows, it was based on daily feed costs. However, economic values for milk protein or milk fat do not include the costs for providing additional protein or fat in the diet since feed cost calculations for milking cows were based on energy requirements rather than based on both energy and proteins. If protein-rich diets were provided to meet higher milk protein production that would further increase the feed cost. Due to lack of information on cow weight, feed cost for maintenance was calculated

for a fixed body weight of cows. Bio-economic models in this study can be updated in the future to include energy and protein-based feed cost calculations. Cow weight can then be included as a trait to account for maintenance costs.

Feed was not considered as a limiting factor in large-scale dairy farms due to their ability to bear the cost of concentrates even at times of low income. However, in most developing countries, the supply of feed with adequate quantity and quality is limited. Even, large-scale farms experience restricted forage supply during periods of prolonged droughts. Therefore, a limited supply of feed would restrict the expression of the cow's production and reproduction potential. These models can be refined in the future to include the feed availability and interactions between farm inputs, which could be translated into monetary values.

In this study, the ratio of variable to fixed costs was 75:25. Derived revenues and costs largely resemble the economic activities in an average large-scale dairy farm in Sri Lanka. There could be discrepancies due to a lack of information when calculating the costs. A recent study to estimate the costs of commercial dairy farms in Sri Lanka estimated variable and fixed costs as 64% and 36%, respectively, which is slightly different from the current study (Maddegoda et al., 2020). The objective of this paper was to calculate the marginal profit of breeding objective traits and slight differences in fixed cost that are not affected by trait changes could be ignored. Therefore, EVs derived in this study are adequate to define the relative importance of each breeding objective trait for genetic improvement programmes and to transform and use them as economic weights in a selection index for genetic improvement of dairy cattle in Sri Lanka.

5 | LIMITATIONS AND RECOMMENDATIONS

Out of seven traits in the current breeding objective, six traits were based on milk production and reproduction traits, and the breeding objective developed reflects mainly the milk yield output. Therefore, current index may favour selection of high yielding but less functional dairy cows, which is not favourable for tropical countries. Adaptability and functional traits such as survival, longevity, feed efficiency, and disease and heat tolerance are highly important in breeding objectives for tropical dairy production systems due to environmental stresses that interfere with production, fertility and survival of cattle. Survival and longevity increase the number of heifers available for replacement, income from selling male calves and productive life span. Selection of dairy cattle that can efficiently utilize tropical forages to produce milk is beneficial to cut down the costs associated with cultivation of improved pasture/fodder under production systems in Sri Lanka. Disease and heat tolerance are important determinants of productivity in tropical dairy production systems. Cow weight is directly proportional to feed costs for maintenance and milk production; hence, it would be good to select dairy cows targeting an optimum mature cow weight. Even though the importance of these functional traits has been identified, these traits were not included as breeding objective traits in the current study due to shortage of data accounting for these traits and/or the associated costs and returns. Absence of relevant data recording is a major limitation for selection of these traits in the tropics. Therefore, it is important to increase the awareness about significance of collecting required data and introduction of protocols to collect and store data related to the above functional traits. This will enable the development of genetic evaluation procedures to achieve the expected genetic change in both productivity and adaptability, health and survival of temperate cows in the tropics.

The current pricing system for milk, fat and protein does not favour the genetic improvement of FY and PY, and it would be costly to have cows producing higher fat and protein yields than the current levels. The feed costs for milking cows were calculated based on the energy requirement for maintenance and milk production. If protein- and fat-rich diets are provided to compensate for the increase in milk fat and milk protein requirements, feed costs could increase further. Therefore, the payment for additional fat and protein in milk should be revised considering feed costs, the monetary benefits of having higher fat and protein content in milk, and considering the human nutritional aspects. Moreover, the breeding objective should be regularly reviewed based on the market and environmental concerns potentially new important traits should be incorporated in the future.

6 | CONCLUSIONS

This study demonstrates that genetic improvement of milk yield, age at first calving, number of services per conception, calving interval and resistance to mastitis will have a positive impact on the profitability of dairy farms. Negative economic values for fat and protein yields show that genetic improvements for higher fat and protein yields than the current fat and protein yields are not economical. Breeding objective traits defined in this study are a first step for the development of a selection index for use in dairy cattle breeding programme(s) for temperate dairy breeds in Sri Lanka, which should be extended to include traits describing adaptability, health and survival traits.

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CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in this article.

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APPENDIX 1

Daily net energy requirement of a cow for maintenance and milk production

Daily total net energy requirement (ER, MJ of NE per cow per day) of a cow is equal to the sum of daily net energy requirement for maintenance (ER_M, MJ NE per cow per day) and daily net energy requirement for milk production (ER_{MILK}, MJ NE per cow per day) as follows:

$$ER = ER_M + ER_{MILK} \quad (A.1)$$

Daily net energy requirement for maintenance (ER_M, MJ ME per cow per day) was estimated using the following equation by CSIRO (2007):

$$ER_M = \left[1.4 \times \frac{0.28W^{0.75}\exp(-0.03A)}{k_m} + 0.1ME_p\right] \times k_m \quad (A.2)$$

where $\boldsymbol{W}$ = live weight (kg), $\boldsymbol{A}$ = age (years), k_m = net efficiency of use of ME for maintenance and ME_p = the amount of dietary ME (MJ) being used directly for production. Metabolizable energy for production (ME_p, MJ ME per cow per day) was obtained by dividing the net energy for production (ER_{MILK}, MJ NE per cow per day) by the appropriate k_l value. Values for k_m and k_l were taken as 0.7 and 0.62 respectively (McDonald et al., 2011). Daily net energy requirement for milk production (ER_{MILK}, MJ NE per cow per day) was predicted using the fat, protein and lactose concentrations in milk (Equation 9). The derived energy requirements and price per MJ of NE of milking cow diet are given in Table A1.

APPENDIX 2

Calculation of feed cost per one mega joule of net energy

It was assumed that the current ration for lactating cows fulfils the daily energy requirements for maintenance and milk production. Feed cost of one MJ of NE (FC_{NE}, LKR per MJ NE) was calculated as follows:

$$FC_{NE} = \frac{P_{df5}}{ER} \quad (A.3)$$

where P_{df5} = daily average feed cost for lactating cows (833 LKR per cow per day), ER = daily energy requirement by a cow for maintenance and milk production (NE, MJ of NE per cow per day).

The mixed ration for lactating cows consists of molasses (65% of dry matter, 1.5 kg per day), chopped sorghum and maize (25% of dry matter, 15 kg per day), beer pulp (30% of dry matter, 2 kg per day), grasses (18% of dry matter, 10 kg per day), lactating cow meal (90% of dry matter, 10 kg per day) and premix (0.065 kg per day). Currently, the feed is provided on a per weight basis, that is 12% of body weight, on a fresh weight basis. The cost of the ration is around 21,600 LKR per ton.

TABLE A1 Derived energy requirements and price per MJ of NE of milking cow diet

Energy requirement/price	Abbreviation	Unit	Value
Average daily energy requirement for maintenance and milk	ER	MJ of NE per cow per day	77
Energy requirement to produce a kg of milk	ER_{MILK}	MJ of NE/kg of milk	3.01
Energy requirement to produce a kg of fat	ER_{FAT}	MJ of NE/kg of fat	38.1
Energy requirement to produce a kg of protein	ER_{PROT}	MJ of NE/kg of protein	24.5