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Linear type trait genetic trends in Irish Holstein-Friesian dairy animals

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Abstract

The objective of the present study was to investigate the genetic trends of 18 subjectively scored linear type traits describing animal morphology, as well as udder, teat, feet and leg conformation. The analysis was undertaken using 2,932,700 Holstein-Friesian females born in the Republic of Ireland between the years 2000 and 2020, inclusive. The results indicate that Holstein-Friesian females have progressively become shorter in stature as well as shallower (i.e. body depth) and less angular. The reduction in genetic merit for stature score since the year 2004 was, however, only observed in non-herdbook-registered heifers. Furthermore, the reducing score in body depth (i.e. narrower) and angularity (i.e. less angular) was approximately twice as fast in non-herdbook-registered heifers as it was in herdbook-registered heifers. Differences in the genetic merit of the body-related traits for calves born versus those that became cows only existed prior to 2010 with little biological differences thereafter; this observation was common across most of the linear type traits. Genetic merit for locomotion in non-herdbook-registered animals has deteriorated over the 20-yr period, while the foot angle over that period is becoming lower; no such trends were observed for the herdbook-registered animals. Large differences not only in the trends themselves, but also in the mean genetic merit for udder traits existed when comparing herdbook-registered calves versus non-registered calves. In conclusion, genetic merit for many of the traits evaluated has trended relatively consistent in a given direction, albeit the cumulative change in genetic s.d. units per traits over the 20-yr period was very small.

Keywords

Conformation • feet • mammary • morphology • teat

Introduction

Dairy cow breeding goals are constantly evolving, especially in recent decades (Miglior *et al*., 2005; Cole & VanRadan, 2018). The ideal cow in the modern era is therefore changing. Monitoring genetic trends, coupled with calculated expected responses to selection derived from selection index theory (Cameron, 1997), provides useful insights into the historical changes in the population as well as the future expected changes, respectively. While such trends and expected responses are routinely investigated for traits directly included in breeding goals (Heringstad *et al*., 2005; Berry *et al*., 2014; García-Ruiz *et al*., 2016), such exercises are not routine for traits not explicitly included in breeding goals. Linear type traits are one such suite of traits, since they are not directly part of the Irish national dairy cow breeding goal (Berry *et al*., 2007).

Linear type traits in dairy cows describe biological extremes. They are subjectively scored by trained professional assessors with the vast majority of assessments being undertaken in lactating first parity cows. In fact, only first parity linear type trait assessments are included in most national genetic evaluations (https://interbull.org/ib/geforms), including in Ireland (Berry *et al*., 2004). The traits assessed can generally be categorised into three main classes, namely those associated with body size, the mammary system (i.e. the udder and teats) and those associated with feet and leg conformation. One of the main initial motivations for such a scoring system was to act as early predictors of particularly (functional) longevity (Rogers *et al*., 1988; Rogers *et al*., 1989; Berry *et al*., 2005), fertility (Berry *et al*., 2004; Zink *et al*., 2011), lameness (Van Dorp *et al*., 1998; Ring *et al*., 2018) and udder ailments (Rogers *et al*., 1991; Van Dorp *et al*., 1998; Berry *et al*., 2004). This was in an era when the actual gold standard traits themselves (i.e. actual longevity, fertility, lameness, mastitis/somatic cell count) were not routinely recorded. As data on the gold standard traits accumulated, genetic evaluations based on these gold standards proliferated with the emphasis on the linear traits waning. So much so, that

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it is now unclear what, if any, emphasis producers directly place on animal conformation. This may, however, change with an ageing herd, the proliferation of automatic milking machines where udder conformation and teat characteristics are paramount, and in grazing animals having to walk longer distances as part of larger herds.

The objective of the present study was to describe how genetic merit for 18 different linear type traits in the Irish Holstein-Friesian population has changed over the past two decades; these traits reflect assessments of the overall morphology (e.g., size) of the animal as well as the conformation of the udder, teats, feet and legs. The objective was achieved by using the Irish national database to calculate the mean annual genetic merit of these traits for the Irish Holstein-Friesian population, which was also stratified into those animals registered or not with the Irish Holstein-Friesian Herdbook. Also of interest was whether the observed genetic trends differed between the heifer calves born versus those that eventually became cows.

Materials and methods

All data used in the present study originated from the Irish Cattle Breeding Federation (www.icbf.com), which manages the national database. The available data included ancestral information and estimates of genetic merit for the 18 linear type traits from the August 2021 Irish national genetic evaluation. Animals were stratified based on whether or not they were registered with the Irish Holstein-Friesian Herdbook.

Linear type traits

The genetic evaluation for linear type traits in Irish dairy cows is undertaken using a series of multi-trait models based on data from only primiparous cows. The 18 traits evaluated are given in Table 1, along with the genetic s.d. and heritability estimates used in the national evaluation. All data originate from only first parity cows assessed in the first 305 d of lactation. Differences between classifiers in their range of scoring are accounted for by pre-adjusting each of the type traits prior to the genetic evaluation by the ratio of the s.d. of the classifier to the mean of the s.d. calculated across classifiers for that trait in that year as outlined by Brotherstone (1994). Fixed effects included in the national genetic evaluation model are herd-date of scoring, age at scoring (quadratic effect), stage of lactation (quadratic effect) and calendar month of calving, as well as both the heterosis coefficient and recombination loss coefficient of the cow. Animal is included as a random effect in the model with relationships among animals accounted for via the

Table 1: Biological interpretation of the linear scores assessed along with the genetic s.d. (σ_g) and heritability (h^2) used in the national genetic evaluation plus the phenotypic mean and genetic s.d. of the base population (σ_{Base})

	Score		Genetic evaluation		Base	
Traits	**1**	**9**	σ_g	h^2	**Mean**	σ_{Base}
Stature	130 cm	154 cm	0.72	0.45	6.41	0.91
Chest width	Narrow	Wide	0.62	0.23	5.26	0.41
Body depth	Shallow	Deep	0.56	0.27	5.70	0.43
Angularity	Coarse	Sharp	0.59	0.28	5.95	0.72
Rump angle	High pins	Low pins	0.64	0.31	4.10	0.35
Rump width	Narrow	Wide	0.51	0.21	5.66	0.31
Body condition score	Thin	Fat	0.63	0.18	4.85	0.52
Fore udder attachment	Loose	Tight	0.54	0.17	5.66	0.44
Rear udder height	Very low	Very high	0.59	0.21	6.16	0.60
Udder support	Broken	Strong	0.39	0.11	6.02	0.38
Udder depth	Below hocks	Above hocks	0.63	0.30	5.81	0.39
Teat position, rear view	Wide	Close	0.70	0.26	4.26	0.49
Teat position, side view	Close	Apart	0.49	0.19	5.77	0.29
Rear teat placement	Outside of quarter	Crossing	0.61	0.21	5.94	0.42
Teat length	Short	Long	0.73	0.34	4.61	0.38
Rear leg, side view	Straight	Sickled	0.32	0.09	5.39	0.21
Foot angle	Low	Steep	0.34	0.09	5.00	0.19
Locomotion	Very lame	Even gait	0.27	0.07	5.94	0.15

numerator relationship matrix. Phenotypic records on 246,870 linear-classified cows are included in the national genetic evaluations. The base population used in the national genetic evaluation consists of 6,889 Holstein-Friesian sires born between the years 1994 and 2003, inclusive. The phenotypic mean of the daughters of these sires as well as the s.d. of the sire estimated breeding values (EBVs) for each trait are given in Table 1. Prior to use in the establishment of the genetic trends, the EBVs for each trait were individually rebased to the base population and rescaled to the population-wide genetic s.d. used in the national genetic evaluations (Table 1).

Genetic trends

The rebased and rescaled EBVs for all linear traits of all Holstein-Friesian heifer calves and separately Holstein-Friesian cows born in Irish dairy herds between the years 2000 and 2020 (only up to 2018 for cows), inclusive, were obtained. Only females with a known sire and dam were considered. Holstein-Friesian in the present study was defined as animals with a predicted Holstein-Friesian proportion of at least 82.5% based on recorded ancestry. Separate genetic trends were derived for heifer calves and cows. Differentiation between animals registered or not in the Irish Holstein-Friesian Herdbook was also made when calculating the genetic trends. The total number of Holstein-Friesian heifer calves and cows included in the trend analysis was 2,932,700 (1,272,756 registered and 1,659,944 non-registered) and 2,406,329 (1,202,187 registered and 1,204,142 non-registered), respectively. Simple linear regression was fitted through the various trends across different time periods to summarise the annual rate of genetic change across time.

Results

Body traits

The genetic trends for all seven body-related linear type traits by year of birth for all heifer calves irrespective of herdbook registration status are shown in Figure 1. Heifer calves are progressively becoming shorter in stature as well as shallower (i.e. body depth) and less angular; a simple linear regression fitted through each trait since the year 2004 indicates an

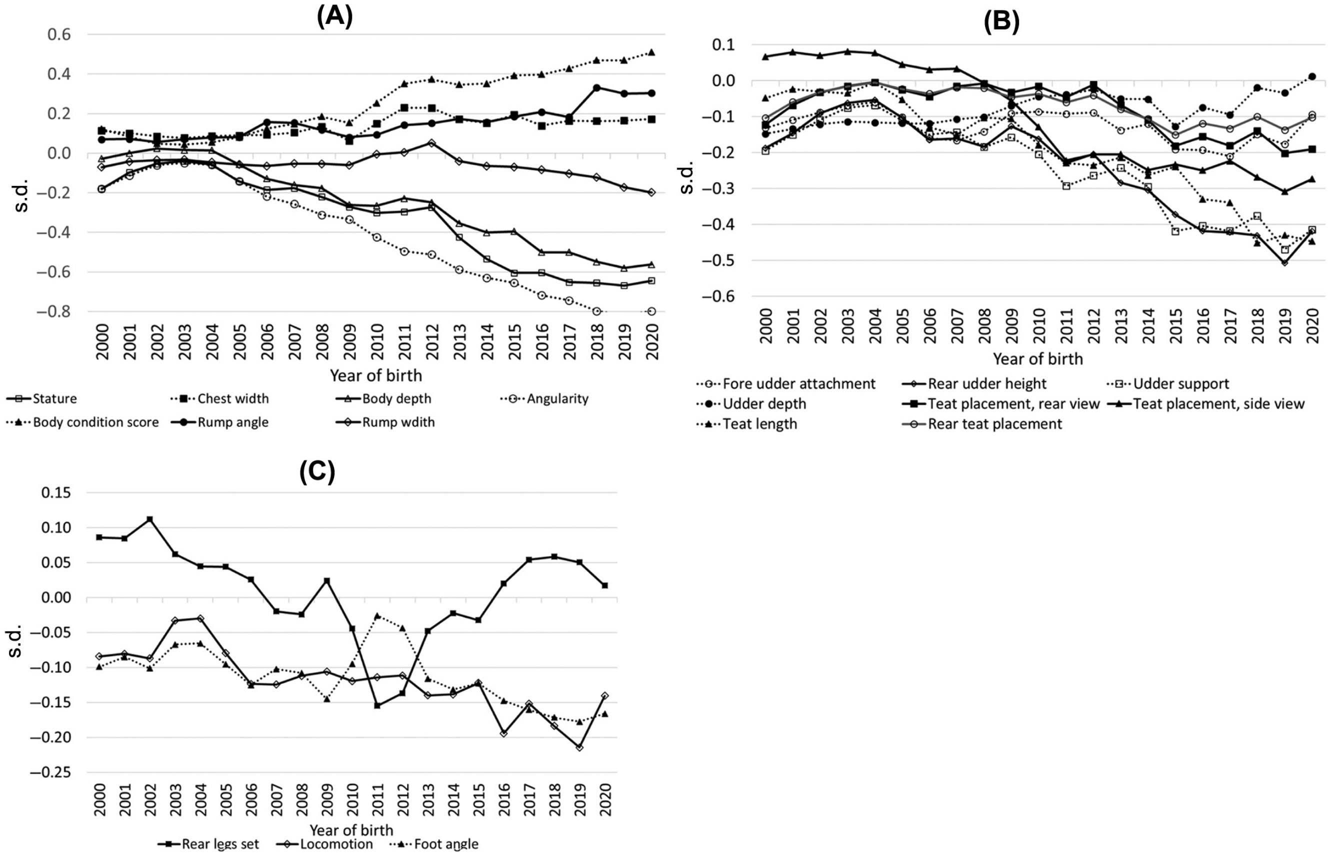

Figure 1. Mean annual estimated breeding value (in genetic s.d. units) for (A) body traits, (B) udder traits and (C) feet and legs by year of birth for heifer calves.

annual decline of 0.04 (s.e. = 0.003), 0.04 (s.e. = 0.002) and 0.05 (s.e. = 0.002) genetic s.d. units, respectively. This would equate to an average expected difference in phenotypic score between calves born in 2004 versus 2020 of 0.47 scores shorter in stature, 0.32 scores shallower body depth and 0.45 scores less angular on the 1–9 scale. The genetic s.d. for stature, body depth and angularity in the entire population is 0.72, 0.56, and 0.59 units, respectively. Although genetic trends for rump width remained relatively constant between the years 2000 and 2012, animal rumps got narrower by, on average, 0.03 (s.e. = 0.003) genetic s.d. units per annum since then. Chest width, rump angle and body condition score all increased (i.e. wider, lower pins, fatter) annually, on average, by 0.005 (s.e. = 0.001), 0.01 (s.e. = 0.001) and 0.02 (s.e. = 0.002) genetic s.d. units, respectively, over the 20-yr period of the study. Comparing calves born in 2000 versus 2020, the mean expected phenotypic score of the latter is expected to be, on average, 0.06 (wider), 0.15 (lower pins) and 0.31 (fatter) units greater on the 1–9 scale than those calves born in 2000 for chest width, rump angle and body condition score, respectively. This equates to 0.10, 0.23 and 0.50 genetic s.d. unit difference, respectively (Table 1).

Many of the genetic trends for the body-related traits differed depending on whether the heifer calf was herdbook-registered or not (Figure 2). Moreover, even if the genetic trends of the two sub-populations of animals were in a similar direction, a clear difference in the mean of the two sub-populations was evident for many of the traits (Figure 2). The reduction in genetic merit for stature since the year 2004 was only observed in non-registered heifer calves, while the reducing score in body depth (i.e. narrower) and angularity (i.e. less angular) was approximately twice as fast in non-registered heifer calves as it was in herdbook-registered heifer calves. The annual genetic trend in body condition score was similar irrespective of herdbook registration status of the calves (Figure 2). Relative to herdbook-registered calves, non-registered calves born in the year 2020 were 0.98 genetic s.d. units shorter on stature, while the corresponding values for body depth, angularity and rump width were 0.40 (shallower), 0.68 (less angular) and 0.48 (narrower) genetic s.d. units,

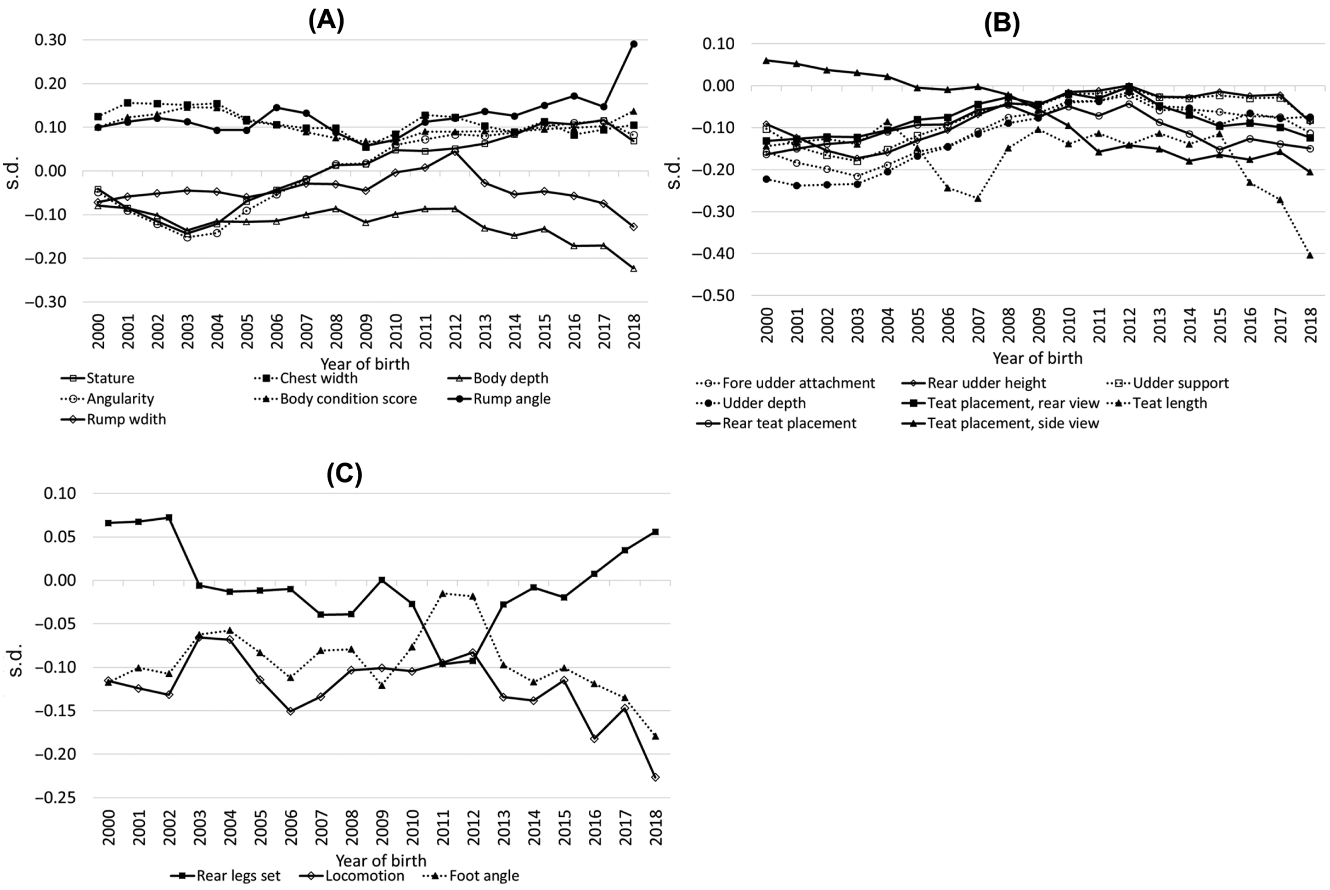

Figure 2. Mean annual estimated breeding value (in genetic s.d. units) for (A) body traits, (B) udder traits and (C) feet and legs by year of birth for cows minus the respective annual means for the heifer calves born.

respectively. Relative to herdbook-registered calves born in the year 2020, their non-registered contemporaries were, on average, 0.08, 0.10 and 0.25 genetic s.d. units wider, lower pins and fatter, respectively.

Differences in the mean annual genetic merit of the body-related traits for calves versus cows by year of birth only existed prior to 2010 with little biological differences thereafter (Figure 3). Prior to the year 2010, relative to the mean genetic trend for heifer calves, the mean genetic trend for cows represented shorter stature, shallower, less angular animals who also were, on average, of greater body condition with wider chests and lower pins; no difference in rump width existed between the heifers born versus those that eventually calved (Figure 3).

Udder-related traits

Within the entire population, genetic merit for both rear udder height and udder support in heifer calves has reduced since 2004, implying a lower rear udder height and weakening udder support over time (Figure 1). A simple linear regression fitted through the annual mean genetic merit of both traits from the year 2004 to 2020 revealed an annual decline of 0.026 (s.e. = 0.002) and 0.024 (s.e. = 0.002) genetic s.d. units, respectively. This translates to an expected genetic (and phenotypic) difference, on the 1–9 scale, of 0.25 and 0.15 scores between calves born in 2004 versus those born in 2020. Genetic merit for fore udder attachment did not change much by year of birth, but there was a tendency for udder depth score to increase (i.e. more above the hocks) over time. A simple linear regression fitted through the annual trends from 2000 to 2020 indicated an annual increase of 0.01 (s.e. = 0.001) genetic s.d. units; the proportion of variance explained by the simple linear regression was just 0.59, reflecting the somewhat erratic nature of the trend.

Clear differences in the genetic trends for the udder traits were obvious depending on whether the calves were

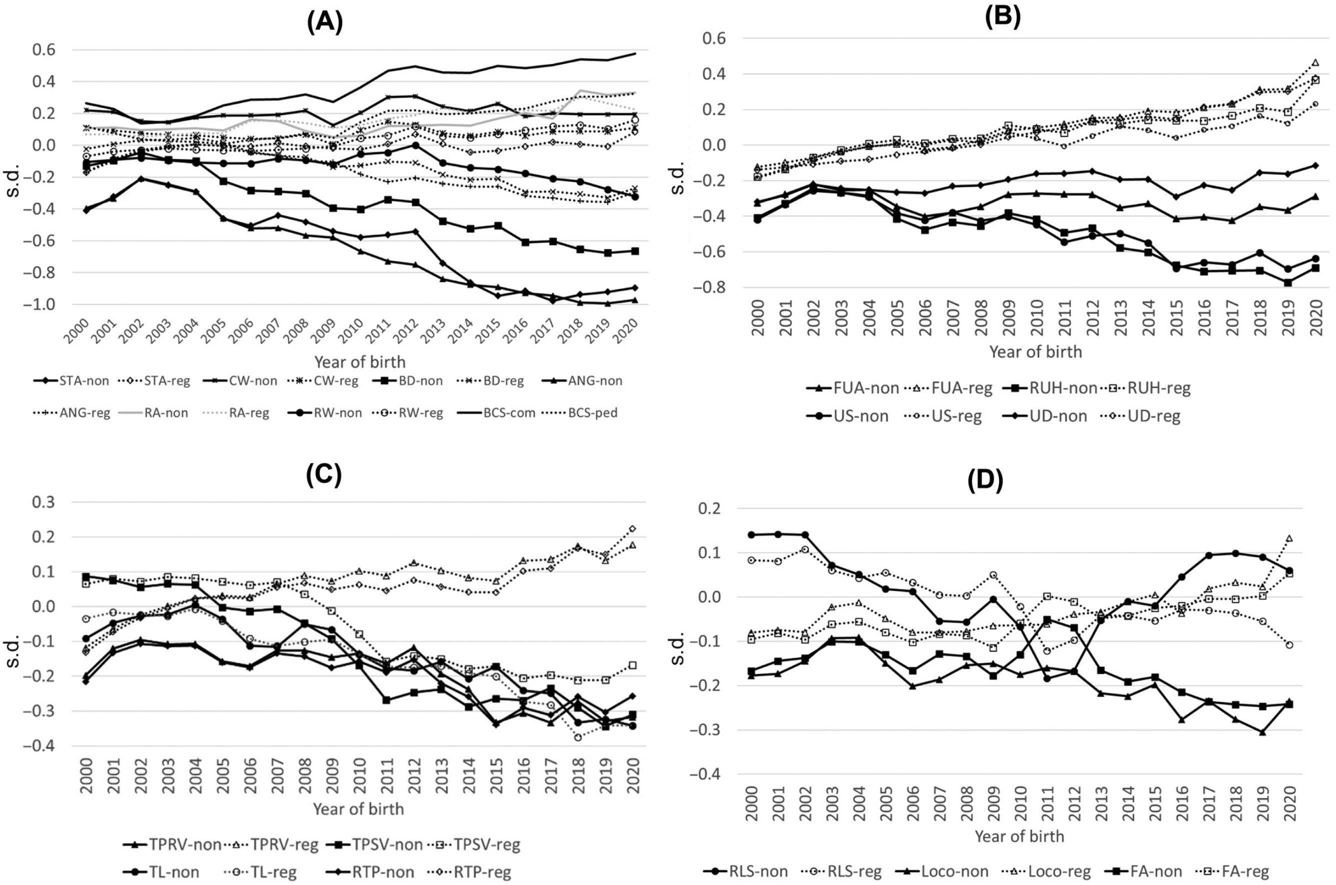

Figure 3. Mean annual estimated breeding value (in genetic s.d. units) for (A) body traits, (B) udder traits, (C) teat traits and (D) feet and leg traits by year of birth for heifer calves differentiated as either registered (-reg) or not (-non) with the Irish Holstein-Friesian Herdbook. STA = stature, CW = chest width, BD = body depth, ANG = angularity, RA = rump angle, RM = rump width, BCS = body condition score, FUA = fore udder attachment, RUH = rear udder height, US = udder support, UD = udder depth, TPRV = teat placement, rear view, TPSV = teat placement, side view, TL = teat length, RTP = rear teat placement, RLS = rear legs set, Loco = locomotion, FA = foot angle.

herdbook-registered or not (Figure 2). Genetic merit for fore udder attachment got tighter, udder support got stronger, rear udder height became higher and udder depth became shallower over time in herdbook-registered calves. In fact, the mean difference in genetic merit between herdbook-registered calves versus non-registered calves born in 2020 was 0.75, 0.87, 1.06 and 0.49 genetic s.d. units for fore udder attachment, udder support, rear udder height and udder depth, respectively. Differences in mean genetic merit of calves born versus those that calved by year of birth were evident between 2000 and 2010 (Figure 3); the difference was minimal thereafter (Figure 3).

Teat-related traits

Teat placement (side view) score of heifer calves born has almost consistently reduced (i.e. teats got closer) year-on-year over the 20-yr period from 2000 to 2020 with a difference in score between these two birth years of 0.22 genetic s.d. units (Figure 1). Similarly, teat length has almost always shortened year-on-year since 2004; a simple linear regression fitted through the annual means of genetic merit for teat length since 2004 reveals an annual shortening of 0.03 (s.e. = 0.002) genetic s.d. units, equating to a difference of 0.41 genetic s.d. units between 2004 and 2020. Teat placement from a rear view has widened and the rear teats themselves have become positioned more outside the quarter from approximately 2007 until 2015, but this trend has remained relatively stable since then (Figure 1).

Trends in mean calf genetic merit were relatively similar irrespective of herdbook registration status for teat placement side view and teat length, but the score for both teat placement rear view and rear teat placement has increased (i.e. closer and crossing) over time in herdbook-registered calves (Figure 2). While differences in mean genetic merit for the teat traits of calves born versus those that eventually calved by year of birth were evident between 2000 and 2010, differences were minimal thereafter (Figure 3). The exception was teat length where the teats of the calves that did not eventually calve were longer than those that did.

Feet and leg traits

Based on a simple linear regression fitted through the annual mean genetic trends (Figure 1), genetic merit for locomotion score has dis-improved by an annual rate of 0.01 (s.e. = 0.001) genetic s.d. units in Holstein-Friesian heifer calves born from the year 2000 to 2020. Genetic merit for foot angle has also reduced (i.e. lower foot angle), on average, by 0.004 (s.e. = 0.001) genetic s.d. units per year between the years 2000 and 2020. While rear legs set score reduced (i.e. straighter) between the years 2000 and 2011, the trend has been more towards sickled legs thereafter (Figure 1). The observed reduction in genetic merit for locomotion and foot angle score was restricted to non-registered heifer calves with no obvious trend over the past 20 yr in herdbook-registered heifer calves. In fact, herdbook-registered heifer calves born in the year 2020 were 0.37 and 0.30 genetic s.d. units greater, respectively, than their non-registered contemporaries born in the same year (Figure 2). Little difference existed across time in the mean annual genetic merit for feet and leg traits of the calves born versus those that eventually became cows (Figure 3).

Discussion

Monitoring the impact of artificial selection on animal characteristics is paramount to sustainable breeding programmes. While documentation of the impact of dairy cow breeding programmes on performance metrics such as milk production (García-Ruiz *et al*., 2016), fertility (Berry *et al*., 2014; García-Ruiz *et al*., 2016) and health (Heringstad *et al*., 2005) exists, less is known on how the morphological attributes of animals, including the structure of the mammary system, has changed over time. Selection index theory can be used to predict the responses to selection for a whole series of traits, once the covariances with the goal traits are known. Deficiencies, nonetheless, exist for such a strategy. For example, the selection index theory assumes that the covariances used in the calculations are known without error for the population under investigation, but also that the relationships among traits are linear across the trajectories. Similarly, it is assumed that producers select animals blindly based on the overall breeding goal with no secondary selection applied. Genetic evaluations for linear type traits are routinely published in most jurisdictions motivated by a desire to provide information to breeders and producers wanting to apply selection pressure on these traits if so desired. Hence, monitoring actual genetic trends is particularly useful for such traits that are not explicitly included in some breeding goals (including Ireland) but where (secondary) selection pressure may be applied by some producers. Clear genetic trends in many of the 18 traits examined in the present study were evident, although the actual change in genetic s.d. units over the 20-yr period was often not very large. In the past two decades, Irish cows not registered in the Irish Holstein-Friesian Herdbook got smaller, narrower and less angular whilst retaining greater body fat reserves at the expense of deteriorating locomotion. While these trends are based on genetic merit, many of the traits are moderately heritable (Table 1), implying that the calculated genetic trends are likely to also be reflected in the phenotypic trends.

The correlations between proven sires' merit on the Irish national dairy cow breeding index, the Economic Breeding Index (EBI; Berry *et al*., 2007) and the predicted transmitting ability of the 18 type traits investigated in the present study are given in Table 2. These correlations were based on 388 Holstein artificially inseminated (AI) sires, born since the year 2000, with phenotypic type trait information for daughters producing in Ireland. The correlations between EBI with stature, body depth and angularity were between −0.58 and −0.44 with a positive correlation of 0.43 between EBI and body condition score. Therefore, the observed trends in linear type traits are not surprising given the correlations that exist between the Irish national breeding goal and the different type traits (Table 2). These correlations are expected to manifest themselves in non-registered cattle more so than in herdbook-registered cattle, where a greater emphasis may be placed on attempting to achieve a higher overall conformation score; this was indeed the case for most traits investigated in the present study. As producers strive to improve the EBI of their herd in the pursuit of greater profit (Ring *et al*., 2021), then an indirect (correlated) reduction in stature, body depth and angularity is expected, as is an increase in body condition score. The same is true for justifying the genetic change in most of the other type traits in non-registered animals. The main exception was udder depth where a negative correlation of −0.22 existed between EBI and predicted transmitting ability for udder depth in AI sires, but where a slow positive (P = 0.04) genetic trend (i.e. towards udders that are more above the hocks) was observed in both registered and non-registered animals. This suggests either genetic drift or that conscious selection towards higher udder depth scores is practiced by sire analysts when identifying candidate bull dams or indeed sires of sires. The rationale for any conscious selection is not clear as udder depth in Irish Holstein-Friesian dairy cows is not genetically correlated with either milk production or somatic cell count, with inconsistent genetic correlations estimated with reproductive performance depending on the reproductive trait being considered (Berry *et al*., 2004).

Table 2: Correlations between the Irish national breeding index, the Economic Breeding Index (EBI) and predicted transmitting ability of the linear type traits from 388 Holstein AI sires with scored daughters in Ireland

Trait	Correlation
Stature	−0.44
Chest width	0.19
Body depth	−0.49
Angularity	−0.58
Rump angle	0.14
Rump width	−0.35
Body condition score	0.43
Fore udder	−0.34
Rear udder height	−0.38
Udder support	−0.39
Udder depth	−0.22
Teat placement rear view	−0.25
Teat placement, side view	−0.26
Rear teat placement	−0.25
Teat length	−0.18
Rear leg set	0.02
Foot angle	−0.16
Locomotion	−0.20

AI = artificially inseminated.

Conclusions from the observed genetic trends in the present study may not, however, be reflected in many other dairy cow populations where both the production system and the associated breeding goals may differ. The major component of the diet of the average Irish dairy cow is *in situ* grazed pasture with the goal of producers (and thus their breeding policy) being to convert as much grazed pasture into milk solids as possible. Individual cow milk yields are not very high as the plane of nutrition from grazed grass is often below that of total mixed ration (TMR), especially in the middle to latter half of the season. While many Irish dairy cows do not stand on concrete for an excessive period of time during the majority of the year, they are often expected to walk long distances from the paddock to the milking parlour twice daily. Moreover, given the high reproductive efficiency sought by Irish dairy farmers, Irish dairy cows produce for many lactations (Ring *et al*., 2021). Hence, while functionality and efficiency in Irish dairy cows is important, the animal-level characteristics contributing to functionality and efficiency in pasture-based production systems may differ to those from confinement production systems.

The genetic trends reported in the present study are on a per genetic s.d. unit basis enabling the genetic change to be compared across traits; the actual units on the 1–9 scale represented by an s.d. are given in Table 1. Although the range in possible linear scores varies from 1 to 9, the extremities of the scale are rarely used and thus the cumulative genetic trends over time should take this into consideration. For example, of all the 18 linear type traits, the proportion of the phenotypic data that were within a 6-score window varied from 0.88 (teat placement rear view) to 0.98 (rear legs set) with the average being 0.95. In fact, on average 0.88 and 0.82 of all scores were within just a 5-score and a 4-score window, respectively. Therefore, the genetic s.d. (or phenotypic s.d. calculated from Table 1 as $\sqrt{\frac{\sigma_a^2}{h^2}}$) is a more appropriate statistic to compare the cumulative trend against the population-wide variability. For example, the reduction in stature score of the heifer calves between 2004 and 2020 equated to 0.65 genetic s.d. units; the respective value for the reduction in angularity was 0.77 genetic s.d. units.

Herdbook registration status

Herdbook registration was traditionally reserved for producers with a strong interest in the conformation of their animals. In Ireland, however, greater financial compensation is received if a herd of herdbook-registered animals is depopulated due to, for example, a bovine tuberculosis outbreak. Therefore, large differences in the conformation of animals depending on whether or not they were herdbook-registered was not necessarily expected, although a subset of the producers who herdbook-register their animals would still have a keen interest in animal conformation. This was largely born out in the genetic trends in the present study. In 2000, herdbook-registered heifer calves born were taller, narrower, deeper, more angular with less condition and with higher pins and wider rumps. The same was true in 2020, albeit the differences were larger for many traits; for example, herdbook-registered heifer calves born in 2020 were 0.98 genetic s.d. units taller and 0.68 genetic s.d. units more angular than their non-registered heifer contemporaries born in the same year. This suggests greater selection pressure on both traits in herdbook-registered animals and could be a function of greater selection intensity for milk yield in some of these herds; greater milk yield is genetically correlated with both taller (genetic correlation of 0.21 to 0.42 – De Groot *et al*., 2002; Berry *et al*., 2004) and more angular (genetic correlation of 0.48 to 0.91 – De Groot *et al*., 2002; Berry *et al*., 2004) Holstein cows. Such a hypothesis is also substantiated when comparing the udder conformation traits of heifer calves differing in herdbook registration status. Udder conformation is particularly important for many breeders as it constitutes a large proportion of the overall conformation score assigned to an animal (De Groot *et al*., 2002). On a genetic s.d. unit basis, herdbook-registered heifers born in 2020 had a 0.75, 1.06, 0.87 and 0.49 unit higher score for fore udder attachment (i.e. tighter), rear udder height (i.e. higher), udder support (i.e. stronger) and udder depth (i.e. above hocks) than their non-registered heifer contemporaries. Fore udder attachment, rear udder height and udder support are positively genetically correlated (0.32–0.48; Berry *et al*., 2004) with milk yield in Irish Holstein cows while the genetic correlation between milk yield and udder depth is −0.05 (Berry *et al*., 2004).

Calves versus cows genetic trends

Little difference was evident post-2010 between the mean genetic merit for linear scores of heifer calves versus those that became cows. This is most likely due to the expansion of the Irish dairy herd post-2010 in anticipation of the abolishment of the European Union (EU) milk quotas (in 2015) operational in Ireland. This resulted in an increase in milk output nationally post-2010 following at least two decades of stagnation (https://data.cso.ie/). When piecewise linear regression was fitted through the annual trends of the difference between the calf and cow means for a given linear trait, the breakpoint for all the body-related traits was between 2008.6 and 2008.9 with the exception of rump width, which was 2011.9. The opportunity for voluntarily not retaining certain heifers as graduates to the mature herd was eroded nationally in the period flanking the abolishment of milk quotas in light of a massive demand for replacement heifers. Hence, the scope to direct for slaughter, heifers with less desirable conformation was less post-2010, which would have contributed to the small difference observed between heifer calves born versus those that calved in this period. In the future, however, should restrictions on herd expansion be enforced due to, for example, environmental constraints or limited land availability, the differences in (genetic merit for the) body- and udder-related traits between heifer calves born versus those that calved may develop. Assuming the observed differences in genetic merit of the calves and cows pre-2010 were due to preferential selection, the producers did favour shorter stature, wider and shallower cows that were less angular and better conditioned; the favoured cows also had looser, lower udders below the hock with weaker support and shorter teats.

Implications

Monitoring genetic trends is useful to predict the characteristics of the cow of the future, should past trends continue into the future. From the perspective of linear type traits, the size or conformation of the future animal is of interest. Trends in a given direction may not necessarily be deleterious and should be interpreted within the context of both the mean of the population and the profit expected for a given conformation type. It should also be noted that several of the linear type traits may be deemed to have intermediate optima (e.g. foot angle, teat placements and length). Therefore, the sign of the genetic trend should take cognisance of the mean of the population as a whole. This is particularly important when comparing non-registered and registered animals where differences in the population mean were obvious. For some traits, differences in opinion may exist on the optimum score depending on the farm system as was evident when comparing non-registered animals versus registered animals. For example, smaller cows are, on average, expected to be more efficient (Berry & McCarthy, 2021), which is a likely contributing factor to a reduction in stature in non-registered animals, a trend not observed in herdbook-registered animals.

Some of the observed trends in the present study may indeed be interpreted to be favourable. One such trend is that for body condition score which is increasing both in the registered and non-registered populations. Body condition score is well accepted to be both genetically (Pryce *et al*., 1998; Berry *et al*., 2003) and phenotypically (Roche *et al*., 2009) related to improved health and fertility in dairy cows. The genetic correlation between body condition score and angularity is −0.84 to −0.77 (Veerkamp & Brotherstone, 1997; Berry *et al*., 2004), which is why the genetic trend for angularity is declining. Nonetheless, some of the genetic trends may be cause for concern, especially those related to udder conformation or teat characteristics. Extreme conformation or characteristics (e.g. very short teats) may be undesirable and may have unfavourable repercussions if genetic trends continue. Poor teat placement may impact suitability for automatic milking systems because of the requirement by the milking machine to rapidly and accurately be able to locate and attach to the teats. Nonetheless, the actual difference in mean EBV for each of the four teat traits between the years 2000 and 2020 was just 0.07 and 0.001 genetic s.d. units for teat placement rear view and rear teat placement, respectively, while the difference for teat placement side view and teat length over that 20-yr period was 0.34 and 0.40 genetic s.d. units, respectively. Using the phenotypic mean of the base population, this equates to an expected phenotypic score on the 1–9 scale of 5.62 and 4.32 for teat placement side view and teat length, respectively. Both scores are therefore still near the centrepoint of the 1–9 scale. While many conformation traits have not been demonstrated to (strongly) associate with longevity (Rogers *et al*., 1989; Boldman *et al*., 1992; Setati *et al*., 2004), such potential associations may only materialise in very old cows (Williams *et al*., 2022). The optimal culling rate in dairy cows is thought to be 18%, which translates to an expected average age at culling of 5.6 lactations (i.e. 1/0.18). To realise such a target requires some cows to achieve potentially 10 or more lactations prior to culling to compensate for the cows which inevitably are culled in first or second parity. Reproductive performance is improving in many dairy cow populations (Berry *et al*., 2014; García-Ruiz *et al*., 2016) contributing to this greater longevity. The cumulative effect of stresses over time (i.e. walking distances over time) coupled with the progressive and generalised loss of muscle mass and strength as individuals age (i.e. sarcopenia; Santilli *et al*., 2014; Costagliola *et al*., 2016) implies that traits particularly associated with locomotive ability and udder support may become more important contributors to culling decisions in older cows (Williams *et al*., 2022). This needs to be considered when evaluating the characteristics of the cow of the future and whether such characteristics will be realised if past trends persist.

Conclusions

Trends in genetic merit for many of the 18 linear type traits do exist across the 20-yr period from 2000 to 2020 in Irish Holstein-Friesian animals, albeit most differ depending on if the animal is registered with the breed society or not. For most traits, however, the difference in genetic s.d. units between heifer calves born in 2000 versus those born in 2020 was relatively small. Only stature, body depth and angularity differed by more than 0.40 genetic s.d. units between 2000 and 2020 with animals becoming shorter, shallower and less angular. While some traits like locomotion deteriorated over the time period of the study, the cumulative change in genetic merit between heifer calves born in 2000 versus those born in 2020 was only 0.12 genetic s.d. units less.

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References

Berry, D.P., Harris, B.L., Winkelman, A.M. and Montgomerie, W. 2005. Phenotypic associations between traits other than production and longevity in New Zealand dairy cattle. *Journal of Dairy Science* **88**: 2962–2974.

Berry, D.P., Wall, E. and Pryce, J.E. 2014. Genetics and genomic of reproductive performances in dairy and beef cattle. *Animal* **8**: 105–121.

Berry, D.P., Buckley, F., Dillon, P., Evans, R.D., Rath, M. and Veerkamp, R.F. 2003. Genetic relationships among body condition score, body weight, milk yield, and fertility in dairy cows. *Journal of Dairy Science* **86**: 2193–2204.

Berry, D.P., Buckley, F., Dillon, P.G., Evans, R.D. and Veerkamp, R.F. 2004. Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows. *Irish Journal of Agriculture and Food Research* **43**: 161–176.

Berry, D.P. and McCarthy, J. 2021. Contribution of genetic variability to phenotypic differences in on-farm efficiency metrics of dairy cows based on body weight and milk solids yield. *Journal of Dairy Science*. **104**: 12693–12702.

Berry, D.P., Shalloo, L., Cromie, A.R., Veerkamp, R.F., Dillion, P., Amer, P.R., Kearney, J.F., Evans, R.D. and Wickham, B. 2007. The economic breeding index: a generation on. Irish Cattle Breeding Federation. Available online: https://www.icbf.com/wp/wp-content/uploads/2013/06/economic breeding index.pdf. [Accessed 18 November 2020].

Boldman, K.G., Freeman, A.E., Harris, B.L. and Kuck, A.L. 1992. Prediction of sire transmitting abilities for herd life from transmitting abilities for linear type traits. *Journal of Dairy Science* **75**: 552–563.

Brotherstone, S. 1994. Genetic and phenotypic correlations between linear type traits and production traits in Holstein-Friesian dairy cattle. *Animal Science* **59**: 183–187.

Cameron, N. 1997. Selection Indices and Prediction of Genetic Merit in Animal Breeding, CABI, UK.

Cole, J.B. and VanRaden, P.M. 2018. Possibilities in an age of genomics: the future of selection indices. *Journal of Dairy Science* **101**: 3686–3701.

Costagliola, A., Wojcik, S., Pagano, T.B., De Biase, D., Russo, V., Iovane, V., Grieco, E., Papparella, S. and Paciello, O. 2016. Age-related changes in skeletal muscle of cattle. *Veterinary Pathology* **53**: 436–446.

DeGroot, B.J., Keown, J.F., Van Vleck, L.D. and Marotz, E.L. 2002. Genetic parameters and responses of linear type, yield traits, and somatic cell scores to divergent selection for predicted transmitting ability for type in Holsteins. *Journal of Dairy Science* **85**: 1578–1585.

García-Ruiz, A., Cole, J.B., VanRaden, P.M., Wiggans, G.R., Ruiz-López, F.J. and Van Tassell, C.P. 2016. Changes in genetic selection differentials and generation intervals in US Holstein dairy cattle as a result of genomic selection. *Proceedings of the National Academy of Science* **113**: E3995–E4004.

Heringstad, B., Chang, Y.M., Gianola, D. and Klemetsdal, G. 2005. Genetic analysis of clinical mastitis, milk fever, ketosis, and retained placenta in three lactations of Norwegian red cows. *Journal of Dairy Science* **88**: 3273–3281.

Miglior, F., Muir, B.L. and Van Doormaal, B.J. 2005. Selection indices in Holstein cattle of various countries. *Journal of Dairy Science* **88**: 1255–1263.

Pryce, J.E., Esslemont, R.J., Thompson, R., Veerkamp, R.F., Kossaibati, M.A. and Simm, G. 1998. Estimation of genetic parameters using health, fertility and production data from a management recording system for dairy cattle. *Animal Science* **66**: 577–584.

Ring, S.C., Twomey, A.J., Byrne, N., Kelleher, M.M., Pabiou, T., Doherty, M.L. and Berry, D.P. 2018. Genetic selection for hoof health traits and cow mobility scores can accelerate the rate of genetic gain in producer scored lameness in dairy cows. *Journal of Dairy Science* **101**: 10034–10047.

Ring, S.C., Evans, R.D., Cromie, A.R. and Berry, D.P. 2021. Cross-sectional analyses of a national database to determine if superior genetic merit translates to superior dairy cow performance. *Journal of Dairy Science* **104**: 8076–8093.

Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford, K.J. and Berry, D.P. 2009. Body condition score and its association with dairy cow productivity, health, and welfare. *Journal of Dairy Science* **92**: 5769–5801.

Rogers, G.W., Hargrove, G.L., Lawlor, T.J. and Ebersole, J.L. 1991. Correlations among linear type traits and somatic cell counts. *Journal of Dairy Science* **74**: 1087–1091.

Rogers, G.W., McDaniel, B.T., Dentine, M.R. and Johnson, L.P. 1988. Relationships among survival rates, predicted differences for yield, and linear type traits. *Journal of Dairy Science* **71**: 214–222.

Rogers, G.W., McDaniel, B.T., Dentine, M.R. and Funk, D.A. 1989. Genetic correlations between survival and linear type traits measured in first lactation. *Journal of Dairy Science* **72**: 523–527.

Santilli, V., Bernetti, A., Mangone, M. and Paoloni, M. 2014. Clinical definition of sarcopenia. *Clinical Cases of Miner Bone Metabolites* **11**: 177–180.

Setati, M.M., Norris, D., Banga, C.B. and Benyi, K. 2004. Relationships between longevity and linear type traits in Holstein cattle population of Southern Africa. *Tropical Animal Health and Production* **36**: 807–814.

Van Dorp, T.E., Dekkers, J.C.M., Martin, S.W. and Noordhuizen, J.P.T.M. 1998. Genetic parameters of health disorders, and relationships with 305-day milk yield and conformation traits of registered Holstein cows. *Journal of Dairy Science* **81**: 2264–2270.

Veerkamp, R.F. and Brotherstone, S. 1997. Genetic correlations between linear type traits, food intake, live weight and condition score in Holstein Friesian dairy cattle. *Animal Science* **64**: 385–392.

Williams, M., Sleator, R.D., Murphy, C.P., McCarthy, J. and Berry, D.P. 2022. Re-assessing the importance of linear type traits in predicting genetic merit for survival in an aging Holstein-Friesian dairy cow population. *Journal of Dairy Science* **105**: 7550–7563.

Zink, V., Štípková, M. and Lassen, J. 2011. Genetic parameters for female fertility, locomotion, body condition score, and linear type traits in Czech Holstein cattle. *Journal of Dairy Science* **94**: 5176–5182.