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Comparison between reproductive, productive, health and lifetime traits of Holstein dairy cows across different generations under Egyptian conditions

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Research Article

Keywords: Holstein, Generation, Milk production, Fertility, Health, Lifetime

Posted Date: July 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10189857/v1

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Abstract

The objective of this study was to compare between reproductive, productive, health and lifetime traits across five generation of Holstein dairy cows in Egypt. The data of 8999 completed records for 2980 Holstein dairy cows were studied covering the period from 1996 to 2022 in El-Alamia farm which is belonging to Universal Company for Agricultural Development and Soil Reclamation and has a commercial dairy herd located at Nubaria region in the K 90 Alex - Cairo desert road.

The traits under study were: Age at first calving (AFC, month), Days open (DO, day), Calving interval (CI, day), Gestation length (GL, day), Lactation length (LL, day), Total milk yield (TMY, kg), 305 day milk yield (305d-MY, kg), Days dry (DD, day), Mastitis number (MN, no), Lameness number (LN, no), Age at last calving (ALC, month), Life production age (LPA, month), Complete lactation number (CLN, no), Longevity (L, month), Life milk yield (LMY, kg) and Life daily milk yield (LDMY, kg).

The results showed that all traits under study were significantly influenced by generations. G5 recorded the highest TMY and 305d-MY and LL (7970.41, 5846.80 kg, 394.39 day, respectively). While, G5 recorded the lowest mastitis and lameness number (0.004 and 0.10 number, respectively). On the other hand, the longest gestation length and longevity were observed in G1 (278.38 day and 82.74 month, respectively). While, G2 scored the longest calving interval (503.51 day), in the same trend, the longest days dry found in G2 and recorded 71.71 day.

In conclusion, five generations of Holstein genetic upgrading under Egyptian conditions have produced a population that is simultaneously more productive per lactation and less productive per lifetime. Progressive improvement in milk yield has been systematically offset by deteriorating reproductive efficiency, shortened productive careers, and declining longevity—outcomes attributable to the escalating mismatch between the metabolic demands of high-merit genetics and the nutritional and thermal realities of subtropical dairy production.

1. Introduction

Dairy cattle production represents a critical pillar of global food security, supplying protein, energy, and micronutrients to billions of people, particularly in developing regions where per capita animal protein consumption continues to rise. The Holstein-Friesian breed dominates commercial dairy production worldwide, owing to its unparalleled genetic capacity for milk yield, and its widespread adoption has been facilitated by the global dissemination of frozen semen from genetically elite sires via artificial insemination (AI). Since the mid-twentieth century, AI combined with best linear unbiased prediction (BLUP) of breeding values has enabled rapid and sustained genetic improvement in dairy cattle populations across temperate nations, with contemporary dairy cows yielding more than twice the milk produced by their counterparts five decades ago—more than half of this enhancement being attributable to genetic selection (**Oltenacu and Broom, 2010; Karina et al**., **2025**). The success of these programs has stimulated widespread adoption of Holstein genetics in developing countries, including those in

Africa and the Middle East, where national dairy industries are under increasing pressure to meet growing domestic milk demand.

Egypt presents a paradigmatic case of rapid Holstein genetic upgrading under subtropical conditions. As one of Africa's most populous nations and largest dairy consumers, Egypt has progressively intensified its commercial dairy sector through successive rounds of AI with high-merit North American and European semen, resulting in herds comprising animals of progressively higher Holstein genetic fractions across multiple generations. However, the Egyptian production environment imposes substantial biotic and abiotic constraints on the expression of imported genetic potential. The temperature–humidity index (THI) routinely exceeds the bovine comfort threshold of 68 during summer months, suppressing luteinizing hormone pulsatility, impairing oocyte quality, reducing conception rates, and diminishing milk yield (**Altyeb et al**., **2025**). These thermally mediated constraints are compounded by endemic disease pressure, variable nutritional quality, and management systems that evolved under lower genetic merit conditions and have not uniformly adapted to the escalating metabolic demands of high-producing animals. The result is a profound gene-by-environment interaction that limits the realization of genetic gains and may generate unanticipated trade-offs between per-lactation performance and lifetime functional fitness.

The efficiency of the dairy farming system depends on re productive and productive performance of the herd **(Ayalew et al.**, **2018).** Reproductive and productive traits are the most important economic traits as sources of income for dairy farmers where high-producing and fertile cows are usually profitable **(Cervo et al.**, **2017).** Breeding and selection programs in dairy herds have focused on the improvement of fertility and milk production traits **(Potgieter et al.**, **2014).**

The Holstein breed's trajectory of intensive selection for milk yield has been accompanied by well-documented deterioration in several functional traits. The negative genetic correlation between milk production and reproductive efficiency is among the most consequential antagonisms in dairy cattle breeding: as genetic merit for yield increased, days open, services per conception, and calving interval lengthened, while conception rates declined (**Nasr et al**., **2021; Fahim et al**., **2025**). Concurrently, dairy cow longevity has generally decreased in high-producing populations, as selection pressure for yield has indirectly reduced resilience against the metabolic and health challenges associated with high milk output, particularly during the periparturient period (**Dallago et al**., **2021; Hu et al**., **2021**). These fitness costs are further amplified in tropical and subtropical environments, where the metabolic burden of heat stress adds to the already substantial energetic demand of lactation. Recognition of these antagonisms has driven the progressive integration of fertility (daughter pregnancy rate, DPR), productive life (PL), and health traits into composite selection indices in North American and European breeding programs since the mid-1990s **(García-Ruiz et al**., **2016**); however, the extent to which such improvements in selection philosophy have translated into phenotypic gains in herds operating under non-temperate conditions remains inadequately characterized.

Despite the magnitude and speed of Holstein genetic upgrading occurring across Egypt and the broader Middle East and North Africa (MENA) region, rigorous multi-generation analyses of its consequences for the full spectrum of productive, reproductive, health, and lifetime traits remain scarce in the peer-reviewed literature. Most published studies from the region have examined performance within single generations or across parity number rather than across generations defined by sire origin and genetic merit tier, and few have simultaneously assessed the lifetime productivity trade-offs that underpin the economic sustainability of upgrading programs. Understanding how successive generations of genetic improvement interact with local production environments to shape not only per-lactation output but also reproductive efficiency, health burden, and productive career length is essential for evidence-based decisions about sire selection strategy, management investment, and breed composition policy in Egyptian and analogous dairy systems **(Hammoud., 2013; Salem and Hammoud., 2016; Ramadan., 2018).**

The evaluation of dairy herds is important in studying dairy cattle management, because it influences profitability through milk production, reproductive performance, culling risks and animal sales. A regular evaluation of dairy herd performance is required to understand how it impacts on herd management, feeding policy and herd health.

The present study was therefore designed to evaluate the performance of Holstein dairy cows across five successive generations maintained under Egyptian subtropical conditions.

2. Material and Methods

All procedures involving animals were performed in compliance with the ethical standards of the Animal Care Committee at Damanhour University (Approval No: DUFA-2026-P15).

2.1. Data collection

The data of 8999 completed records for 2980 Holstein dairy cows were studied covering the period from 1996 to 2022 in El-Alamia farm which is belonging to Universal Company for Agricultural Development and Soil Reclamation and has a commercial dairy herd located at Nubaria region in the K 90 Alex - Cairo desert road. Animals were housed in open barns with shades. Animals were fed according to the NRC requirements and were housed freely in open partly shaded yards. Animals were machine-milked twice a day at 7 a.m. and 4 p.m. and milk yield was recorded weekly in a fixed test day.

2.2. Traits under study

The traits under study were Age at first calving (AFC, month), Days open (DO, day), Calving interval (CI, day), Gestation length (GL, day), Lactation length (LL, day), Total milk yield (TMY, kg), 305 day milk yield (305d-MY, kg), Days dry (DD, day), Mastitis number (MN, no), Lameness number (LN, no), Age at last calving (ALC, month), Life production age (LPA, month), Complete lactation number (CLN, no), Longevity length (Long., month) which is measured as the period in months from birth to culling date from the

herd, lifetime total milk yield (LTY, kg) which is calculated as the total milk a cow gives in her lifetime and Life daily milk yield (LDY, kg/d) which is calculated from dividing the lifetime total milk yield by the longevity length in days.

2.3. Data preparation and generation study

Abnormal records of cows which were affected by udder troubles or reproductive disorders were excluded. Also, milk production records for cows which produced milk for a period less than 100 days were excluded from the study. After excluded the abnormal records, the data was divided into five groups according to the generation number which were the parent (F1; the cows which established the herd, 2643 records of 625 cows) the 2nd generation (F2, 2591 records of 740 cows), the 3rd generation (F3, 1451 records of 470 cows), the 4th generation (F4, 1274 records of 508 cows) and the 5th generation (F5, 1040 records of 637 cows).

2.4. Statistical analysis

Data were analyzed by using linear mixed model least squares analysis with unequal subclass numbers using the PROC GLM procedure of SAS (SAS, 2015). Also, Duncan's multiple range tests was used for means comparison. The following model was used for analysis the effect of generation on all performance traits under study:

$$Y_{ij} = \mu + G_i + e_{ij}$$

Where:

Y_{ij} = an observation of each of the traits studied,

μ = the overall mean,

G_i = the effect of the i^{th} generation, j=(1–5) where 1 = F0 (Parents; the cows which established the herd), 2 = F1 (the first generation; daughter of F0) and 3 = F2 (the second generation; daughter of F1) and so on,

e_{ij} = the random error term associated with each observation (0, $\delta^2 e$).

3. Results

3.1. Reproductive Traits

3.1.1. Age at First Calving

According to the data presented in Table 1 for Holstein dairy cows, it was observed that generation had a highly significant effect on age at first calving. The results revealed that G1 recorded the lowest AFC (25.91 months), which differed significantly from all other generations. AFC increased progressively from G1 through G3, reaching 30.84 months in G3. G4 (30.66 months) did not differ significantly from any

adjacent generation, while G5 (30.12 months) was significantly lower than G3 but higher than G2 (29.55 months). G2 was significantly lower than G3 yet significantly higher than G1.

3.1.2. Days Open

For days open, the results indicated that there were significant differences among generations for this trait. We noticed that G1 had the shortest DO (198.31 days), which was significantly lower than G2 (222.85 days), G4 (222.56 days), and G5 (213.58 days), but did not differ significantly from G3 (209.46 days). Generations G2, G4, and G5 were statistically similar to one another, while G3 was intermediate and did not differ from G1 or from G2, G4, and G5.

3.1.3. Calving Interval

The effect of generation on calving interval (CI) was highly significant ($P < 0.001$). The results showed that G1 recorded the shortest CI (452.11 days), which was significantly lower than all remaining generations. G2 had the longest CI (503.51 days), significantly exceeding G3 (485.45 days), G4 (486.84 days), and G5 (476.39 days), which were statistically similar to one another.

3.1.4. Gestation Length

A consistent declining pattern was observed from G1 (278.38 days) to G5 (273.54 days) for gestation length (Table 1). The results indicated that G1 and G2 (277.61 days) did not differ significantly from each other, while G3 (276.70 days), G4 (275.65 days), and G5 each formed distinct groups separated by significant differences, with each successive generation recording a significantly shorter gestation than the preceding one.

3.2. Productive Traits

3.2.1. Lactation Length

The results obtained in Table 1 observed that generation had significantly influenced on lactation length. There was a general increasing trend across generations, G5 recording the longest LL (394.39 days) and G1 the shortest (359.61 days). G5 was significantly higher than G1, G2 (377.56 days), and G3 (369.21 days), but did not differ significantly from G4 (386.61 days). G4 was in turn significantly higher than G1 and G3 but not from G2. G2 and G3 were not significantly different from each other. G1 was the lowest and differed significantly from G2, G4, and G5 but not from G3.

3.2.2. Total Milk Yield

In Table 1, Total milk yield (TMY) was significantly affected by generation. The results showed a clear ascending pattern, with G5 recording the highest TMY (7970.41 kg) and G1 the lowest (6329.99 kg). G5 differed significantly from all other generations. G4 (7545.86 kg) was significantly higher than G1, G2 (6483.17 kg), and G3 (6920.69 kg) but significantly lower than G5. G3 was significantly higher than G1 and G2.

3.2.3. 305-Day Milk Yield

Significant differences were observed among generations for 305-day milk yield (Table 1). G5 recorded the highest 305d-MY (5846.80 kg), differing significantly from all other generations. G4 (5481.54 kg) was significantly lower than G5 but higher than G1, G2, and G3. G3 (5165.26 kg) was significantly higher than G1 (4844.03 kg) and G2 (4728.29 kg), which did not differ significantly from each other and represented the lowest values recorded across all generations.

3.2.4. Days Dry

The data in Table 1 showed the effect of generation on days dry (DD) was highly significant, the longest dry period was recorded in G1 (70.82 days) and G2 (71.71 days) and did not differ significantly from each other or from G3 (67.87 days). G4 (65.69 days) and G5 (63.97 days) recorded the shortest dry periods and were statistically similar to each other, while both were significantly lower than G1 and G2. G3 occupied an intermediate position and did not differ significantly from any other generation.

Table (1): Least squares means of reproductive and productive traits across five generations of Holstein dairy cows.

Trait	Generation					SEM	P-value
	G 1	G 2	G 3	G 4	G 5		
Age at First calving, mo	25.91^{d}	29.55^{c}	30.84^{a}	30.66	30.12^{b}	0.097	0.001
Days Open, d	198.31^{b}	222.85^{a}	209.46^{ab}	222.56^{a}	213.58^{a}	4.479	0.001
Calving interval, d	452.11^{c}	503.51^{a}	485.45^{b}	486.84^{b}	476.39^{b}	4.289	0.001
Gestation length, d	278.38^{a}	277.61^{ab}	276.70^{b}	275.65^{c}	273.54^{d}	0.300	0.001
Lactation Length, d	359.61^{d}	377.56^{cd}	369.21^{bc}	386.61^{ab}	394.39^{a}	4.826	0.001
Total milk yield, kg	6329.99^{d}	6483.17^{d}	6920.69^{c}	7545.86^{b}	7970.41^{a}	98.299	0.001
305d-Milk yield, kg	4844.03^{d}	4728.29^{d}	5165.26^{c}	5481.54^{b}	5846.80^{a}	64.691	0.001
Days dry, d	70.82^{a}	71.71^{a}	67.87^{ab}	65.69^{b}	63.97^{b}	1.198	0.001

3.3. Health Traits

3.3.1. Mastitis Number

The results in Table 2 showed that generation exerted a highly significant effect on mastitis number (MN). It showed a clear declining pattern across generations, with G1 recording the highest mastitis number (0.869) and G5 the lowest (0.004). G1 differed significantly from all subsequent generations. G2

(0.159) was significantly lower than G1 but did not differ significantly from G3 (0.083). G3 and G4 (0.029) were statistically comparable, while G4 and G5 were not significantly different from each other, with G5 being significantly lower than G1, G2, and G3.

3.3.2. Lameness Number

Significant differences among generations were detected for lameness number (LN, $P < 0.001$; Table 2). The results revealed that G2 (1.06) and G3 (1.00) recorded the highest lameness numbers and did not differ significantly from each other. Both were significantly higher than G1 (0.30), G4 (0.37), and G5 (0.10). G1 and G4 were statistically similar, while G5 recorded the lowest lameness number and differed significantly from all other generations except G4, from which it was also significantly different.

3.4. Lifetime Traits

3.4.1. Age at Last Calving

For age at last calving trait, the data in Table 2 observed that generation significantly affected age at last calving (ALC; $P < 0.001$). The results revealed a consistent declining pattern from G1 (73.32 months) to G5 (35.73 months). G1 and G2 (71.19 months) did not differ significantly and represented the oldest ages at last calving. G3 (62.42 months), G4 (49.52 months), and G5 each differed significantly from one another and from G1 and G2, with each successive generation recording a significantly lower ALC.

3.4.2. Life Production Age

Life production age (LPA) was significantly influenced by generation. A progressive and significant decline was observed from G1 (56.70 months) through G5 (16.71 months), the results indicated that all five generations differed significantly from one another. G1 recorded the longest productive life, while G5 had the shortest, with G2 (49.57 months), G3 (40.53 months), and G4 (29.13 months) occupying intermediate positions in descending order.

3.4.3. Complete Lactation Number

According to complete lactation number, the results showed that all five generations were significantly different from one another, with G1 recording the highest number (4.20 lactations) and G5 the lowest (1.63 lactations). G2 (3.50), G3 (3.09), and G4 (2.51) were each significantly different from adjacent generations, reflecting a consistent and progressive reduction in the number of complete lactations across successive generations.

3.4.4. Longevity

The data in Table 2 indicated that G1 (82.74 months) and G2 (79.31 months) had comparable longevity (L) and were significantly higher than all subsequent generations. G3 (71.28 months) was significantly lower than G1 and G2 but significantly higher than G4 (59.90 months) and G5 (46.82 months). G4 and G5 were each significantly different from all other generations, with G5 recording the shortest longevity overall.

3.4.5. Lifetime Milk Yield

Lifetime milk yield (LMY) was significantly affected by generation. G1 recorded the highest LMY (25,260 kg), which was significantly greater than all other generations. G2 (22,303 kg) was significantly lower than G1 but did not differ significantly from G3 (21,214 kg). G3 and G4 (19,177 kg) were statistically comparable, while G5 recorded the lowest LMY (13,178 kg), which was significantly lower than all other generations.

3.4.6. Lifetime Daily Milk Yield

In Table 2, significant differences among generations were detected for lifetime daily milk yield. G4 recorded the highest LDMY (10.67 kg/d), which was significantly greater than all other generations. G1 (10.18 kg/d) and G3 (9.92 kg/d) were statistically similar and significantly higher than G2 (9.37 kg/d) and G5 (9.38 kg/d), which did not differ from each other. This pattern suggests that daily milk output per cow was not consistently correlated with generation sequence when evaluated on a lifetime basis.

Table (2): Least squares means of health and lifetime traits across five generations of Holstein dairy cows.

Trait	Generation					SEM	P-value
	G 1	G 2	G 3	G 4	G 5		
Mastitis number, no	0.869^{a}	0.159^{b}	0.083^{bc}	0.029^{c}	0.004^{d}	0.026	0.001
Lameness number, no	0.30^{b}	1.06^{a}	1.00^{a}	0.37^{b}	0.10^{c}	0.055	0.001
Age at Last calving, mo.	73.32^{a}	71.19^{a}	62.42^{b}	49.52^{c}	35.73^{d}	1.414	0.001
Life production age, mo.	56.70^{a}	49.57^{b}	40.53^{c}	29.13^{d}	16.71^{e}	1.430	0.001
Complete lactation number, no	4.20^{a}	3.50^{b}	3.09^{c}	2.51^{d}	1.63^{e}	0.088	0.001
Longevity, mo.	82.74^{a}	79.31^{a}	71.28^{b}	59.90^{c}	46.82^{d}	1.429	0.001
Lifetime Milk yield, kg	25260^{a}	22303^{b}	21214^{bc}	19177^{c}	13178^{d}	712.462	0.001
Lifetime daily Milk yield, kg/d	10.18^{b}	9.37^{c}	9.92^{b}	10.67^{a}	9.38^{c}	0.349	0.001

4. Discussion

4.1. Reproductive Traits

The progressive increase in age at first calving (AFC) from G1 (25.91 months) to a peak in G3 (30.84 months), followed by modest stabilization in G4 and G5, reflects the cumulative interaction between escalating genetic merit for milk production and the nutritional and thermal limitations of the Egyptian subtropical environment. The G1 value aligns with the internationally recommended optimum of 23–24 months, which minimizes rearing costs while preserving first-lactation yield potential (**Ettema and Santos, 2004; Bene et al**., **2025**). The divergence from this optimum in subsequent generations is consistent with delayed puberty and impaired ovarian cyclicity in heifers experiencing heat stress and suboptimal plane of nutrition—conditions endemic to Egyptian dairy operations where the temperature–humidity index (THI) routinely exceeds the comfort threshold of 68 during summer months (**Altyeb et al**., **2025**). As genetic merit for milk production accumulated, the energetic demand of the peripubertal period likely intensified, rendering heifers increasingly vulnerable to these stressors. Importantly, AFC values in G3–G5 substantially exceeded the recommended threshold, highlighting the persistent challenge of deploying high-merit temperate genetics without commensurate investment in environmental amelioration.

The significant increase in days open (DO) from G1 (198.31 days) to G2 (222.85 days), with subsequent generations sustaining similarly elevated values, is mechanistically rooted in the deepening postpartum negative energy balance (NEB) that characterizes higher-yielding cows with insufficient nutritional support. Prolonged NEB suppresses hypothalamic GnRH pulsatility, delaying first postpartum ovulation and extending the interval to conception. **Nasr et al**. **(2021)** reported mean DO values of approximately 147.9 days for purebred Holsteins under subtropical conditions in Egypt—notably lower than the present study's values—suggesting that herd size, management intensity, and advancing genetic merit collectively compound the reproductive burden. The absence of further significant deterioration between G2, G4, and G5 implies that DO reached a management-limited ceiling beyond which technological interventions, rather than additional genetic change, are required. The generation-associated lengthening of calving interval (CI), peaking in G2 (503.51 days) before partial recovery in G3–G5 (476–487 days), closely parallels the DO pattern and reflects the same biological mechanism. The well-documented negative genetic correlation between milk production and reproductive efficiency (**Fahim et al**., **2025**) provides the theoretical framework for the G1-to-G2 deterioration, while the partial recovery in later generations is consistent with the progressive broadening of North American selection indices to include daughter pregnancy rate (DPR) from the early 2000s onward. The systematic and significant decline in gestation length from G1 (278.38 days) to G5 (273.54 days) reflects the genetic correlation between shorter gestation and higher milk production potential, a relationship documented by **Galluzzo et al**. **(2024)** in Italian Holsteins, who cautioned that selecting for extreme gestation length may have adverse downstream consequences for fertility and neonatal vitality.

4.2. Productive Traits

The generation-associated improvements in total milk yield (TMY: +26%, from 6,329.99 to 7,970.41 kg) and 305-day milk yield (305d-MY: +1,003 kg, from 4,844.03 to 5,846.80 kg) represent the most economically positive findings of this study and are consistent with the sustained positive genetic trends

for milk production documented in Holstein populations following the adoption of artificial insemination with genetically superior bulls and, more recently, genomic selection **(García-Ruiz et al**., **2016).** The non-significant difference between G1 and G2 for 305d-MY, followed by stepwise improvements in G3–G5, suggests that a critical threshold of nutritional support and management capacity was required before genetic gains could be phenotypically expressed—a pattern characteristic of gene-by-environment interaction in tropical dairy systems (**Vargas-Leitón et al**., **2024**). The magnitude of improvement across generations, while meaningful, is more modest than the annual gains of 100–150 kg typically reported in temperate Holstein populations, confirming that the Egyptian production environment substantially constrains the realization of imported genetic potential. The parallel extension of lactation length (G1: 359.61 days → G5: 394.39 days) and shortening of days dry (G1–G2: ~71 days → G4–G5: ~64–66 days) reflect improved mammary persistence and an adaptive management response to enhanced lactation curve quality in later generations, respectively.

4.3. Health Traits

The dramatic decline in mastitis number from G1 (0.869) to G5 (0.004), and in lameness from a G2–G3 peak (~ 1.00–1.06) to a G5 minimum (0.10), must be interpreted with considerable caution due to the confounding effect of survivorship bias. Later-generation cows completed substantially fewer lactations (G5: 1.63 vs. G1: 4.20), drastically reducing their cumulative exposure time to udder infection and locomotory challenges; raw health event counts per cow therefore underestimate disorder incidence in shorter-lived generations. Standardization of these data as incident rates per cow-year at risk would be essential before concluding genuine health improvement. That said, a contribution from genetic progress cannot be excluded: somatic cell score and productive life have been included in North American multi-trait selection indices for decades, providing consistent indirect selection pressure against mastitis susceptibility, and **Donnelly et al**. **(2023)** documented genetic selection for reduced health treatment cost should be possible by using producer-recorded health treatment records supplemented with treatment costs in commercial Holstein herds.

The non-monotonic lameness trajectory—peaking in G2–G3 and declining in G4–G5—likely reflects a transitional period in which the metabolic demands of increasing genetic merit outstripped local management capacity before adaptive improvements in nutrition, hoof trimming protocols, and housing progressively reduced lameness burden.

4.4. Lifetime Traits

The systematic declines in age at last calving (G1: 73.32 → G5: 35.73 months), life production age (G1: 56.70 → G5: 16.71 months), complete lactation number (G1: 4.20 → G5: 1.63), and longevity (G1: 82.74 → G5: 46.82 months) collectively define a population in which progressively higher per-lactation genetic merit is being realized at the cost of dramatically shortened productive careers. The G5 productive life of barely 16.71 months—at which point earlier generations were approaching peak lifetime productivity—signals an accelerating cycle of involuntary culling driven by the convergent failures of reproduction, health, and metabolic adaptation documented in this study. This trajectory is consistent with the review

by **Li et al**. **(2021)**, who emphasized that maximum per-cow profitability is realized at approximately the sixth lactation, a milestone approached only by G1 and G2 in the present population. **Hu et al**., **2021** further demonstrated that productive life decreases progressively when AFC exceeds 29 months—a threshold breached by G3–G5 in the present study, creating a self-reinforcing cycle of delayed first calving and compressed productive careers. The negative genetic correlation between productive life and milk yield, widely documented in Holstein populations (**Hu et al**., **2021; Fahim et al**., **2025**), provides the mechanistic underpinning for this antagonism, which is further amplified by the thermal and nutritional constraints of the Egyptian production environment.

The central paradox of the present dataset is most clearly expressed in the lifetime milk yield (LMY) data: despite a 26% increase in per-lactation TMY from G1 to G5, LMY declined by approximately 48% (25,260 → 13,178 kg), confirming that shortened productive careers have catastrophically eroded the cumulative productivity gains embedded in each successive generation's superior genetics. **Vargas-Leitón et al., (2024)** comparing purebred Holsteins with crossbred populations in the humid tropics, similarly found that purebred Holsteins achieved the highest per-lactation yields but suffered lower lifetime productivity—validating that this inverse relationship between per-lactation performance and lifetime output is a systemic feature of high-merit Holstein genetics under tropical production constraints rather than an anomaly specific to the present herd. The lifetime daily milk yield (LDMY) data offer a partial qualification: G4 recorded the highest LDMY (10.67 kg/d), suggesting it represented a transitional optimum in which genetic merit for production was sufficiently high to drive meaningful daily output while productive career length had not yet declined to the extreme levels observed in G5. The convergence of G5 and G2 LDMY values (9.38 vs. 9.37 kg/d), despite G5's markedly superior 305d-MY, powerfully illustrates that the efficiency of converting genetic potential into lifetime milk output had effectively stagnated—the yield gains of G5 being entirely consumed by its precipitously shorter herd life.

5. Conclusion

The findings of our study underscore the imperative of adopting holistic multi-trait selection strategies that balance production merit with functional fitness, and of investing in the environmental and nutritional infrastructure necessary to translate genetic potential of Holstein dairy cattle into sustained lifetime productivity.

Declarations

Ethical approval

This work was performed in accordance with the guidelines of the Animal Care and Use Committee of the Damanhour University

Conflict of interest

The authors declare that they have no conflict of interest.

Author contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by AE, AK, AA, DE, and AR. The first draft of the manuscript was written by AE, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability

All data generated or analysed during this study are included in this published paper.

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