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RETROSPECTIVE: DURATION AND EFFICIENCY OF DAIRY COWS PRODUCTIVE LIFESPAN DEPENDING ON AGE AT FIRST CALVING AND FIRST LACTATION MILK PRODUCTIVITY

Vitalii Siriak[1], Yuriy Polupan[1], Ruslana Stavetska[2]

[1]Institute of Animal Breeding and Genetics nd. a. M.V. Zubets of National Academy of Agrarian Science of Ukraine, 1 Pogrebniaka, Chubynske, Boryspilskyi rayon, Kyivska oblast, 08321, Ukraine
[2]Department of Genetics, Breeding and Selection of Animals, Bila Tserkva National Agrarian University, pl. 8/1 Soborna, Bila Tserkva, Kyivska oblast, 09117, Ukraine

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Vastutav autor: Corresponding author: Ruslana Stavetska

E-mail: rstavetska@gmail.com

ORCID:
0000-0003-1245-9161 (VS)
0000-0001-7609-2739 (YP)
0000-0003-0149-1908 (RS)

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ABSTRACT. The retrospective analysis involved 562 Holstein cows, 545 Ukrainian Black-and-White dairy cows and 100 Ukrainian Red-and-White dairy cows in Breeding Station Terezyne, Kyiv region. The influence of age at first calving and first lactation milk yield on the duration and efficiency of the productive lifespan of cows was studied. The results showed that with the increase of age at first calving from less than 22 to more than 34 months there was a steady tendency to reduction in the longevity and lifetime productivity of cows. There was found a statistically significant ($P < 0.001$) inverse correlation between the age at first calving and indicators of duration and efficiency of productive lifespan ($r = –0.177…–0.459$). The age at first calving determines 3.0–21.2% of the phenotypic variability of the considered indicators of duration and efficiency of the productive lifespan of cows ($P < 0.001$). According to the set of features, the most rational is the planning of age at first calving before 26 months, *i.e*. heifers need to be served before 15 months of age. With the first lactation milk yield increases and the duration and efficiency of the productive lifespan of cows increase curvilinearly. Higher longevity is typical for cows with an average 305-d milk yield in the first lactation of 6 001–8 000 kg, and higher lifetime productivity – with the highest milk yield in the first lactation (over 9 000 kg). There was found a relatively low positive correlation between 305-d milk yield in the first lactation and the parity and lifespan ($r = 0.087…0.164$, $P < 0.001$) and a moderately significant relationship – with lifetime productivity and lifetime daily milk yield ($r = 0.327…0.504$, $P < 0.001$). The milk yield of primiparous cows has a relatively low impact on the variability of lifespan, productive lifetime and total lactation length ($\eta_x^2 = 3.6–5.6\%$, $P < 0.001$) and a higher impact on the indicators of lifetime milk productivity and milk productivity per one day of life, productive lifetime and lactation ($\eta_x^2 = 12.5–35.6\%$, $P < 0.001$). The productive lifespan of cows with first lactation milk yield over 6 000 kg can be considered quite effective.

Introduction

Milk is one of the best natural foods and one of the most important animal products for human consumption. Most of the milk produced in the world (about 91%) comes from cattle, although in some countries sheep, goats and buffaloes are the major producers of milk (FAO, 2022). In recent years, the emphasis on production traits, and especially the increase in production per head of livestock, has been of particular importance. Since milk is one of the most important sources of income for most livestock producers and there is also a sufficient program for recording and collecting data about milk, and on the other hand, the maximum genetic improvement is when the number of traits is considered, the choice for milk production is important (Mohammadabadi *et al.*, 2021). Moreover, high milk yields often lead to poor health and fertility of cows

and, as a result, increased intensity of their culling (Adamczyk *et al.*, 2017; Dallago *et al.*, 2021). This reduces the economic efficiency of the dairy herd. Because of the above mentioned, the duration and efficiency of the productive lifespan of cows are considered indicators of the efficiency of breeding and welfare of dairy cattle (Adamczyk *et al.*, 2017; De Vries, Marcondes, 2020; Vredenberg *et al.*, 2021). In 2021, the US Net Merit (NM$) included new indicators (feed saved, heifer livability, early first calving) and updated weight coefficients for some other dairy cattle selection indicators. In particular, the share of the sub-index of productive life of cows has increased (VanRaden *et al.*, 2021; Zhang, Amer, 2021), which is an important indicator of this trait's relevance.

Longevity and lifetime productivity of cows are determined by genotypic, environmental factors and ontogenetic parameters of animal body formation (Kulak *et al.*, 1997; Sherwin *et al.*, 2016; De Vries, Marcondes, 2020; Schuster *et al.*, 2020). Important factors of ontogenetic development that affect the longevity of cows are the age at first calving and first lactation milk yield. The speed of renewal and the cost of repairing the herd depends on the age at the first calving of cows. With low heredity of age at the first calving ($h^2 = 0.086$) (Nilforooshan, Edriss, 2004) and a weak correlation between age at first calving and lifespan of cows (r = 0.104…0.255) (Shkurko, 2014) there was proved its significant effect on milk yield, milk fat yield, the productive lifetime of cows (Nilforooshan, Edriss, 2004), lifetime daily milk yield (Haworth *et al.*, 2008), calving interval (Kučević *et al.*, 2020).

The optimal age of the dairy cows at first calving is considered to be 23–25 months (Do *et al.*, 2013; Nilforooshan, Edriss, 2004). In the study of Froidmont *et al.* (2013) the highest total lactation length and milking days was obtained at first calving age within 22–26 months. If the age at first calving is less than 22 months, the loss of 305-d milk yield in the first lactation is 590–800 kg (Elahi Torshizi, 2016), when above 26 months – 170–600 kg (Pirlo *et al.*, 2000). The daily milk yield of cows that calved for the first time at 22–25 months of age is 2.1–2.4 kg higher than that of animals with older or younger ages at first calving (Storli *et al.*, 2017; Eastham *et al.*, 2018). Based on the analysis of 19 publications from different geographical areas and the use of different breeds, covering information on 2.4 million cows, Steele (2020) concluded that the optimal age at first calving was 22–25 months. In the study of Almasri *et al.* (2020), Syrian Shami cows with age at first calving before 25 months showed the best indicators of longevity and lifetime milk productivity. Sanova (2020) argues that the productive lifetime of cows decreases with age at first calving increase. In the population of Korean Holsteins, it was concluded that with the reduction of age at first calving from 32.8 to 22.3 months, lifetime profit increases from 727.3 to 2 363.6 US dollars (Do *et al.*, 2013). El-Awady *et al.* (2021) report that in Egyptian buffalos reducing the age at first calving from 1 670 ± 119 to 918 ± 41 days helps to prolong the longevity in the herd from 3.88 ± 1.51 to 8.43 ± 2.3 lactations, to increase lifetime milk yield from 10 271 ± 2 943 to 20 898 ± 3 546 kg, with lifetime profit increase from $ 222 to $ 3 778. At the same time, Pirlo *et al.* (2000) found slight differences in the longevity of cows, whose age at first calving ranged from 22.4 to 27.4 months. In the Australian Holstein population, the age at first calving did not affect the lifetime days in milk and the number of parities per lifetime (Haworth *et al.*, 2008).

To assess the duration and efficiency of a dairy cow's productive lifespan, the highest prognostic value have first lactation milk yield, milk fat yield and milk protein yield, and daily milk yield in the first lactation is a reliable indicator of milk yield in subsequent lactations, its lifetime productivity and longevity (Haworth *et al.*, 2008).

Most researchers have found a positive correlation between first lactation milk yield and cows' longevity (Jairath, Dekkers, 1995; du Toit *et al.*, 2009; Abdelharith *et al.*, 2019; Almasri *et al.*, 2020), first lactation milk yield and herd culling rates (Haine *et al.*, 2017). Du Toit *et al.*, (2011) concluded that direct selection by milk productivity does not lead to undesirable genetic changes in the dairy cow's longevity.

The genetic correlation between the cow survival during three lactations and their milk productivity is quite high and varies according to various data from 0.60 to 0.99 (Jairath, Dekkers, 1995; Boettcher *et al.*, 1999; du Toit *et al.*, 2009). The relationship between 305-d first lactation milk yield and the lifetime number of lactations, lifetime days in milk, lifespan and productive lifetime and lifetime milk yield varies from 0.13 to 0.49 (Abdelharith *et al.*, 2019).

According to Januś and Borkowska (2012), primiparous cows with high milk yields are more productive in subsequent lactations. Wathes *et al.* (2014) state that cows with slightly lower than average milk yield in the herd at the first lactation are characterized by higher lifetime productivity, because these animals have the good reproductive ability and are being used in the herd for a long time.

Some researchers have found a negative correlation between the milk yield and the productive lifetime of dairy cows (Haworth *et al.*, 2008; Sawa, Bogucki, 2010; Karatieieva, 2019; Levina *et al.*, 2020). According to their results, the high milk yields of primiparous cows lead to a reduction in the longevity and productive lifetime of cows (Sawa, Bogucki, 2010; Karatieieva, 2019). According to Levina *et al.* (2020), in case the first lactation milk yields are within 4 100–5 000 kg, survival of cows after the first lactation was 67–75%, for milk yields of 10 100–11 000 kg – only 10–21%.

This study aimed to investigate the effect of age at first calving and milk yield of primiparous cows on the duration and efficiency of their productive lifespan.

Materials and Methods

The study was conducted by a retrospective statistical experiment in the herd of dairy cattle in Breeding Station Terezyne, which is located in the Kyiv region, Ukraine (49°51′27″ N, 30°6′36″E). Materials of the electronic information base ORSEK have been used. The generated matrix of observations in the sta format contained information about 5 703 cows by 458 variables. Of these, 3 908 animals had information on the date of calving (1989–2016) and the first lactation milk productivity of primiparous cows (Polupan, Siriak, 2019). A comparison of group averages revealed significant differences in the level of growing and feeding (estimated indirectly by the milk yield of primiparous cows) for chronologically different years of the first calving (3 671–8 054 kg). The range of variability of group averages (4 383 kg) is by 2.6 times higher than the total standard deviation of the sample (1 684 kg), which causes probable inaccuracy of statistical and genetic estimates and conclusions for chronologically long (19 years) periods of different conditions for growing, feeding and lactation of animals in the herd (Polupan *et al.*, 2019, 2020). Analysis of average first lactation milk yield in different years at first calving identified a relatively similar cluster from 2003 to 2008, taking into account the methodical requirement for forming a retrospective sample for the year of first calving no later than eight years before the date of analysis (Polupan, 2010). During this period, the average 305-d milk yield of primiparous cows ranged from 5 521 to 7 188 kg (lim = 1 667 kg) with a standard deviation (S.D.) of 1 383 kg (1.21 S.D.), which gives reason to expect close to reliable results of comparative analysis of animals of different genetic and genealogical groups. The level of heifer growing during this period provided 618 g of average daily live weight gain up to one year of age and 613 g at 12–18 months of age. The analysis included information on the productivity of 562 Holstein cows, 545 – Ukrainian Black-and-White and 100 – Ukrainian Red-and-White dairy cows.

A retrospective analysis of the duration and efficiency of the productive lifespan of cows was carried out according to our proposed method (Polupan, 2010). In the control animal group, we took into account the lifetime number of lactations and calves born alive, lifespan (days) (L), productive lifetime (PL), total lactation length (TLL), lifetime milk yield (kg), fat yield (kg) and protein yield (kg), lifetime, productive life and total lactation daily milk yield (kg), daily milk fat (g) and daily milk protein (g) yields (Polupan, 2010). The coefficients (%) of a productive lifetime (CPL), lactation (CL) and productive use (CPU) were calculated according to the considered periods by the following formula (Pelekhatyi *et al.*, 1999; Polupan, 2010):

C_PL=PL/L×100;

〚C〛_L=TLL/PL×100;

C_PU=TLL/L×100

According to age at first calving and 305-d first lactation milk yield, the control cows were divided into eight groups by age at first calving with a class interval of 60 days, by the milk yield of primiparous cows a class interval was 1 000 kg.

The calculations were performed by methods of mathematical statistics using the software package Statistica 12.0. The results reliability was compared with three standard levels of statistical significance with their designation: P <0.05, P <0.01, P <0.001.

Results and Discussion

With the increase of age at first calving on average from 647 to 1 084 days (from less than 22 to more than 34 months), there is a steady trend to reduce the longevity and lifetime productivity of cows (Table 1).

Table 1. Duration and efficiency of dairy cows' productive lifespan depending on age at first calving *($\bar{x}$ ± S.E.)*

Parameters		Group by age at first calving, months							
		<22	22–24	24.1–26	26.1–28	28.1–30	30.1–32	32.1–34	>34
Number of cows		36	116	270	311	227	148	58	26
Age at first calving, days		647 ± 2.3	708 ± 1.5	760 ± 1.0	818 ± 0.9	877 ± 1.1	937 ± 1.4	988 ± 2.1	1 084 ± 9.7
Lifetime	no. of lactations	3.83 ± 0.310^{b}	4.09 ± 0.174^{c}	3.88 ± 0.097^{c}	3.43 ± 0.093^{a}	3.02 ± 0.107	2.75 ± 0.129	2.72 ± 0.202	2.50 ± 0.356
	calves born alive	4.65 ± 0.355^{b}	4.53 ± 0.209^{b}	4.45 ± 0.116^{c}	3.99 ± 0.111^{a}	3.85 ± 0.147	3.64 ± 0.207	3.21 ± 0.359	3.58 ± 0.452
Duration, days	lifespan	2 369 ± 115.3^{b}	2 299 ± 69.9^{a}	2 313 ± 39.7^{b}	2 205 ± 38.2^{a}	2 055 ± 48.1	2 009 ± 59.0	2 008 ± 89.9	1 906 ± 141.8
	productive lifetime	1 722 ± 115.6^{c}	1 591 ± 69.9^{c}	1 553 ± 39.8^{c}	1 387 ± 38.3^{c}	1 178 ± 48.1^{a}	1 072 ± 59.0	1 021 ± 89.9	822 ± 141.1
	total lactation	1 494 ± 103.1^{c}	1 378 ± 60.2^{c}	1 348 ± 34.2^{c}	1 212 ± 33.2^{c}	1 030 ± 41.4^{b}	936 ± 49.0	886 ± 76.0	711 ± 115.2
Lifetime productivity, kg	milk yield	27 671±2 091^{c}	27 231±1 287^{c}	26 059±754^{c}	22 344 ±704^{c}	18 231±796	16 286±959	15 617±1 572	13 547±2 390
	milk fat + milk protein	1 949 ± 148.4^{c}	1 928 ± 91.1^{c}	1 866 ± 54.2^{c}	1 587 ± 50.7^{c}	1 286 ± 56.8	1 146 ± 69.4	1 092 ± 112.7	940 ± 174.5
Daily milk yield per cow, kg	lifespan	11.1 ± 0.28^{c}	11.2 ± 0.28^{c}	10.7 ± 0.18^{c}	9.5 ± 0.17^{c}	8.1 ± 0.21^{b}	7.3 ± 0.24	7.0 ± 0.41	6.2 ± 0.60
	productive lifetime	16.1 ± 0.63	17.2 ± 0.30^{a}	16.8 ± 0.21	16.1 ± 0.23	15.9 ± 0.31	15.7 ± 0.37	15.4 ± 0.69	17.9 ± 0.99^{a}
	total lactation	18.4 ± 0.65	19.7 ± 0.31^{b}	19.2 ± 0.23^{a}	18.2 ± 0.24	17.7 ± 0.32	17.5 ± 0.38	17.4 ± 0.72	19.4 ± 0.89
Daily milk fat and protein yields per cow, g	lifespan	782 ± 37.6^{c}	792 ± 20.2^{c}	767 ± 12.9^{c}	671 ± 12.7^{c}	568 ± 14.9^{b}	512 ± 17.6	488 ± 29.6	422 ± 44.8
	productive lifetime	1 132 ± 44.8	1 216 ± 22.0^{b}	1 199 ± 15.8^{a}	1 137 ± 16.7	1 091 ± 21.1	1 079 ± 24.9	1 064 ± 48.2	1 199 ± 64.0
	total lactation	1 296 ± 45.8	1 392 ± 22.7^{c}	1 375 ± 17.4^{b}	1 289 ± 17.4	1 223 ± 22.0	1 202 ± 26.1	1 201 ± 50.3	1 304 ± 59.6
Coefficient, %	productive lifetime	69.5 ± 2.12^{c}	65.3 ± 1.23^{c}	64.0 ± 0.73^{c}	59.2 ± 0.75^{c}	52.2 ± 1. 05^{c}	48.0 ± 1.33^{b}	46.0 ± 2.00^{a}	36.6 ± 3.66
	lactation	87.4 ± 1.44	87.2 ± 0.53	87.4 ± 0.40	88.3 ± 0.43	89.5 ± 0.60^{b}	89.8 ± 0.61^{b}	88.4 ± 1.16	91.5 ± 1.70^{a}
	productive use	60.4 ± 1.96^{c}	56.7 ± 1.08^{c}	55.8 ± 0.64^{c}	51.9 ± 0.66^{c}	46.1 ± 0.89^{c}	42.5 ± 1.08^{c}	40.3 ± 1.70^{a}	32.3 ± 2.83

Groups' significant differences were indicated by lowercase letters, where the level of the significance was denoted: ^{a} – P < 0.05; ^{b} – P < 0.01; ^{c} – P < 0.001.

The most effective was the productive lifespan of cows with age at first calving within 22–24 months, which dominate the animals with age at first calving 34 months and more by lifetime number of lactations by 1.59 ± 0.396 or 63.6% (P <0.001), by lifetime calves born alive – by 0.95 ± 0.498 or 26.5% (P <0.01), by lifespan – 393 ± 158.1 days or 20.6% (P <0.05), by productive lifetime – 769 ± 157.5 days or 93.6%, (P <0.001), by total lactation length – 667 ± 130.0 days or 93.8% (P <0.001), by lifetime milk yield – 13 684 ± 2 714.4 kg or 101.0% (P <0.001), by lifetime milk fat and milk protein yields – 988 ± 196.8 kg or 105.1% (P <0.001), by lifetime daily milk yield – 5.0 ± 0.66 kg or 80.6% (P <0.001), by lifetime daily milk fat and milk protein yields – 370 ± 49.1 g or 87.7% (P <0.001), by coefficients of a productive lifetime – 28.7 ± 3.86% (P <0.001) and productive use – 24.4 ± 3.03% (P <0.001). At a reliable level, the majority of the considered traits of the duration and efficiency of productive lifespan, compared to the late calving group, remains the advantage of caws with age at first calving from 24.1 to 28 months.

At the age at first calving less than 22 months, the efficiency of productive lifespan compared to the group with age at first calving 22–24 months does not decrease significantly, and by lifespan, lifetime calves born alive, productive lifetime and total lactation length, lifetime milk yield, milk fat yield and milk protein yields, coefficients of a productive lifetime and productive use it is even slightly increasing.

Thus, according to the set of features, the most rational is the planning of the first calving before 26 months of age, *i.e.* heifers need to be bred before 15 months of age. This coincides with several scientists' opinions (Nilforooshan, Edriss 2004; Haworth *et al.*, 2008; Do *et al.*, 2013; Froidmont *et al.*, 2013; Storli *et al.*, 2017; Eastham *et al.*, 2018; Almasri *et al*, 2020; Steele, 2020) and is slightly lower than the results, obtained by Russian scientists (Nekrasov *et al.*, 2017), who consider the optimal age at first calving for Holstein cows 25.1–27 months, for Red-and-White dairy breed – 27.1–29 months. There is no significant precaution of age at first conception even before 13 months with intensive rearing of heifers.

In our study, the coefficients of a productive lifetime and productive use confirm the tendency to reduce the duration of productive lifetime and cows' lifetime milk production by increasing their age at first calving. Nilforooshan and Edriss (2004) also found a positive effect of lowering the age of first calving on milk yield and the productive lifetime of cows.

Correlation analysis revealed a statistically significant (P <0.0001) inverse correlation of age at first calving with lifetime number of lactations (r = –0.273 ± 0.0279), longevity (r = –0.177 ± 0.0285), lifetime milk yield (r = –0.322 ± 0.0274 %), lifetime milk fat yield and milk protein yields (r = –0.325 ± 0.0275), lifetime daily milk fat and daily milk protein (r = –0.438 ± 0.0261) and the coefficient of a productive lifetime (r = –0.459 ± 0.0257).

Dispersion analysis confirmed a significant effect of age at first calving on lifetime number of lactations (η_x^2 = 7.7 ± 0.55%, F = 14.09, P <0.001), lifetime calves born alive (η_x^2 = 4.5 ± 0.90%, F = 4.98, P <0.001), longevity (η_x^2 = 3.3 ± 0.57%, F = 5.73, P <0.001), productive lifetime (η_x^2 = 8.8 ± 0.54%, F = 16.22, P <0.001), total lactation length (η_x^2 = 8.8 ± 0.54%, F = 16.35, P <0.001), lifetime milk yield (η_x^2 = 10.4 ± 0.53%, F = 19.66, P <0.001), lifetime milk fat and milk protein yields (η_x^2 = 10.7 ± 0.53%, F = 20.24, P <0.001), lifetime daily milk yield (η_x^2 = 18.8 ± 0.48%, F = 39.21, P <0.001), total lactation daily milk yield (η_x^2 = 3.0 ± 0.57%, F = 5.29, P <0.001), lifetime daily milk fat and milk protein yields (η_x^2 = 19.8 ± 0.48%, F = 41.48, P <0.001), productive lifetime daily milk fat and milk protein yields (η_x^2 = 3.0 ± 0.58%, F = 5.25, P <0.001) and total lactation length daily milk fat and milk protein yields (η_x^2 = 4.9 ± 0.56%, F = 8.80, P <0.001), on the coefficients of productive lifetime (η_x^2 = 21.2 ± 0.47%, F = 45.41, P <0.001) and productive use (η_x^2 = 20.6 ± 0.47% , F = 43.89, P <0.001).

Thus, by comparison of group averages, correlation and variance analysis there was proved the feasibility of planning early age at the first conception of heifers (13–15 months), does not reduce the duration and efficiency of the productive lifespan of cows.

A comparison of group averages revealed the effect on the duration and effectiveness of the productive lifespan of dairy cows (Table 2).

Cows with the lowest 305-d first lactation milk yield (up to four tons, on average 3 364 ± 72.2 kg) are characterized by the lowest indicators of duration and effectiveness of productive lifespan. With the milk yield of primiparous cows increasing, the duration and efficiency of the productive lifespan of cows increase curvilinearly. If we do not take into account the indicators of the group with the first lactation milk yield over 10 tons due to its small number and, consequently, statistical uncertainty of assessment, the highest level of total lactations and calves, longevity, productive lifetime and total lactation length were observed in cows with 305-d first lactation milk yield 6–7 tons. Further increase in the milk yield of primiparous cows is accompanied by a gradual decrease in these indicators. However, they remain higher than in groups with low productivity of primiparous cows (up to 5 tons). From 153 cows with the first lactation milk yield up to 5 tons per there was received on average 3.70 calves, and from 799 animals with milk yield over 6 tons – 4.19 calves, which is higher by 0.49 heads or by 13.2%. The corresponding indicators of these animals within the lifetime number of lactations were 2.83 and 3.62 (+0.79 lactation or 27.9%), longevity – 1 891 and 2 302 days (+411 days or +21.7%), by productive lifetime – 1 042 and 1 483 days (+441 days or + 42.3%), by total lactation length – 920 and 1 291 days (+371 days or +40.3%).

Table 2. Duration and efficiency of dairy cows' productive lifespan depending on first lactation milk yield *($\bar{x}$ ± S.E.)*

Parameters		Group by 305-d first lactation milk yield, kg							
		<4 000	4 000–5 000	5 001–6 000	6 001–7 000	7 001–8 000	8 001–9 000	9 001–10 000	>10 000
Number of cows		50	103	225	319	293	159	25	3
305-d first lactation average milk yield, kg		3 364 ± 72.2	4 570 ± 26.5	5 556 ± 18.1	6 522 ± 15.8	7 468 ± 16.1	8 397 ± 21.6	9 311 ± 45.4	10 185 ± 122.7
Lifetime	no. of lactations	2.78 ± 0.222	2.85 ± 0.151	3.32 ± 0.121^{a}	3.85 ± 0.095^{c}	3.56 ± 0.096^{b}	3.30 ± 0.120^{a}	3.32 ± 0.325	3.67 ± 0.333^{a}
	calves born alive	3.88 ± 0.291	3.61 ± 0.241	4.03 ± 0.160	4.31 ± 0.118^{b}	4.18 ± 0.118^{a}	4.04 ± 0.153	3.94 ± 0.378	3.33 ± 0.333
Duration, days	lifespan	1 910 ± 91.4	1 882 ± 60.8	2 063 ± 48.4^{a}	2 354 ± 38.7^{c}	2 297 ± 39.7^{c}	2 210 ± 47.7^{c}	2 268 ± 156.3^{a}	2 430 ± 248.6^{a}
	productive lifetime	1 061 ± 93.8	1 033 ± 63.2	1 237 ± 49.2^{a}	1 532 ± 39.5^{c}	1 486 ± 40.2^{c}	1 389 ± 48.5^{c}	1 421 ± 164.5^{a}	1 564 ± 232.8^{a}
	total lactation	927 ± 78.7	916 ± 54.0	1 068 ± 41.3^{a}	1 321 ± 33.7^{c}	1 301 ± 35.2^{c}	1 211 ± 41.6^{c}	1 274 ± 146.4^{a}	1 419 ± 207.0^{a}
Lifetime productivity, kg	milk yield	10 833±1 265	13 966±1 069	18 435±821^{c}	24 617±697^{c}	25 484±742^{c}	24 837±842^{c}	28 439±3 075^{c}	34 169±5 030^{c}
	milk fat + milk protein	750 ± 90.1	969 ± 76.0	1 294 ± 58.7^{c}	1 747 ± 49.7^{c}	1 817 ± 53.5^{c}	1 774 ± 60.6^{c}	2 039 ± 225.5^{c}	2 427 ± 355.5^{c}
Daily milk yield per cow, kg	lifespan	5.0 ± 0.37	6.7 ± 0.31^{c}	8.1 ± 0.20^{c}	9.9 ± 0.16^{c}	10.5 ± 0.16^{c}	10.9 ± 0.20^{c}	11.8 ± 0.70^{c}	13.9 ± 0.64^{c}
	productive lifetime	9.7 ± 0.45	13.1 ± 0.38^{c}	14.8 ± 0.23^{c}	16.1 ± 0.16^{c}	17.2 ± 0.18^{c}	18.5 ± 0.30^{c}	20.9 ± 0.78^{c}	21.9 ± 0.29^{c}
	total lactation	11.0 ± 0.53	14.6 ± 0.41^{c}	16.9 ± 0.25^{c}	18.5 ± 0.17^{c}	19.6 ± 0.19^{c}	21.0 ± 0.28^{c}	23.0 ± 0.74^{c}	24.1 ± 0.24^{c}
Daily milk fat and milk protein yields per cow, g	lifespan	346 ± 26.6	465 ± 21.8^{b}	563 ± 14.5^{c}	699 ± 11.2^{c}	751 ± 12.0^{c}	778 ± 14.3^{c}	841 ± 51.8^{c}	990 ± 46.5^{c}
	productive lifetime	663 ± 31.5	899 ± 26.0^{c}	1 027 ± 16.4^{c}	1 134 ± 11.4^{c}	1 223 ± 12.9^{c}	1 323 ± 21.5^{c}	1 487 ± 53.6^{c}	1 554 ± 11.6^{c}
	total lactation	751 ± 37.1	1 006 ± 28.9^{c}	1 170 ± 17.7^{c}	1 305 ± 12.4^{c}	1 391 ± 13.7^{c}	1 497 ± 20.4^{c}	1 636 ± 53.2^{c}	1 710 ± 6.4^{c}
Coefficient, %	productive lifetime	50.9 ± 2.21	50.8 ± 1.46	54.6 ± 1.00^{a}	61.4 ± 0.76^{c}	61.4 ± 0.76^{c}	59.9 ± 1.02^{c}	57.5 ± 3.49	63.7 ± 3.30^{c}
	lactation	88.9 ± 1.04	89.6 ± 0.69^{b}	88.1 ± 0.59	87.2 ± 0.41	88.1 ± 0.43	88.2 ± 0.57	90.8 ± 1.22^{b}	90.8 ± 0.41^{c}
	productive use	44.9 ± 1.84	45.2 ± 1.23	47.6 ± 0.84	53.3 ± 0.65^{c}	53.9 ± 0.68^{c}	52.5 ± 0.87^{c}	51.8 ± 3.02^{c}	57.9 ± 2.77^{c}

Groups' significant differences were indicated by lowercase letters, where the level of the significance was denoted: ^{a} – $P < 0.05$; ^{b} – $P < 0.01$; ^{c} – $P < 0.001$.

Lifetime milk production increases curvilinearly with increasing first lactation milk yield of cows to more than 9–10 tons. The lifetime milk yield of cows with 305-d first lactation milk yield 9 001–10 000 kg is 2.63 times higher than that of the group with milk yield up to 4 000 kg, and the lifetime milk fat and milk protein yields – by 2.72 times. With primiparous cows' milk yield of more than 6 000 kg, the lifetime milk yield exceeds 24 tons, and the lifetime milk fat and milk protein yields – 1.7 tons, which provides sufficient efficiency for the productive lifespan of cows. The physiological stress of primiparous cows with milk yield over 9–10 tons does not lead to a decrease in lifetime milk production, but on the contrary, is accompanied by its maximum growth to 29 053 kg of milk yield and 2 081 kg of milk fat and milk protein yields.

Lifetime daily milk yield and lifetime daily milk fat and milk protein yields with increasing milk production of primiparous cows from less than 4 000 kg to more than 9 000 kg steadily increase by 140% (from 5.0 to 12.0 kg) and 148% (from 346 to 857 g), respectively. The same increase was found in productive life daily milk yield (by 116%, from 9.7 to 21.0 kg), in total lactation daily milk yield (by 110%, from 11.0 to 23.1 kg), in productive life daily milk fat and milk protein yields (by 125%, from 663 to 1 494 g), and in total lactation daily milk fat and milk protein yields (by 119%, from 751 to 1 644 g). Thus, 305-d milk yield of primiparous cows over 6 tons can be considered quite effective for their productive lifespan. Such animals have a higher lifetime daily milk yield by 4.3 kg compared to animals with 305-d first lactation milk yield less than 5 tones (10.4 *vs.* 6.1 kg) or by 70%, by lifetime daily milk fat and milk protein yields respectively by 313 g (739 *vs.* 426 g) or by 42% ($P < 0.001$).

The coefficient of the productive lifetime of cows increases curvilinearly from 50.9 to 58.2%, and the coefficient of productive use – from 44.9 to 52.5% with increases in milk production of primiparous cows from less than 4 000 kg to more than 9 000 kg. According to the lactation coefficient, which characterizes the ratio of lactation and dry periods during the productive lifetime of cows, intergroup differentiation was less significant without a clear pattern both for age at first calving (Table 1) and first lactation milk yield (Table 2).

Correlation analysis revealed a relatively low, but statistically significant direct correlation between 305-d first lactation milk yield and lifetime number of lactations ($r = 0.087 \pm 0.0291$, $P = 0.003$), longevity ($r = 0.164 \pm 0.0290$, $P < 0.001$) and more significant – with lifetime milk yield ($r = 0.327 \pm 0.0276$, $P < 0.001$), lifetime milk fat and milk protein yields ($r = 0.336 \pm 0.0275$), $P < 0.001$), lifetime daily milk fat and milk protein yields ($r = 0.504 \pm 0.0254$, $P < 0.001$) and the coefficient of a productive lifetime ($r = 0.212 \pm 0.0287$, $P < 0.001$). Thus, our research results refute the statements of several authors (Haworth *et al.*, 2008; Sawa, Bogucki, 2010; Wathes *et al.*, 2014; Karatieieva, 2019; Levina *et al.*, 2020; Sanova, 2020) about the inverse correlation between first lactation milk yield and longevity and a productive lifetime of cows, and confirm the results of majority researchers' on the existence of a reliable direct correlation between these traits (Jairath, Dekkers, 1995; Boettcher *et al.*, 1999; Haworth *et al.*, 2008; du Toit *et al.*, 2009; du Toit *et al.*, 2011; Januś, Borkowska, 2012; Abdelharith *et al.*, 2019; Almasri *et al.*, 2020).

Dispersion analysis confirmed a significant, albeit relatively low, effect of primiparous cows' milk yield on lifetime number of lactations ($\eta_x^2 = 3.6 \pm 0.58\%$, $F = 6.32$, $P < 0.001$), longevity ($\eta_x^2 = 5.3 \pm 0$, 57%, $F = 9.17$, $P < 0.001$), productive lifetime ($\eta_x^2 = 5.6 \pm 0.57\%$, $F = 9.85$, $P < 0.001$) and total lactation length ($\eta_x^2 = 5.6 \pm 0.57\%$, $F = 9.88$, $P < 0.001$), on the coefficients of a productive lifetime ($\eta_x^2 = 7.5 \pm 0.56\%$, $F = 13.32$, $P < 0.001$) and productive use ($\eta_x^2 = 7.1 \pm 0.56\%$, $F = 12.59$, $P < 0.001$). A more significant impact of 305-d first lactation milk yield is on lifetime milk yield ($\eta_x^2 = 12.5 \pm 0.52\%$, $F = 23.76$, $P < 0.001$),

lifetime milk fat and milk protein yields (η_x^2 = 13.0 ± 0.52%, F = 24.95, P <0.001), lifetime daily milk yield (η_x^2 = 25.1 ± 0.45%, F = 55.36, P <0.001), productive life daily milk yield (η_x^2 = 29.3 ± 0.42%, F = 69.36, P <0.001), total lactation daily milk yield (η_x^2 = 32.7 ± 0.40%, F = 81.18, P <0.001), lifetime daily milk fat and daily milk protein yields (η_x^2 = 26.3 ± 0.45%, F = 58.59, P <0.001), productive life daily milk fat and daily milk protein yields (η_x^2 = 32.7 ± 0.40%, F = 80.92, P <0.001) and total lactation daily milk fat and daily milk protein yields (η_x^2 = 35.6 ± 0.39%, F = 91.94, P <0.001). This coincides with the statement of Poslavska *et al.* (2017), who also found the strongest effect of first lactation milk yield on productive life and total lactation daily milk yield, milk fat and milk protein yields at significantly higher values of impact strength (54.97–62.47%). The results of our research are close to the results of Haworth *et al.* (2008), who note that neither age at first calving nor first lactation milk yield have a significant effect on the lifetime number of lactations.

Thus, the comparison of group averages, the correlation and variance analysis refuted the inexpediency warning for high milk production of primiparous cows (over 6–9 tons), which does not reduce the duration and efficiency of the productive lifespan of cows.

Conclusion

With the increasing age at first calving from less than 22 to more than 34 months, there is a steady trend to reduce the longevity of dairy cows and reduce their lifetime production. There was found a statistically significant (P <0.001) inverse correlation between the age at first calving and indicators of duration and efficiency of productive lifespan (r = –0.177…–0.456). The age at first calving determines 3.0…21.2% of the phenotypic variability of the studied indicators of duration and efficiency of the productive lifespan of cows (P <0.001). The most rational is the planning of the first calving before 26 months, i.e. heifers need to be bred before 15 months of age, without the significant precaution of mating even at the age of 13 months with intensive rearing of heifers.

With the increasing milk yield of primiparous cows, the duration and efficiency of the productive lifespan of cows increase curvilinearly. Higher longevity is typical for cows with an average 305-day first lactation milk yield of 6 001–8 000 kg, and higher lifetime production is typical for cows with the highest first lactation milk yield (over 9 000 kg). A relatively low, but statistically significant (up to P <0.001) direct correlation reveals between 305-d first lactation milk yield and lifetime number of lactations and longevity (r = 0.087…0.164) and more significant – with lifetime and daily milk yield (r = 0.327…0.504). The milk yield of primiparous cow has a relatively low, but significant (P <0.001) effect on the variability of lifespan, productive lifetime and total lactation length (η_x^2 = 3.6…5.6%), the coefficients of a productive lifetime and productive use (η_x^2 = 7.1…7.5%) and more significant – on the indicators of a lifetime, productive life, total lactation and daily milk production (η_x^2 = 12.5…35.6%). The productive lifespan of cows with first lactation milk yield over 6 000 kg can be considered quite effective, as long as provides a lifetime milk yield of more than 24 tons and a lifetime milk fat and milk protein yields of more than 1.7 tons.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

YP – study conception and design;
VS – acquisition of data;
RS – analysis and interpretation of data;
RS (70%), VS (30%) – drafting of the manuscript;
YP (70%), RS (30%) – critical revision and approval of the final manuscript.

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