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Economic modeling and selection for longevity traits in dairy cattle

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Research Article

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Abstract

Different definitions have been proposed for longevity, making it challenging to compare methods for estimating the economic significance of survival traits. Simple profit functions often fail to capture biological complexity, whereas bioeconomic models, though comprehensive, can be difficult to apply. This study aimed to develop a versatile framework for estimating the economic value (EV) of longevity traits and designing optimal selection indices. The approach can accommodate various definitions of longevity (e.g., herd life, productive life, number of lactations, stayability or survival across lactations) and be applied across production systems. The economic model is founded on a stable herd age structure at equilibrium, where changes in survival rates influence profitability and age distribution. Average survival rates between parities determine the distribution of cows across parities and the number of replacements needed to maintain a steady-state herd structure. Iranian production and economic data were used for parameterization, and EVs were estimated accordingly. Seven selection indices were developed, incorporating production, reproduction, somatic cell score (SCS), longevity and type traits. The estimated economic weights were \$0.12/kg for milk yield, \$5.56/kg for fat yield, \$5.50/kg for protein yield, \$2.73/month for productive life, \$22.6/year for herd life, \$0.18/percentage point for survival, \$37.59/lactation for number of lactations, \$-3.84/day for days open and \$-122.87/unit for SCC. Excluding longevity from the breeding goal led to the lowest observed genetic gain, demonstrating that including longevity traits positively influences overall genetic improvement. The greatest genetic progress was achieved by indices enhancing productive life through indirect selection on fore udder conformation. This study demonstrates that (1) the flexible approach enables estimation of EVs under multiple longevity definitions and (2) selection for productive life, particularly via indirect selection on fore udder traits, improves longevity, enhances production and reduces SCC.

Premature culling remains a major challenge in the global dairy industry, leading to considerable financial losses, reduced genetic selection opportunities and heightened consumer concern over animal welfare, all of which can negatively affect the demand for dairy products (Miglior *et al.*, 2005). Longevity is a key performance trait of economic importance and is widely recognized as a global indicator of animal welfare (Pritchard *et al.*, 2013; Thomsen and Houe, 2018; Adamie *et al.*, 2023; Akhtar *et al.*, 2023). By appropriately extending the productive lifespan, profitability can be increased by 10–15% (Gazzarin *et al.*, 2025).

True longevity in dairy cows is generally defined as the animal's ability to remain in the herd and avoid culling, regardless of the underlying reason. Longevity is a complex trait influenced by numerous factors, including milk yield, health status, reproductive performance, temperament and overall productive performance. Economic variables such as milk and carcass prices, feed costs, veterinary and breeding expenses, as well as the availability of replacement heifers, also play a critical role in determining a cow's productive lifespan (Bascom and Young, 1998; De Vries, 2013).

As a result, numerous definitions and methodologies have been developed to measure longevity. The definition and measurement of longevity vary among countries involved in dairy cattle genetic improvement programmes. Common indicators include age at last calving, number of lactations (NL) and length of productive life (LPL), which refers to the time from first calving to culling. Longevity may also be defined as herd life (HL), representing the duration from birth to culling or death. Additional measures include stayability (STAY), which reflects a cow's ability to avoid culling, and survivability (SR), which describes the proportion of cows surviving to a specific point in time. SR is typically calculated by dividing the number of cows that

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have survived to a given time point by the number of cows in the opportunity group (Ducrocq *et al.*, 1988; Yazdi *et al.*, 1999; Brickell and Wathes, 2011; Sasaki *et al.*, 2018; Dallago *et al.*, 2021).

In practice, genetic evaluations for longevity are routinely conducted in various countries using different definitions and methodologies. For example, in several European countries such as France, the Netherlands, Germany, Denmark, the Czech Republic and Italy, longevity is measured as length of productive life (der Linde C and de Jong, 2003). In the United States, productive life is defined as months in milk, recorded up to a maximum of 84 months but counted only up to 10 months per lactation, since records longer than 305 days are not stored (VanRaden and Wiggans, 1995). In Canada, cow survival is recorded as binary traits at multiple time points: from first calving to 120 days in milk (DIM), 120 to 240 DIM, 240 DIM to second calving, survival to third calving and survival to fourth calving. These traits are evaluated using a multiple-trait linear animal model to account for genetic differences across these periods (Sewalem *et al.*, 2007). In New Zealand and Australia, longevity is defined as the percentage of cows surviving from one lactation to the next (Schuster *et al.*, 2020). Longevity as a genetic trait is generally considered to have low heritability worldwide. Heritability estimates for longevity traits range from 0.03 to 0.15 (Madgwick and Goddard, 1989; Vollema and Groen, 1997; Van Pelt *et al.*, 2015; Nejad *et al.*, 2021). Genetic correlations between longevity and other traits, such as production, conformation, health and fertility, are typically low to moderate (Zavadilova and Stipkova, 2012; Kern *et al.*, 2015; Hu *et al.*, 2021). Given the low heritability of longevity and the fact that realized longevity, without the use of predictive or genomic information, becomes available only at the end of a cow's life, direct selection for these traits results in slow genetic progress (Cassell, 2009). Therefore, direct selection for longevity may in some situations be less effective than selecting for more heritable traits. Consequently, type traits, including conformation, health and reproduction-related traits, have been used as indirect indicators for longevity (Essl, 1998; Sewalem *et al.*, 2005; Miglior *et al.*, 2017). This approach has led to multitrait evaluations that combine both direct and indirect measures, improving the effectiveness of genetic selection for longevity (Miglior *et al.*, 2017).

In animal breeding, the genetic merit of future generations must be improved to achieve efficient production under evolving economic, environmental and social conditions (Groen *et al.*, 1997). The economics of dairy cattle production require that the breeding objective facilitates optimal genetic progress toward a clearly defined economic goal. To establish a breeding goal, it is essential to know individual breeding values, their reliabilities, genetic correlations and economic values (EVs; Hazel and Lush, 1942). Therefore, an EV for survival is necessary to determine the optimal emphasis on this trait in selection relative to others, and to quantify the economic benefits of including survival in breeding programmes. EV, as defined by Hazel (1943), represents the value of a one-unit improvement in a trait while keeping all other traits in the breeding goal constant. Previous studies have derived relative EVs for survival traits using bioeconomic modelling or through the first derivative of profit function methodologies (e.g. Van Arendonk, 1991; VanRaden and Wiggans, 1995; Wolfova *et al.*, 2007; Sadeghi-Sefidmazgi *et al.*, 2012; De Vries, 2017).

The simplicity and limitations of applied profit functions, combined with the complexity of bioeconomic models and differences in trait definitions, make it challenging to compare the economic importance of survival across countries. Therefore, the objective of this study was to describe a general and flexible approach for deriving EVs for survival to be used in selection indices. This approach can easily accommodate alternative definitions of survival traits and be applied across a wide range of production systems. As a case study, Iranian production and economic data were used to illustrate the calculations.

Materials and methods

This research investigated longevity using four major and practical definitions (LPL, HL, NL and SR) that are commonly employed in breeding programmes across various countries. Different strategies were designed and implemented to improve longevity.

Economic weights

This study analysed data on production, reproduction, lifespan and somatic cell score (SCS) collected between 2011 and 2021 from six dairy herds in two provinces (Isfahan and Chahar Mahaal en Bakhtiari) in Iran. Herds were selected based on their use of an accurate recording system (Livestock Management Software, Modiran). All farms participate in a systematic recording programme managed by the Animal Breeding Centre of Iran. Descriptive statistics summarized the production data and economic factors used here to derive EVs for the traits under consideration. Data extracted from the farm databases for each individual cow were: herd and cow identification, sire identification, lactation period, calving date, age at first calving (AFC), dry period length, 305-day milk yield, fat and protein percentage of milk. Data editing was performed to ensure reliability and consistency; hence, records with parity >7, AFC outside 19–38 months, dry period length outside 30–160 days, pregnancy period outside 240–295 days, and 305-d milk yield, fat and protein of milk outside three standard deviations from the mean were excluded from the analysis. Finally, after data editing, a total of 131,688 cows were used to calculate survival rates and estimate EVs. The parity structure of the herds showed that 35% of the cows were in first parity, 25% were in second parity, and 40% were in their third or more lactation periods.

The calculations accounted for current economic conditions, including an inflation rate of 46% and an interest rate of 24%. To ensure consistency, all prices and costs were converted from Iranian Rial (IRR) to US dollars using a conversion rate of 1 USD = 500,000 IRR. The mean values of production data, prices, and unit costs used for estimating EVs, along with the herd structure input parameters before and after the improvement in cow survival, are summarized in Tables 1 and 2, respectively.

Economic values of longevity traits

Approach overview

This method uses an economic model that characterizes the population structure of a dairy herd, establishing a close link between farm performance and profitability, both before and after genetic improvements in survival across successive parities. A general and adaptable framework is used here for estimating the EV of survival, suitable for incorporation into selection indexes. The approach has been widely used in commercial selection indexes for dairy cattle, beef cattle and sheep (Amer *et al.*, 2001, 2014; Byrne *et al.*, 2017; Kerslake *et al.*, 2018), but the methodology has not previously been fully described in the scientific literature. Here it is shown that this approach can readily accommodate various definitions of survival traits and is applicable across diverse production systems. The

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Table 1. Average biological and economic parameters used in the economic value calculations

Parameter	Value
Biological	
305-day milk of parity 1, kg	11,589
305-day milk of parity 2, kg	13,122
305-day milk of parity 3 +, kg	13,639
Live weight of culled cows on parity 1, kg	560.0
Live weight of culled cows on parity 2, kg	620.0
Live weight of culled cows on parity 3+, kg	720.0
Calving interval, day	420
Cows dying on farm, %	0.10
Economic	
Payment on milk, $/kg milk	0.30
NEL, $/Mcal	0.22
MP, $/kg	0.62
Cull cow average price, $/kg of live weight	2.58
Replacement heifer cost, $/heifer	797.03
Average Breeding Worth (BW) trend, $/year	15.00
Interest rate	0.24

model's application is demonstrated through the estimation of EVs for multiple, interrelated definitions of cow longevity traits within Iranian dairy production systems. Unlike complex bioeconomic models or profit function derivative approaches, which have been commonly used in previous studies (e.g., Van Arendonk, 1991; VanRaden and Wiggans, 1995; Sadeghi-Sefidmazgi *et al.*, 2012; De Vries, 2017), the methodology presented here offers a novel and more flexible alternative.

Model description

Economic value of longevity traits

The EV of cow longevity (a_L) was defined as the marginal change in herd profitability divided by the expected increase in a reference longevity trait, resulting from a specified percentage increase in survival probabilities across one or more parities. That is,

$$a_L = \frac{\bar{M}^* - \bar{M}}{\bar{L}^* - L} \quad (1)$$

where $\bar{M}$ and $\bar{M}^*$ are modelled herd average profitability per cow before and after genetic improvement in longevity, respectively. L and $\bar{L}^*$ are the herd averages of any longevity or survival trait phenotype definitions before and after genetic improvement, respectively. Both profitability and survival are functionally dependent on herd structure before (h) and after (h*) genetic improvement. We first describe herd profitability as a general function of herd structure $\bar{M}(h)$ as follows.

$$M(h) = \sum_{i=1}^{n} (p_i \pi_i + q_i \omega_i) - p_1 RC \quad (2)$$

where p_i is the proportion of the breeding herd by parity i such that p_1 is the number of calving replacements required to maintain the herd at an equilibrium level, π_i is the milk income after subtraction of variable per animal production costs in parity i. Variables q_i and ω_i are the proportion of the breeding herd that are culled and their average salvage value after accounting for on farm deaths respectively at the end of parity i, and RC is the total pre-calving cost to add a replacement first calving cow to the herd. Milk revenues, feed costs, and genetic merit, are the main factors that should be accounted for in the definition of π_i. In addition, nonfeed costs including mastitis, lameness, rebreeding and calving difficulty may also differ significantly between parities. These components can have partially offsetting effects on the overall benefits of having an older herd. Thus, the term $\sum_{i=1}^{n} p_i \pi_i$ in equation 1 accounts for the net benefits accrued from having an increased average age in the herd as survival rate improves, but before any consideration of changes in herd replacement costs is made.

To calculate the marginal profit associated with cow survival, we derive the long-term equilibrium herd structure as a function of survival rates, following the approach of Amer *et al.* (2001). Industry-average survival rates (SR) from parity i to i + 1, up to a maximum of n parities, serve as the primary inputs for the herd structure model. For the purpose of this model, the survival rate at first (SR_0) is defined as 1, reflecting that survival is modelled for cows that successfully begin their first lactation. These survival rates determine the equilibrium lactation frequency (LFi), which represents the age distribution of the milking herd across parities, as follows

$$LF_i = \frac{\prod_{j=1}^{i} SR_{j-1}}{\sum_{i=1}^{n} \left(\prod_{j=1}^{i} SR_{j-1} \right)} \quad (3)$$

which in turn drives, lactation culling rate (LCR) i.e. the proportion of cows in the average herd that exit from the herd after parity i,

$$LCR_i = \frac{LF_i - LF_{i+1}}{LF_1} \quad (4)$$

The lactation salvage rate (SLCR) accounts for the proportion of exiting cows that die at each parity on farm as opposed to reaching slaughter (FD) (Farm Death) as follows;

$$SLCR_i = LCR_i (1 - FD_i) \quad (5)$$

The marginal increase in herd profit was calculated by comparing the above revenue and cost components for a herd with average industry survival rates (base herd before genetic improvement, SR) and a herd with improved survival rates (after genetic improvement $SR^* = SR + \theta$). The variables of LF_i, LCR_i and $SLCR_i$ are functions of survival rates and after genetic improvement can be shown as $LF_i^* = LF_i(SR, \theta)$, $LCR_i^* = LCR_i(SR, \theta)$ and $SLCR_i^* = SLCR_i(SR, \theta)$ which means they are a function of both base survival rates, SR, and the amount of genetic improvement in survival modelled (θ). Using the above-mentioned variables, changes in the equilibrium herd age structure as a result of a genetic change in any survival trait of interest can be calculated and accounted for in the breeding objective.

Due to the flexibility of the proposed approach and depending on the cow survival definitions, it is possible to derive appropriate EVs for construction of economic selection indices. If the cow longevity trait is defined as lifetime (e.g. HL, productive life) in a breeding objective so that it is a trait expressed only once in the animals life, then the EV for the trait (a_L) can be calculated as

$$a_L = \frac{\sum_{i=1}^{n} (\bar{M}^* - \bar{M})}{\bar{P}^* - \bar{P}} \quad (6)$$

Here, the EV,a_L, is in terms of the change in $ per cow per year from a 1 unit change in the per lifetime longevity trait, the breeding value for which might be expressed in days, months, or years so that $\bar{P}^*$ and P would correspondingly computed in days, months

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Table 2. Herd structure input parameters before and after improvement in cow survival

	Base herd before genetic improvement				Survival-improved herd by 1%			
Parity	SR[a]	LF[b]	LCR[c]	SLCR[c]	SR*	LF*	LCR*	SLCR*
1	0.700	0.364	0.300	0.300	0.710	0.357	0.290	0.290
2	0.710	0.255	0.203	0.203	0.720	0.253	0.199	0.199
3	0.612	0.181	0.193	0.192	0.622	0.182	0.193	0.193
4	0.541	0.111	0.140	0.140	0.551	0.114	0.143	0.143
5	0.494	0.060	0.083	0.083	0.504	0.062	0.087	0.087
6	0.461	0.030	0.081	0.081	0.471	0.031	0.088	0.088

[a]Survival rate,
[b]lactation frequency,
[c]lactation culling rate, and
[d]lactation salvage rate.

or years. Alternatively, if the longevity trait is expressed once per parity (e.g. survival rate to the next parity), then the EV for a 1% increase in cow survival (a_{SR}) can be calculated as

$$a_{SR} = \left[\bar{P} \times \frac{\sum_{i=1}^{n} (\bar{M}^* - \bar{M})}{\bar{P}^* - \bar{P}}\right] - R_{Adj} \quad (7)$$

where $\bar{P}$ and $\bar{P}^*$ are average number of parities per cow in the base and survival-improved herd, respectively. The symbol n indicates the parity numbers over which profits are summed. R_{Adj} is an optional rescaling adjustment to account for the fact that EVs are not always derived based on a fixed number of animals (e.g. Smith *et al.*, 1986). In the situation where feed energy available for dairy cows within the farm is limited, this rescaling adjustment could take the form of

$$R_{Adj} = \left(\frac{E_{day}}{E_T}\right) \times wir_{\$} \quad (8)$$

where E_T is average energy for cows during lactation weighted by parity across herd (Mcal); $E_{day}$is the per cow change in energy required across a weighted (by parity) herd after herd survival has been increased by 1 day (Mcal) and $wir_{\$}$ is weighted average Iran's net revenue over variable costs ($/cow).

If the cow survival trait is defined as the cow's ability to be retained within the herd, from parity 1 to 2 (S_{12}), from parity 2 to 3 (S_{23}), from parity 3 to 4 (S_{24}), or from parity 4 to 5 (S_{45}) as five separate traits in the breeding objective, in this case, the EV for each trait ($a_{s_{ij}}$) can be calculated using equation 8 with a few changes. First, in the survival-improved herd, just for the trait of interest (S_{ij}), average industry survival rates will be improved by 5% ($SR^*_{ij} = SR_{ij} + 5\%$) instead of 1% to avoid rounding error. Then, profit change per cow on a herd when survival i^{th} to i + 1st lactation is improved by 1% per parity 1 cow ($\Delta P_{s_{ij}}$) should be calculated as

$$\Delta P_{Sij} = \frac{0.01}{0.05} \times \left[\mathring{a}_{i=1}^{n} (\bar{M}^* - \bar{M})/LF_1\right] \quad (9)$$

where LF_1 is proportion of cows exiting the herd from first parity which is equal to the herd annual replacement rate and the multiplication of 0.01/0.05 is needed to express profit change per 1% increase in the S_{ij} trait. And finally, EV for each successive survival traits ($a_{s_{ij}}$) can be separately calculated as

$$a_{S_{ij}} = \Delta P_{S_{ij}} - R_{Adj} \quad (10)$$

Economic value of other traits

The bioeconomic model given in (Sadeghi-Sefidmazgi *et al.*, 2012) was used to estimate the EVs of the other traits, including production, reproduction and SCS. Probability of survival increased by a specified percentage across one or more parities. i.e.

$$a_T = \frac{\bar{M}^* - \bar{M}}{\bar{T}^* - T} \quad (11)$$

where $\bar{M}$ and $\bar{M}^*$ are marginal herd profitability before and after genetic improvement in trait i, respectively. T and $\bar{T}^*$ are the value of trait i before and after genetic improvement, respectively. The economic weights (EWs) of the traits were determined by multiplying the EV of each trait with cumulative discounted expression terms (CDEs) which adjust for difference in the timing of expression and the numbers of animals expressing different traits (e.g. Berry *et al.*, 2006).

Breeding objectives

To examine five alternative breeding goals (H) in the breeding programme of Iranian dairy cows, important economic traits milk yield (MY), fat yield (FY), protein yield (PY), days open (DO), SCS, productive life (PL), HL, number of lactation (NL) and survival rate (SR) were defined. H1 did not include any longevity trait; H2 included PL; H3 included HL; H4 included SR; and H5 included NL.

The aggregate genotype was defined for each of these breeding goals as follows:

$$\begin{aligned}
H_1 &= EW_{MY}(EBV_{MY}) + EW_{FY}(EBV_{FY}) + EW_{PY}(EBV_{PY}) \\
&\quad + EW_{SCS}(EBV_{SCS}) + EW_{DO}(EBV_{DO}) \\
H_2 &= EW_{MY}(EBV_{MY}) + EW_{FY}(EBV_{FY}) + EW_{PY}(EBV_{PY}) \\
&\quad + EW_{SCS}(EBV_{SCS}) + EW_{DO}(EBV_{DO}) + EW_{PL}(EBV_{PL}) \\
H_3 &= EW_{MY}(EBV_{MY}) + EW_{FY}(EBV_{FY}) + EW_{PY}(EBV_{PY}) \\
&\quad + EW_{SCS}(EBV_{SCS}) + EW_{DO}(EBV_{DO}) + EW_{HL}(EBV_{HL}) \\
H_4 &= EW_{MY}(EBV_{MY}) + EW_{FY}(EBV_{FY}) + EW_{PY}(EBV_{PY}) \\
&\quad + EW_{SCS}(EBV_{SCS}) + EW_{DO}(EBV_{DO}) + EW_{SR}(EBV_{SR}) \\
H_5 &= EW_{MY}(EBV_{MY}) + EW_{FY}(EBV_{FY}) + EW_{PY}(EBV_{PY}) \\
&\quad + EW_{SCS}(EBV_{SCS}) + EW_{DO}(EBV_{DO}) + EW_{NL}(EBV_{NL})
\end{aligned}$$

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Table 3. The heritabilities of and production, longevity, type, somatic cell score and fertility traits[a]

Traits	Milk yield	Fat yield	Protein yield	PL	HL	SR	NL	SCS	DO	UD	DF
h^2	0.23	0.22	0.22	0.10	0.08	0.04	0.07	0.11	0.03	0.18	0.27

[a]Shokri Sangari *et al.* (2025).

Table 4. The genetic correlations between longevity traits and production, type, somatic cell score and fertility[a]

Traits	Milk yield	Fat yield	Protein yield	SCS	DO	UD	DF
PL	0.47	0.34	0.31	−0.30	−0.54	0.55	–
HL	0.52	0.30	0.63	–	0.40	–	0.40
SR	0.23	0.29	0.33	−0.38	–	–	–

[a](Shokri *et al.*, 2025)

Table 5. Economic values, genetic expressions and estimated economic weights for each breeding objective trait

Trait	Economic value ($/unit of trait/cow/year)	Genetic expression	Economic weight ($/unit of trait)
Milk, Kg	0.12	1	0.12
Fat, Kg	5.56	1	5.56
Protein, kg	5.50	1	5.50
Days open, day	−3.84	1	−3.84
Somatic cell score	−122.87	1	−122.87
Productive life, month	21	0.13	2.73
Herd life, year	174.38	0.13	22.66
Survival rate, %	1.41	0.13	0.18
Number of lactations, number	289.31	0.13	37.59

Selection index scenarios

Different selection strategies incorporating the contrast breeding goals were compared for their ability to improve longevity in Iranian Holstein dairy cows. The selection indices used for these strategies were various combinations of production traits, reproduction, body cell score, lifespan and type traits. In order to determine the selection criteria for each index scenario, we modelled phenotypic recording scenarios of MY, FY, PY, SCS, DO, PL, PL, HL, SR and NL for bulls with 60 daughters using selection index theory. A total of 7 selection indices were considered to evaluate the effect of different longevity traits on the response to selection through indirect or direct selection based on heritabilities and their genetic correlations (Tables 3 and 4) used from a meta-analysis study of genetic parameters for longevity traits (Shokri Sangari *et al.*, 2025).

In the first scenario, five different selection indices for longevity traits were developed based on direct selection on longevity traits assuming 60 daughters recorded and these were then compared based on genetic and economic selection differentials for the corresoinding aggregate genotypes predicted using selection index theory.

$$I_1 = b_{MY}.MY + b_{FY}.FY + b_{PY}.PY + b_{DO}.DO + b_{SCS}\,.\,SCS$$
$$I_2 = I_1 + b_{PL}.\,PL$$
$$I_3 = I_1 + b_{HL}.\,HL$$
$$I_4 = I_1 + b_{SR}.SR$$
$$I_5 = I_1 + b_{NL}.\,NL$$

Table 6. Average biological and economic parity parameters in a herd before and after genetic improvement in cow survival rate across parities used in the economic value calculations

Parameter	Unit	Base herd	Survival-improved herd
Replacement rate of cows	%	48.80	47.80
Average parity per cow	lactation/cow	2.05	2.09
Milk revenue	$/cow/lactation	3814.65	3825.49
Salvage value of cull cows	$/cow/lactation	771.90	760
Feed costs	$/cow/lactation	2973.41	2978.44
Replacement cost	$/cow/lactation	389.12	381.04
Genetic trend effect	$/cow/lactation	−17.21	−17.70

For the second scenario, indicator traits were considered as selection criteria for improving longevity. Type traits (e.g., conformation, udder traits) have historically been used as indicators for longevity. Studies show that certain type traits correlate positively with longevity, although the relationships can be complex and sometimes nonlinear (Vollema and Groen, 1997; Strapák *et al.*, 2005). type traits related to udder characteristics are the most important indicators of productive longevity in dairy cows. These traits show moderately to highly positive correlations with longevity, which increase as the cow ages. Cows with better udders and teats have a greater chance of avoiding early culling due to poor udder conformation or issues such as mastitis or injury (Vukašinović *et al.*, 1995). Therefore, type traits that are more heritable and easier to measure than longevity traits were examined using meta-analysis to determine the genetic correlation between existing type traits and longevity traits (Shokri Sangari *et al.*, 2025). Two type traits with the highest genetic correlation with longevity traits are: fore udder (FU) with productive life and dairy form (DF) with the HL. These correlated type traits were taken into consideration as indirect selection criteria in indices I_6 and I_7:

$$I_6 = I_1 + b_{FU}.\,FU$$
$$I_7 = I_1 + b_{DF}.\,DF$$

The values of b were derived from the formula $\mathbf{b} = \mathbf{P}^{-1}\mathbf{G}\,\mathbf{a}$, where $\mathbf{P}$ is a t × t phenotypic (co)variance matrix of correlated traits where phenotypic variances and covariances based on the assumption of 60 daughter records per candidate sire, $\mathbf{G}$ is a t × m genetic covariance matrix for m traits in the breeding goal with t correlated traits in the selection index incorporating the additive genetic relationships between sources of information, and $\mathbf{a}$ is a m × 1 vector of relative economic weights for traits in the breeding goal. The predicted selection differential (SD) for a specific trait in the breeding goal was determined using standard selection index methods as outlined by (Dekkers, 2003).

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Table 7. Expected genetic gains for breeding objective traits based on 7 selection indices, index accuracy,and total index response

Traits	Selection Index[a]						
	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Genetic gain ($/unit gain)							
Milk yield, kg	918.76	928.67	920.90	915.70	916.95	1202.86	916.13
Fat yield, kg	36.09	36.29	35.90	36.26	36.41	37.03	36.21
Protein yield, kg	33.98	33.17	34.22	33.91	33.66	40.78	33.92
Somatic cell score, unit	0.06	0.04	0.06	0.06	0.06	0.03	0.06
Days open, day	4.57	3.20	4.71	4.58	4.47	5.37	4.58
Productive life, month	–	4.07	–	–	–	4.30	–
Herd life, year	–	–	0.39	–	–	–	0.36
Survival rate %	–	–	–	0.04	–	–	–
Number of lactations, lactation	–	–	–	–	0.10	–	–

[a]Traits included in indices: I_1 (milk yield, fat yield, protein yield, somatic cell score and days open), I_2 (milk yield, fat yield, protein yield, somatic cell score, days open and productive life), I_3 (milk yield, fat yield, protein yield, somatic cell score, days open and herd life), I_4 (milk yield, fat yield, protein yield, somatic cell score, days open and survival rate), I_5 (milk yield, fat yield, protein yield, somatic cell score, days open, and number of lactations, lactation), I_6 (milk yield, fat yield, protein yield, somatic cell score, days open and fore udder) and I_7 (milk yield, fat yield, protein yield, somatic cell score, days open and dairy form).

Table 8. Expected economic gains for breeding objective traits based on 7 selection indices, index accuracy and total index response

Traits	Selection Index[a]						
	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Economic gain ($/unit gain)							
Milk yield, kg	110.30	111.40	110.50	109.90	110.00	144.30	109.90
Fat yield, kg	200.60	205.00	202.90	204.90	205.70	209.20	204.60
Protein yield, kg	186.90	182.40	188.20	186.50	185.10	224.30	186.60
Somatic cell score, unit	−7.10	−5.11	−6.93	−7.23	−7.07	−4.25	−7.12
Days open, day	−15.91	−11.12	−16.39	−15.94	−15.56	−18.67	−15.94
Productive life, month	–	11.12	–	–	–	11.75	
Herd life, year	–	–	8.74	–	–	–	0.98
Survival rate %	–	–	–	0.01	–	–	–
Number of lactations, lactation	–	–	–	–	3.76	–	–
Index accuracy	0.89	0.90	0.89	0.89	0.89	0.96	0.89
Total selection index response, ($/unit gain)	470	490	490	480	480	570	480

[a]Traits included in indices: I_1 (milk yield, fat yield, protein yield, somatic cell score and days open), I_2 (milk yield, fat yield, protein yield, somatic cell score, days open and productive life), I_3 (milk yield, fat yield, protein yield, somatic cell score, days open and herd life), I_4 (milk yield, fat yield, protein yield, somatic cell score, days open, and survival rate), I_5 (milk yield, fat yield, protein yield, somatic cell score, days open, and number of lactations, lactation), I_6 (milk yield, fat yield, protein yield, somatic cell score, days open and fore udder) and I_7 (milk yield, fat yield, protein yield, somatic cell score, days open and dairy form).

$$\mathrm{P} = \begin{matrix}\\ \textbf{Record traits}\end{matrix} \begin{matrix}\begin{matrix}\textbf{Record traits}\end{matrix}\\ \begin{bmatrix} \sigma^2_{\mathrm{p}1} & \sigma_{\mathrm{p}\,1,2} & \cdots & \sigma_{\mathrm{p}\,1,\mathrm{t}} \\ \sigma_{\mathrm{p}\,2,1} & \sigma^2_{\mathrm{p}2} & \cdots & \sigma_{\mathrm{p}\,2,\mathrm{t}} \\ \cdots & \cdots & \cdots & \cdots \\ \sigma_{\mathrm{p}\,\mathrm{t},1} & \sigma_{\mathrm{p}\,\mathrm{t},2} & \cdots & \sigma^2_{\mathrm{p}\,\mathrm{t},\mathrm{t}} \end{bmatrix}\end{matrix}$$

$$\mathrm{G} = \begin{matrix}\\ \textbf{Record traits}\end{matrix} \begin{matrix}\begin{matrix}\textbf{Profit traits}\end{matrix}\\ \begin{bmatrix} \sigma_{\mathrm{g}1,1} & \sigma_{\mathrm{g}1,2} & \cdots & \sigma_{\mathrm{g}1,\mathrm{m}} \\ \sigma_{\mathrm{g}2,1} & \sigma_{\mathrm{g}2,2} & \cdots & \sigma_{\mathrm{g}2,\mathrm{m}} \\ \cdots & \cdots & \cdots & \cdots \\ \sigma_{\mathrm{g}\,\mathrm{t},1} & \sigma_{\mathrm{g}\,\mathrm{t},2} & \cdots & \sigma_{\mathrm{g}\,\mathrm{t},\mathrm{m}} \end{bmatrix}\end{matrix}$$

$$\mathrm{C} = \begin{matrix}\\ \textbf{Profit traits}\end{matrix} \begin{matrix}\begin{matrix}\textbf{Profit traits}\end{matrix}\\ \begin{bmatrix} \sigma_{\mathrm{g}1,1} & \sigma_{\mathrm{g}1,2} & \cdots & \sigma_{\mathrm{g}1,\mathrm{m}} \\ \sigma_{\mathrm{g}2,1} & \sigma_{\mathrm{g}2,2} & \cdots & \sigma_{\mathrm{g}2,\mathrm{m}} \\ \cdots & \cdots & \cdots & \cdots \\ \sigma_{\mathrm{g}\,\mathrm{m},1} & \sigma_{\mathrm{g}\,\mathrm{m},2} & \cdots & \sigma_{\mathrm{g}\,\mathrm{m},\mathrm{m}} \end{bmatrix}\end{matrix}$$

Here, the symbol σ^2 denotes the variance of each trait, whereas σ represents the covariance between pairs of traits.

$$\mathbf{s}\,(\boldsymbol{b}'\mathbf{G})\,/\sqrt{\mathbf{b}'\mathbf{G}\mathbf{a}}$$

where s is the selection intensity, assumed to be 1.4 (corresponding to the top 20% of selected sires), and b′ is the transpose of the selection index weight vector. The accuracy of a selection index was also calculated as described in (Dekkers JC, 2003).

$$\sqrt{\mathbf{b}'\mathbf{G}\mathbf{a}/\mathbf{a}'\mathbf{C}\mathbf{a}}$$

Where **a** is a vector of economic weight for m traits in a breeding goal and **C** is a m × m genetic (co)variance matrix among the traits in the breeding goal.

Results

Economic values

EVs, genetic expressions and estimated EWs for each breeding objective trait are in Table 5. The CDE genetic expression for longevity traits was set at 0.13, a factor that significantly modulated their economic weights relative to their intrinsic EVs.

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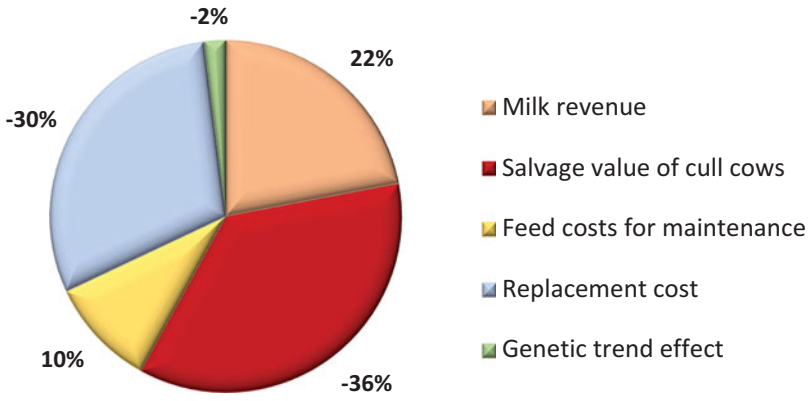


Figure 1. The relative contribution of different components to estimate economic value for cow survival under the Iranian production system.

Longevity traits

Change in key revenue and cost components in a herd before and after genetic improvement in cow survival rate across parities applicable to the estimation of EVs of longevity traits are presented in Table 6. Average profit per parity for longevity traits increased from \$1206.81 to \$1208.31 per cow per lactation when survival increased by 1% which finally led to a marginal change of \$1.50 per cow per lactation when each cow was expected to live 0.04 parities longer in the herd with improved survival. The economic weight for longevity traits (PL, HL, SR and NL) were \$2.73 month/cow/year, \$22.6 year/cow/year, \$0.18 percentage/cow/year and \$37.59 number/cow/year, respectively (Table 5). This contributed to the \$8.12 lower replacement costs per parity when survival increased. In addition, as shown in Table 6, when cow survival improved, it is expected to cause a reduction in the salvage value of cull cows and in the genetic trend effect while revenue from sales of milk, along with feed costs, would be increased. Relative contribution of different components to estimate EV for cow longevity traits under Iranian production systems are shown in Figure 1. Accordingly, the most important factor affecting the EV of longevity traits was the salvage value of cull cows (−36%). Replacement costs (−30%) and milk revenue (22%) were the next most important economic components related to cow longevity. The relative contribution of different components to estimate the EV for cow longevity is represented in Figure 1.

Other traits

The EWs of MY, FY and PY were 0.12, 5.56 and 5.5 \$/day/cow/year, respectively. The average EWs for DO and SCS were \$-3.84 days/cow/year and \$-122.87 units/cow/year (Table 5).

Selection index scenarios

As a result, in this study, the inclusion of four important traits of longevity (HL, PL, SR, NL) in the improvement goals was investigated and compared. This study explored the impact of selecting for different longevity traits in dairy cows, aiming to optimize both economic and genetic gains. Therefore, seven separate indices were designed, each of which focuses on a specific longevity attribute. The expected genetic and economic gains for each breeding objective trait using different selection indices are presented in Tables 7 and 8. Among the evaluated indices, I6 produced the most pronounced improvements. In particular, this index generated the highest expected genetic gains for milk yield (1202.86 kg) and protein yield (40.78 kg), together with the largest corresponding economic gains for the same traits. Furthermore, I6 achieved the greatest index accuracy (0.96), representing a marked improvement compared with the baseline index (I_1), and yielded the highest total selection index response (\$570 per unit gain). Regardless of direct or indirect selection for longevity, the total selection index response was generally higher if PL rather than other longevity traits was used in the selection index.

Discussion

Economic weights

In designing a breeding strategy, it is important to clearly define traits and assign appropriate EVs to them. The EV of a trait refers to the contribution it has to the change in profit per unit change of that trait, assuming no changes in any other traits (Hazel and Lush, 1942). In practice, estimating the EV of longevity is challenging due to the influence of several factors and the absence of a universally accepted definition. As described by Rendel and Robertson (1950) and used by many researchers (e.g., Van Arendonk, 1991; VanRaden and Wiggans, 1995; Groen *et al.*, 1997), improvement in cow longevity can enhance the profitability of a dairy farm by (a) decreasing annual costs for replacement of cows, (b) increasing the average milk production of the farm through an increase in the proportion of cows in the higher producing age group, (c) reducing the number of replacements to be reared and therefore allowing an increase in size of the milking farm for a given acreage.

The large variety of environmental, management and marketing circumstances for dairy farming have made it impossible to consider a unique definition for cow survival in selection indexes across the major countries undertaking dairy cattle genetic improvement. In such situations, complex bioeconomic models or first derivatives of profit function approaches have been widely applied (e.g., Van Arendonk, 1991; VanRaden and Wiggans, 1995; Sadeghi-Sefidmazgi *et al.*, 2012; De Vries, 2017). These approaches typically generate EVs specific to a country and for a single survival trait definition and are not capable of calculating EVs for longevity according to different definitions. This is important because genetic evaluation system research and development is increasingly testing reductionist definitions of longevity, whereby survival phenotypes are separated according to lactation number, stage of lactation and removal reasons (Veerkamp and van Pelt, 2019). The present proposed approach, focusing on herd structure, offers a flexible method for estimating the EV of various longevity traits, applicable not only to dairy cows but also to other production systems, incorporating different longevity traits. The main advantage of this approach is its flexibility in defining and calculating the EV of

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longevity based on various criteria. The EV of longevity can be calculated for cow survival traits defined explicitly according to lactation number, stage of lactation and even specific to removal reasons.

The average estimated EV for PL was $21/month/cow/year. This was adjusted using a CDE genetic expression coefficient of 0.13 to get an EW of $2.73/month/cow/year. In previous studies, Sadeghi-Sefidmazgi *et al.* (2012) reported an EV of $10.13/month for PL, and Nadri *et al.* (2023) reported an EV of $2.77/month for PL, which was lower than the EV reported in this study. Komlosi *et al.* (2010) reported that the amounts varied between $0.12 and $1.52 per day across European nations. According to Cole and Van Raden (2010), the estimated EV for a productive life in the United States is $35 per month. (Sasaki *et al.*, 2018) reported that the EW of PL ranged from $0.57 to $0.61 each day. The EW of SR was calculated by Byrne et al. to be $7.92/percentage/cow/year. For Japanese Holstein cattle, (Sasaki *et al.*, 2018) reported an EW of SR ranging from $12.40 to $15.15 percentage/cow/year. The EW of SR in this study was 0.18 percentage/cow/year, which was significantly different from that in other investigations. These discrepancies can be attributed to the model that was used, changes in the management system assumptions, and different economic conditions around the world.

The estimated EVs for production traits in this study differed from those in prior investigations (Sadeghi-Sefidmazgi *et al.*, 2012; Ghiasi *et al.*, 2013; Nadri *et al.*, 2023), even though the definition of the trait and the pricing method for milk yield were the same. Ghiasi *et al.* (2013) reported an EW for MY of $0.193/kg/cow/year; Sadeghi-Sefidmazgi *et al.* (2012) reported EVs of $0.15/kg/cow/year for MY, $1.36/kg/cow/year for FY and $−1.02/kg/cow/year for PY. Nadri *et al.* (2023) reported EVs of $0.34/kg/cow/year for MY, $6.93/kg/cow/year for FY and $5.53/kg/cow/year for PY, in comparison with $0.12, $5.56 and $5.50, respectively. Variations in the price at which milk is sold as well as production expenses, such as labour and feed, account for the fluctuation in MY's EVs.

An EV of $-105.67/units/cow/year for SCS was reported by Sadeghi-Sefidmazgi *et al.* (2012) which is lower than the EV of $-122.87/units/cow/year found in this study. This discrepancy may be caused by the difference in the mean of the studied populations, because the EV of the SCS is strongly influenced by it. Compared to the EV of DO reported in this study ($-3.84/days/cow/year), Nadri *et al.* (2023) reported an EV of DO of $-2.71/days/cow/year. The EV of DO was assessed from $3.59 to $7.72 in one Japanese study (Sasaki *et al.*, 2020), which was very different from this study.

Selection index scenarios

The goal of dairy cattle breeding programmes worldwide was to increase milk yield over a long time. Dairy cattle breeding programmes focus has expanded over the last 20 years to include a greater variety of traits, such as longevity, reproductive efficiency, general health and functional traits (Miglior *et al.*, 2005; Kargo *et al.*, 2014). Longevity traits have many definitions. The challenge that exists is which of the traits describing lifespan as the basis of selection is more beneficial and useful. The analysis revealed a clear trend: the inclusion of any longevity trait into the breeding objectives improved the overall response compared to a baseline scenario that completely disregarded longevity. This points to the great economic and genetic gains to be realized with the selection of cows with longer longevity. In direct selection, I_2 and I_3 were the most interesting scenarios. These scenarios focused on directly selecting cows with a longer PL or HL. Both options resulted in favorable economic and genetic gains, which suggested that selection for these traits for longevity compared to selection for NL and SR traits allows achieving more genetic progress and is a good way to improve longevity. Direct selection for PL (I_2) yields the highest genetic gain for MY, SCS and DO, and the greatest economic gain for MY compared to selection for HL, SR and NL. Selection based on HL (I_3) provided superior economic and genetic improvement in terms of PY and highest economic gain for DO, Selection based on NL (I_5) resulted in the highest genetic and economic gain for FY, and selection based on SR (I_4) had the greatest genetic gain for SCS.

The direct selection for longevity is not common because realized longevity only becomes available at the end of the cow's life. An alternative to direct selection for longevity in dairy cattle is the use of indirect traits such as type traits and reproductive traits, which can serve as effective indicators for improving longevity (Essl, 1998; Sewalem *et al.*, 2005, 2008; Miglior *et al.*, 2017; Hu *et al.*, 2021). Indirect selection on longevity traits was examined using I_6 and I_7. Scenario I_6 employing indirect selection based on fore udder (FU) traits indicated the best response rate with high accuracy. This scenario focuses on productive life (PL) in the breeding target. Genetic and economic gains for traits in the breeding objectives were generally higher for I_6 than I_7. This scenario (I_6) has been found to be the most economically beneficial strategy. Scenario I_6, which includes fore udder (FU) data in the selection index and focuses on productive life (PL), resulted in the greatest overall improvement. This approach yielded desirable genetic gains for MY, FY, PY, PL and SCS, and desirable economic gains for MY, FY, PY, PL and DO. Our results support the relationship between udder structure and longevity observed in previous studies. Research consistently demonstrates positive and good correlations between specific udder traits and dairy cattle longevity. Specifically, fore udder length, rear udder attachment and the strength of the central ligament have been identified as key indicators of increased lifespan (Vukašinović *et al.*, 1995; Vacek *et al.*, 2006; Zavadilova and Stipkova, 2012). Cows with appropriate udder structure (strong fore udder attachments, high rear udder attachments and well-defined central ligaments) tend to have extended productive lives (Vacek *et al.*, 2006). Cows with shallower udders and stronger fore udder were more resistant to mastitis and thus were more easily able to avoid culling then these cows are more than survive (Gibson and Dechow, 2018). These findings suggest that selection for these udder traits could contribute to improved longevity in dairy herds. this is probably because a proper udder structure leads to better udder function in milk production and greater resistance to diseases, which ultimately leads to increased longevity.

Conclusions

In this study: firstly describes a general flexible approach for the derivation of EV of cow survival with different definitions under a wide range of production systems not only for dairy enterprises but also for other livestock production worldwide., secondly It was shown that among the various definitions of longevity presented in this study, selection for productive life, especially indirect selection of the fore udder, in addition to improving longevity, also significantly improved production traits and SCS.

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