Italian Journal of Animal Science

ISSN: 1828-051X (Online) Journal homepage: www.tandfonline.com/journals/tjas20

Productive lifespan and lifetime production of dual-purpose and dairy breeds in mixed herds under grassland-based systems

Anna Bieber, Dirk Hinrichs, Florian N. Moser, Ariane Maeschli, Isabella Lora, Giulio Cozzi & Florian Leiber

To cite this article: Anna Bieber, Dirk Hinrichs, Florian N. Moser, Ariane Maeschli, Isabella Lora, Giulio Cozzi & Florian Leiber (2025) Productive lifespan and lifetime production of dual-purpose and dairy breeds in mixed herds under grassland-based systems, Italian Journal of Animal Science, 24:1, 2684-2689, DOI: 10.1080/1828051X.2025.2596845

To link to this article: https://doi.org/10.1080/1828051X.2025.2596845

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

View supplementary material

Published online: 07 Dec 2025.

Submit your article to this journal

Article views: 56

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at https://www.tandfonline.com/action/journalInformation?journalCode=tjas20

ITALIAN JOURNAL OF ANIMAL SCIENCE
2025, VOL. 24, NO. 1, 2684–2689
https://doi.org/10.1080/1828051X.2025.2596845

Taylor & Francis
Taylor & Francis Group

RAPID COMMUNICATION

OPEN ACCESS Check for updates

Productive lifespan and lifetime production of dual-purpose and dairy breeds in mixed herds under grassland-based systems

Anna Bieber[a], Dirk Hinrichs[b], Florian N. Moser[a], Ariane Maeschli[a], Isabella Lora[c], Giulio Cozzi[c] and Florian Leiber[a]

[a]Departement für Nutztierwissenschaften, Research Institute of Organic Agriculture FiBL, Frick, Switzerland; [b]Fachbereich Tierzucht, University of Kassel, Witzenhausen, Germany; [c]Dipartimento di Medicina Animale, Produzioni e Salute – MAPS, University of Padova, Legnaro, Italy

ABSTRACT

Dairy cow longevity is a key trait combining multiple functional traits and is decisive for sustainability of dairy production. This study addresses the hypothesis that under low-input production conditions, dual-purpose breeds outperform dairy breeds in terms of longevity. Herdbook data of 1796 culled Swiss cows in 72 mixed dairy farms were used to compare two dual-purpose breeds (Original Braunvieh (OB) and Simmental (SI)) with three dairy breeds (Swiss Fleckvieh (SF), Brown Swiss (BS) and Holstein (HO)). Each selected mixed herd included at least one dual-purpose and one dairy breed managed under the same conditions. Breeds were compared for length of productive lifespan (LPL; days from first calving to culling), lifetime milk production (LTP; kg energy corrected milk) and average daily milk yield during LPL (DMY_LPL; kg energy corrected milk). OB cows lived significantly longer than HO (1946 ± 71 d vs. 1695 ± 55 d, $p = 0.046$), whereas SI cows did not (1683 ± 62 d, $p = 0.999$). Both dual-purpose breeds produced significantly less milk per day (OB: 17.8 ± 0.3 kg, SI: 18.0 ± 0.3 kg) than SF (19.1 ± 0.2 kg) and HO (19.7 ± 0.3 kg). However, OB cows compensated with greater longevity, resulting in the numerically highest LTP (35,584 ± 1315 kg), which did not statistically differ from the specialised dairy breeds. In conclusion, choosing a dual-purpose breed does not necessarily ensure longer productive lifespans: while OB showed a clear advantage, SI cows exhibited shorter productive lifespan, likely due to breed-specific production conditions.

HIGHLIGHTS

- Longevity is key for sustainability; Original Braunvieh showed longest lifespan (1946 d) and numerically highest lifetime yield (35,584 kg).
- Dual-purpose breeds vary; Simmental cows were culled earlier, likely due to market and herd replacement factors.
- Breed choice and production context strongly affect dairy cow lifetime performance in low-input systems.

ARTICLE HISTORY
Received 18 July 2025
Revised 27 October 2025
Accepted 25 November 2025

KEYWORDS
Longevity; animal health; resource efficiency; low input dairy production; alpine pasture

Introduction

Over the past century, dairy breeds have been intensively selected for high milk yield (Knaus 2009), often associated with negative effects on fitness and health traits leading to increased culling rates (Oltenacu and Broom 2010). Extending the productive lifespan of dairy cows is discussed to improve economic, ecological and ethical sustainability of milk production. Economically, longer productive lifespans reduce rearing costs per unit of milk (Essl 1998). Extended longevity may increase farm profitability, especially in organic systems characterised by a maximum annual milk yield in the 5th lactation and highest profit in the 6th lactation (Horn et al. 2012). Economically optimal lifespan varies, with five years suggested under U.S. conditions (De Vries 2017), while studies across production systems and breeds remain scarce (De Vries and Marcondes 2020).

Ecologically, a longer lifespan improves resource use efficiency and emission footprint by diluting the impact of the non-productive rearing period (Van Middelaar et al. 2014; Grandl et al. 2019).

CONTACT Anna Bieber anna.bieber@fibl.org

Supplemental data for this article can be accessed online at https://doi.org/10.1080/1828051X.2025.2596845

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

Methane emissions were reported to decrease in cows older than 6.5 years onwards (Grandl et al. 2016). Dual-purpose breeds and crossbreeding can further lower emissions per kg of product by integrating milk and beef production (Zehetmeier et al. 2012; Probst et al. 2019). Ethically, longevity is associated with improved welfare and health (Oltenacu and Broom 2010).

Despite these benefits, the average productive lifespan of cows from most developed dairy systems has declined, averaging 2.5–4 years (De Vries and Marcondes 2020; Schuster et al. 2020; Dallago et al. 2021), which is well below cows' physiological potential of up to 20 years (Hoffman and Valencak 2020). Swiss organic herds perform better, with averages of 3.5–4.3 lactations (Bieber et al. 2019). Involuntary culling due to health, fertility or conformation problems remains common (Schuster et al. 2020). External and economic factors, including access to replacements and milk prices, also influence culling decisions (De Vries and Marcondes 2020). While genetic selection for longevity is valuable, it can slow genetic progress in other traits due to extended generation intervals (Stefani et al. 2018).

Breed performance is known to interact with management intensity (Bieber et al. 2020), and previous findings suggest dual-purpose breeds may offer advantages in longevity under low-input conditions (Bieber et al. 2019). These findings raise questions about the role of breed in shaping productive lifespan under low-input conditions like organic systems. The present study aims to compare the length of productive lifespan and lifetime production of two dual-purpose breeds (Original Braunvieh (OB), Simmental (SI)) and three dairy breeds (Brown Swiss (BS), Swiss Fleckvieh (SF), Holstein (HO)) managed under grassland-based, low-input conditions in mixed herds. By focusing on mixed herds, we controlled for differences in management intensity when testing the hypothesis that dual-purpose breeds show superior longevity. The findings aim to support sustainable breed selection for low-input dairy systems.

Material and methods

Data origin, trait definitions and trait calculation

Data were extracted from the Oracle database of Qualitas AG (Zug, Switzerland), which manages genetic and herdbook data for the breeding associations 'Braunvieh Schweiz' and 'swissherdbook'. The database included 580 low-input and organic dairy farms collaborating with the Research Institute of Organic Agriculture, FiBL (https://fibl.qualitasag.ch/FiBL/, accessed 29 April 2022). The present study focused on multiparous cows from the dual-purpose breeds OB and SI and the dairy breeds SF, BS and HO with a recorded culling date. Only mixed herds with at least one dual-purpose and one dairy breed were included. Studied farms had average milk yields ranging from 5000 to 7500 kg/cow and year to be representative for low-input production. The final dataset included 1796 cows from 72 mixed herds. Details on the proportions of breed mixtures are provided in Table S1 of the Supplemental material.

The dataset included cow- and farm-level information relevant to longevity and productivity. Animal-level data comprised cow and farm identification, birth and culling dates, breed, age at first calving, and parity at culling. Lactation-level data covered milk yield (kg), fat and protein contents (%), the fat-to-protein ratio, days in milk, and lactation persistency (ratio of milk yield from days in milk 101–200 to 1–100). Udder health and fertility indicators included the proportion of test-day records with a somatic cell count above 100,000 cells/mL, and calving interval (from the second lactation onwards).

Farm- and environment-related variables included herd size (i.e. test-day records per farm and year, divided by nine, reflecting the average number of records per cow and year), alpine pasturing (yes/no), calving season (winter: September–February; summer: March–August) and calving year (2008–2012). Cows that changed farms were excluded to ensure consistent management.

Target trait definition

Longevity was defined as the length of productive lifespan (LPL), that is, the number of days from first calving to culling.

Lifetime total production (LTP) in energy-corrected milk represented the total milk yield during the productive lifespan, adjusted to 4.0% fat and 3.4% protein according to Heller and Potthast (1990):

$$\text{LTP (kg)} = \text{milk (kg)} \times \left[0.38 \times (\text{fat }\%) + 0.21 \times (\text{protein }\%) + 1.05\right]/3.28$$

where milk (kg) is the total milk production and fat % and protein % are average contents during the cow's productive lifespan.

Average daily milk yield during length of productive lifespan (DMY_LPL in energy corrected milk) was calculated as LTP/LPL.

Statistical analysis

Descriptive characteristics of breeds

To compare descriptive traits across breeds, normality was tested using the Shapiro–Wilk test and homogeneity of variances was assessed via Levene's test for each trait separately. If both assumptions were met, a one-way analysis of variance (ANOVA) was performed followed by Tukey's honest significant difference test for pairwise comparisons. Otherwise, a Kruskal–Wallis test, followed by Dunn's post hoc test with Bonferroni's correction for multiple comparisons were performed. For proportional traits, Chi-squared and Fisher's exact test for pairwise comparisons were applied. Compact letter displays visualised statistically homogeneous groups.

Models for breed comparison

The study's main objective was to assess breed differences in longevity and lifetime production traits while accounting for relevant biological and management factors recorded in the herdbook. Linear mixed effects models were fitted for LPL (d), LTP (kg) and DMY_LPL (kg) using the lme4 package (Bates et al. 2015). Correlations among predictors were examined, and only variables with $|r| < 0.7$ were retained to avoid multicollinearity.

The final model was:

$$Y = \mu + \text{Breed} + \text{AFC} + \text{Milk} + \text{FPR} + \text{Pers} + \text{SCC100} + \text{CI} + \text{nHerd} + \text{Alp} + \text{SE} + \text{Year} + \text{Farm} + \text{e}$$

where Y is the response variable, μ is the overall mean, Breed is the breed (OB, BS, SI, SF and HO), AFC is the age at first calving (months), Milk is the energy corrected milk yield (kg), FPR is the fat–protein ratio, Pers is the lactation persistency, SCC100 is the proportion of test day records with a somatic cell count of >100,000 cells/mL, CI is the calving interval (days), nHerd is the herd size, Alp is the occurrence of alpine pasturing (yes or no), SE is the calving season (winter: September–February or summer: March–August), Year is the year of calving (2008–2012), Farm is the farm identification and e is the random error. Farm was included as a random intercept. All other variables served as control factors to isolate breed effects.

For LPL, functional longevity (adjusted for milk yield) was analysed, reflecting the ability to avoid involuntary culling (Schuster et al. 2020).

The significance of explanatory variables was assessed using Wald's Chi-square tests (*car* package version 3.0-6, Fox and Weisberg 2019), and results are presented in Table S2 of the online Supplemental material. Model fit was evaluated via marginal and conditional R^2 (*MuMIn* package, version 1.43.15, Barton 2019). Pairwise breed comparisons were conducted using Tukey-adjusted least-squares means (*emmeans* package, version 1.4.5, Lenth 2020). Model assumptions were verified through residual inspection.

Multicollinearity was evaluated using generalised variance inflation factors (GVIFs; Fox and Monette 1992), all values were below 1.2, confirming negligible collinearity.

All analyses were conducted in R version 3.6.3 (R Core Team 2020), with significance set at $p < 0.05$.

Results

Descriptive characteristics of Swiss cow breeds

Descriptive statistics of breed characteristics are summarised in Table 1. Milk yield was highest in HO and lowest in SI. Average milk fat content was significantly lower in SI compared with BS, HO and SF, while OB showed intermediate values. Average protein content was significantly higher in BS and OB. The average proportion of test day records with elevated somatic cell count was highest in BS and lowest in SI, with substantial variability. Breeds also differed in the proportion of cows sent to alpine pasture. Winter calving predominated across all breeds, ranging from 80% (SI) to 62% (HO).

Breed differences in longevity and lifetime performance traits

Breed differences in longevity and lifetime production traits are presented in Table 2. Length of productive lifespan was longest in OB (1946 ± 71 days) and shortest in HO cows (1695 ± 55 days) and SI cows (1683 ± 62 days), with SF (1812 ± 53 days) and BS (1781 ± 46 days) showing intermediate values. DMY_LPL was significantly lower in OB (17.8 ± 0.3 kg) and SI (18.0 ± 0.3 kg) compared to SF (19.1 ± 0.2 kg) and HO (19.7 ± 0.3 kg), while BS (18.1 ± 0.2 kg) did not differ from dual-purpose breeds. Despite this, OB cows achieved the numerically highest LTP (35,584 kg), due to their longer LPL.

Discussion

Breed characteristics aligned with expectations: dairy breeds (HO, SF) calved earlier, had lower proportions of seasonal calving compared to SI and a lower rate of cows sent to alpine pastures (HO and SF), along with the highest lactation yield in HO cows. Breed significantly influenced LPL: HO had the shortest LPL but

Table 1. Descriptive characteristics (mean ± standard deviation) of cows belonging to different Swiss dual-purpose and dairy breeds managed in 72 mixed herds.

Trait[1]	Dual-purpose breeds		Dairy breeds			*P*-Value and test type[2]
	Original Braunvieh	Simmental	Swiss Fleckvieh	Brown Swiss	Holstein	
N, cows	191	251	342	571	441	
Herd size, cows	28.4 ± 13.7^{bc}	19.8 ± 8.9^{d}	25.8 ± 13.0^{c}	30.5 ± 16.9^{ab}	32.5 ± 16.7^{a}	<0.001 (KW)
AFC, months	32.6 ± 3.4^{a}	31.1 ± 3.5^{b}	28.4 ± 3.3^{c}	31.5 ± 3.5^{b}	28.4 ± 3.4^{c}	<0.001 (KW)
ECM, kg	6809 ± 2092^{b}	5613 ± 1279^{c}	6670 ± 1470^{b}	6659 ± 1693^{b}	8070 ± 2025^{a}	<0.001 (A)
DIM, days	319 ± 53^{ab}	305 ± 47^{c}	311 ± 42^{bc}	321 ± 55^{ab}	328 ± 60^{a}	<0.001 (KW)
Fat, %	4.03 ± 0.36^{ab}	3.95 ± 0.42^{b}	4.09 ± 0.44^{a}	4.06 ± 0.35^{a}	4.09 ± 0.44^{a}	<0.001 (A)
Protein, %	3.43 ± 0.24^{a}	3.37 ± 0.25^{b}	3.35 ± 0.22^{b}	3.42 ± 0.24^{a}	3.33 ± 0.23^{b}	<0.001 (A)
FPR	1.17 ± 0.11^{b}	1.18 ± 0.12^{b}	1.22 ± 0.12^{a}	1.19 ± 0.11^{b}	1.23 ± 0.12^{a}	<0.001 (A)
SCC100, %	25.4 ± 27.3^{c}	26.0 ± 28.9^{c}	29.7 ± 29.2^{bc}	39.2 ± 31.1^{a}	34.1 ± 31.2^{b}	<0.001 (KW)
CI, days	386 ± 65^{abc}	376 ± 43^{c}	375 ± 50^{bc}	394 ± 62^{a}	387 ± 57^{ab}	<0.001 (KW)
Pers	83.3 ± 9.3^{a}	81.8 ± 11.5^{ab}	80.2 ± 10.2^{b}	80.3 ± 10.2^{b}	80.9 ± 9.9^{b}	<0.001 (A)
Alp pasture, %	39.3^{ab}	53.0^{a}	31.0^{bc}	36.1^{b}	23.4^{c}	<0.0001 (CHI)
Winter calv, %	68.1^{ab}	80.1^{a}	62.6^{b}	68.7^{b}	62.1^{b}	<0.0001 (CHI)

Means within trait with different superscripts (a–c) differ at $p < 0.05$ in the post hoc analysis performed as Tukey's tests for variables previously tested with ANOVA, Dunn tests for traits previously tested with Kruskal–Wallis tests or Fisher's tests for traits previously tested with Chi-squared tests.
[1]Traits: for variables at lactation level, data from the 2nd lactation performance are presented. *N*: sample size; AFC: age at first calving; ECM: energy corrected milk yield of total lactation; DIM: days in milk; fat: milk fat content; protein: milk protein content; FPR: fat protein ratio; SCC100: proportion of test day records with a somatic cell count of >100,000 cells/mL milk; CI: calving interval; Pers: lactation persistency; Alp pasture: percentage of alpine pastured cows; Winter calv: percentage of cows with winter calving.
[2]*p*-values from the ANOVA (A), Kruskal–Wallis test (KW) or Chi-squared test (CHI).

Table 2. Breed differences in length of productive lifespan (LPL), lifetime milk production (LTP) and daily milk yield during length of productive lifespan (DMY_LPL) in kg of energy corrected milk of Original Braunvieh (OB), Simmental (SI), Swiss Fleckvieh (SF), Brown Swiss (BS) and Holstein (HO) dairy cows on 72 Swiss dairy farms with mixed herds as least square mean ± standard error.

Trait	Dual-purpose breeds		Dairy breeds				Model performance[1]	
	OB	SI	SF	BS	HO	*P*-Value[2]	R^2m	R^2c
N, cows	191	251	342	571	441			
LPL, d	1946 ± 71^{a}	1683 ± 62^{b}	1812 ± 53^{ab}	1781 ± 46^{ab}	1695 ± 55^{b}	0.012	5.4	9.1
LTP, kg	$35{,}584 \pm 1315^{a}$	$30{,}564 \pm 1161^{b}$	$34{,}516 \pm 983^{a}$	$33{,}007 \pm 819^{ab}$	$33{,}276 \pm 999^{ab}$	0.015	14.9	16.4
DMY_LPL, kg	17.8 ± 0.3^{c}	18.0 ± 0.3^{c}	19.1 ± 0.2^{b}	18.1 ± 0.2^{c}	19.7 ± 0.3^{a}	<0.001	61.6	73.3

Least square means within trait with different superscripts (a–c) differ at $p < 0.05$ in the post hoc analysis performed as Tukey contrasts.
[1]R^2m: marginal *R*-squared, which represents the variance explained by the fixed effects; R^2c: conditional *R*-squared, which represents the variance explained by the entire model, including both, fixed and random effects.
[2]*p*-values from the analysis of deviance (type II Wald Chi-square test) for the breed effect.

the highest daily milk yields, reflecting known trade-offs in high-yielding cows (Dillon et al. 2003).

OB had the numerically longest LPL and numerically highest LTP, highlighting the potential of dual-purpose breeds in low-input systems. These results align with studies on OB and BS under organic production (Bieber et al. 2019) and with comparisons of local German Angler and modern HO on organic farms (Bieber et al. 2020). Longevity advantages of local breeds have also been reported in some studies from other countries (e.g. Gandini et al. 2007; Walsh et al. 2008; Curone et al. 2016).

In contrast, SI cows had the shortest LPL comparable to dairy breeds, likely due to production system factors. Traditionally, SI offspring are often reared in subsidised mountainous regions, creating incentives to rear more female animals than required for replacement. Consistently, SI showed the highest proportions of cows experiencing alpine pasturing and winter calving. The demand for replacement animals has decreased, likely due to the gradual decline in SI population size in recent years (www.swissherdbook.ch/de/publikationen/statistiken/jahresstatistik, accessed: 24 October 2025), while favourable meat prices (A. Barenco, swissherdbook, personal communication), and abundant availability of heifers – with favourable genetic production potential – (De Vries and Marcondes 2020) encourage early culling, even in mixed herds. This practice appears driven more by market conditions than by health or fertility issues, as alpine grazing has been associated with improved longevity and health in ruminants (Künzi et al. 1988; Ruhland et al. 1999). Despite similar alpine rearing conditions, OB demand is higher because its population has been growing for several years (https://homepage.braunvieh.ch/geschaeftsbericht/, accessed 24 October 2025). These findings likely reflect local management and market conditions and therefore have limited generalisability.

In terms of resource use and emission-related sustainability, the combined protein output of dairy cows – milk, offspring and carcase – must be considered (Pfeifer et al. 2025). A longer productive lifespan is beneficial if crossbred or dual-purpose calves can be fattened efficiently, potentially reducing reliance on suckler cow systems (Zehetmeier et al. 2012; Probst et al. 2019). This potential is particularly relevant for dual-purpose breeds such as SI (Pfeifer et al. 2025). However, our results suggest that economic incentives and breed population demand may prioritise short-term returns over lifetime efficiency. Early culling of dual-purpose breeds such as SI illustrated inherent trade-offs between longevity, milk yield and carcase value. This apparent paradox highlights that optimal multifunctional sustainability is highly system-dependent, underscoring the need for deeper analysis of these trade-offs.

Conclusions

Breed selection and production objectives in low-input systems strongly influence longevity and lifetime performance. Dual-purpose breeds may compensate lower average daily milk yield during longer productive lives, achieving lifetime milk production levels comparable to specialised dairy breeds, as seen in OB. The case of SI cows shows that choosing a dual-purpose breed does not automatically ensure longevity. Early culling in this muscular breed appears driven by economy rather than by health problems or other factors. Future research should address systemic drivers of early culling and develop models for optimising economic efficiency, resource use and emission mitigation linked to longevity. Still, maintaining high animal health and welfare standards remains central to reducing involuntary culling.

Ethical approval

This study did not require ethical approval, as it used only routinely collected data from breeders' associations, with farm and animal identities anonymised before analysis.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

We gratefully acknowledge funding from the EU Horizon 2020 GenTORE Project (Grant Agreement No. 727213).

ORCID

Giulio Cozzi http://orcid.org/0000-0003-0408-1082

Data availability statement

Data remain the property of Qualitas AG (Zug, Switzerland) and are available upon reasonable request under data use agreements.

References

Barton K. 2019. MuMIn: multi-model inference. R package version 1.43.15. https://CRAN.R-project.org/package=MuMIn

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. J Stat Soft. 67(1):48. https://doi.org/10.18637/jss.v067.i01

Bieber A et al. 2019. Production level, fertility, health traits, and longevity in local and commercial dairy breeds under organic production conditions in Austria, Switzerland, Poland, and Sweden. J Dairy Sci. 102(6):5330–5341. https://doi.org/10.3168/jds.2018-16147

Bieber A et al. 2020. Comparison of performance and fitness traits in German Angler, Swedish Red and Swedish Polled with Holstein dairy cattle breeds under organic production. Animal. 14(3):609–616. https://doi.org/10.1017/S1751731119001964

Curone G et al. 2016. Milk ketone bodies assessment in a local Italian cow breed (Modenese) versus Holstein and characterization of its physiological, reproductive and productive performances. Int J Agric Res. 2:15–22.

Dallago GM et al. 2021. Keeping dairy cows for longer: a critical literature review on dairy cow longevity in high milk-producing countries. Animals. 11(3):808. https://doi.org/10.3390/ani11030808

De Vries A, Marcondes MI. 2020. Review: overview of factors affecting productive lifespan of dairy cows. Animal. 14(S1): s155–s164. https://doi.org/10.1017/S1751731119003264

De Vries A. 2017. Symposium review: why revisit dairy cattle productive lifespan? J Dairy Sci. 103:3838–3845.

Dillon P et al. 2003. A comparison of different dairy cow breeds on seasonal grass-based systems of milk production: 2. Reproduction and survival. Livest Sci. 83:35–42.

Essl A. 1998. Longevity in dairy cattle breeding: a review. Livest Prod Sci. 57(1):79–89. https://doi.org/10.1016/S0301-6226(98)00160-2

Fox J, Monette G. 1992. Generalized collinearity diagnostics. J Am Stat Assoc. 87(417):178–183. https://doi.org/10.2307/2290467

Fox J, Weisberg S. 2019. An {R} companion to applied regression. 3rd ed. Sage. https://socialsciences.mcmaster.ca/jfox/Books/Companion/

Gandini G, Maltecca C, Pizzi F, Bagnato A, Rizzi R. 2007. Comparing local and commercial breeds on functional traits and profitability: the case of Reggiana dairy cattle. J Dairy Sci. 90(4):2004–2011. https://doi.org/10.3168/jds.2006-204

Grandl F et al. 2016. Biological implications of longevity in dairy cows: 2. Changes in methane emissions and efficiency with age. J Dairy Sci. 99(5):3472–3485. https://doi.org/10.3168/jds.2015-10262

Grandl F, Furger M, Kreuzer M, Zehetmeier M. 2019. Impact of longevity on greenhouse gas emissions and profitability of individual dairy cows analysed with different system boundaries. Animal. 13(1):198–208. https://doi.org/10.1017/S175173111800112X

Heller D, Potthast V. 1990. Successful feeding of dairy cattle. 2nd ed. DLG-Verlag.

Hoffman JM, Valencak TG. 2020. A short life on the farm: aging and longevity in agricultural, large-bodied mammals. Geroscience. 42(3):909–922. https://doi.org/10.1007/s11357-020-00190-4

Horn M, Knaus W, Kirner L, Steinwidder A. 2012. Economic evaluation of longevity in organic dairy cows. Org Agric. 2(2):127–143. https://doi.org/10.1007/s13165-012-0027-6

Knaus W. 2009. Dairy cows trapped between performance demands and adaptability. J Sci Food Agric. 89(7):1107–1114. https://doi.org/10.1002/jsfa.3575

Künzi N, Leuenberger H, Michel A. 1988. Die Alpung: Ein wichtiger Teil der schweizerischen Rindviehproduktion [Alpine grazing: an important part of Swiss cattle production]. J Anim Breed Genet. 105:279–293.

Lenth R. 2020. emmeans: estimated marginal means, aka least-squares means. R package version 1.4.5. https://CRAN.R-project.org/package=emmeans

Oltenacu PA, Broom DM. 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Anim Welf. 19(S1):39–49. https://doi.org/10.1017/S0962728600002220

Pfeifer C, Winterberg R, Leiber F. 2025. Quantifying the contributing potential of European grasslands to food protein and organic manure in a circular food system. Grass Forage Sci. 80(2):e12713. https://doi.org/10.1111/gfs.12713

Probst S, Wasem D, Kobel D, Zehetmeier M, Flury C. 2019. Treibhausgasemissionen aus der gekoppelten Milch- und Fleischproduktion in der Schweiz [Greenhouse gas emissions from coupled milk and meat production in Switzerland]. Agrarforsch Schweiz. 10:440–445.

R Core Team. 2020. R: a language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Ruhland K, Gränzer W, Groth W, Pricher F. 1999. Blood levels of hormones and metabolites, erythrocytes and leukocytes and respiration and pulse rate of heifers after alpage. J Anim Breed Genet. 116(5):415–423. https://doi.org/10.1046/j.1439-0388.1999.00203.x

Schuster JC, Barkema HW, De Vries A, Kelton DF, Orsel K. 2020. Invited review: academic and applied approach to evaluating longevity in dairy cows. J Dairy Sci. 103(12):11008–11024. https://doi.org/10.3168/jds.2020-19043

Stefani G, El Faro L, Santana Júnior ML, Tonhati H. 2018. Association of longevity with type traits, milk yield and udder health in Holstein cows. Livest Sci. 218:1–7. https://doi.org/10.1016/j.livsci.2018.10.007

Van Middelaar CE, Berentsen PBM, Dijkstra J, van Arendonk JAM, de Boer IJM. 2014. Methods to determine the relative value of genetic traits in dairy cows to reduce greenhouse gas emissions along the chain. J Dairy Sci. 97(8):5191–5205. https://doi.org/10.3168/jds.2013-7413

Walsh S et al. 2008. Effects of breed and feeding system on milk production, body weight, body condition score, reproductive performance and postpartum ovarian function. J Dairy Sci. 91(11):4401–4413. https://doi.org/10.3168/jds.2007-0818

Zehetmeier M, Baudracco J, Hoffmann H, Heißenhuber A. 2012. Does increasing milk yield per cow reduce greenhouse gas emissions? A system approach. Animal. 6(1):154–166. https://doi.org/10.1017/S1751731111001467