Sveriges lantbruksuniversitet
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Genetic Correlations among Longevity, Claw and Leg Health Evaluated in the Nordic Countries and Type Traits Evaluated in USA, in Holstein Dairy Cattle

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Genetiska korrelationer mellan livslängd, ben- och klövhälsa skattade i de nordiska länderna och exteriöregenskaper skattade i USA, för rasen Holstein

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Abstract

The Holstein breed is known for its high milk yield and this has been achieved partially by genetic selection for yield. As a consequence, functional traits have deteriorated. Claw and leg disorders are common reasons for involuntary culling: 8.4% to 8.9% of the Swedish Holstein dairy cattle were culled because of claw and leg problems during 2011 to 2014 and a Swedish dairy cow is productive on average 2.5 lactations. In 2011, a claw health index was included in the selection index of the Nordic countries (Sweden, Denmark and Finland), the Nordic Total Merit index (NTM), to improve claw and leg health and thereby also longevity. Since bulls from USA lack the information about claw disorders, would it be possible to use type traits as indirect traits for improving claw and leg health traits through breeding?

The aim of this study was to investigate if type traits estimated in USA could be used to select for improved claw and leg health and longevity in Holstein cattle in the Nordic countries. Genetic correlations have been estimated between, on one hand, estimated breeding values (EBVs) for type traits estimated in USA, with), on the other hand, EBVs for longevity, claw and leg health obtained from Nordic Cattle Genetic Evaluation (NAV).

Two data files were obtained, one from Holstein Association USA Inc. and one from NAV. The data file from Holstein Association USA Inc. contained EBVs for type traits and the file from NAV contained EBVs for longevity and claw and leg health traits, for Holstein bulls with a minimum of 20 daughters. The data files were merged and that resulted in 610 bulls that had EBVs for claw and leg health – and type traits while 606 bulls had EBVs for longevity traits. Reliability values were estimated from the mean number of daughters and the heritabilities for the various type traits from USA, while reliability values for the traits obtained from NAV were included in the data. Reliability values were then used to adjust the Pearson correlation coefficients between EBVs to estimate the genetic correlations. Significant results were further tested for linear and quadratic regressions.

In general, estimated genetic correlations were low and close to zero. Genetic correlations that were significantly different from zero were found between Longevity in lactation 1 – 5 (L1 – L5) and Stature (0.10 – 0.12), Sole ulcer (SU) and Strength (0.13), Claw index (CI) and Strength (0.12), SU and Body depth (BD) (0.16), CI and BD (0.16), Corkscrew claw (CSC) and Udder depth (UD) (0.13), CSC and Front teat placement (FTP) (-0.17) and CSC and Rear teat placement (RTP) (-0.13). All positive genetic correlations indicate that high scores for the type trait would increase longevity or resistance against claw disorders, while negative correlations indicate a decrease in longevity or resistance against claw disorders, if high scores are given for the type trait. Noteworthy, none of the feet and leg type traits showed genetic correlations different from zero with any of the claw and leg health traits, however, some udder type traits did. The test of linear and quadratic regressions did not show any significant results.

Based on the results from this study, EBVs for type traits estimated in USA are not suitable to use as indirect traits for the improvement of claw and leg health and longevity in the Nordic countries, if the improvement should be effective. The genetic progress within claw and leg health traits could be hampered when semen from bulls, which lack EBVs for claw and leg health, is imported to the Nordic countries. Therefore, including a claw and leg health index in other countries would be preferable.

Sammanfattning

Rasen Holstein är känd för sin höga mjölkavkastning som bland annat uppnåtts genom ensidig selektion för mjölkmängd men med försämrade funktionella egenskaper som konsekvens. Ben och klövsjukdomar är en vanlig orsak till ofrivillig utslagning. 8,4% till 8,9% av svenska Holstein kor slogs ut på grund av ben och klövsjukdomar under åren 2011 till 2014 och en svensk mjölkko är produktiv i genomsnitt 2,5 laktationer. År 2011 infördes ett index för ben- och klövhälsa i de nordiska länderna (Sverige, Danmark och Finland) i det gemensamma avelsindexet Nordic Total Merit index (NTM) för att förbättra ben- och klövhälsa och därigenom mjölkkornas livslängd. Syftet med denna studie var att undersöka om avelsvärden för exteriöregenskaper skattade i USA kan ersätta avelsvärden för ben- och klövhälsa i de nordiska länderna, för rasen Holstein. Genetiska korrelationer har skattats mellan avelsvärden för exteriöregenskaper skattade i USA med avelsvärden för livslängd och med avelsvärden för egenskaper inom ben- och klövhälsa skattade i de nordiska länderna.

Data innehållande avelsvärden för exteriöregenskaper erhölls från Holstein Association USA Inc. som matchades med data från Nordisk avelsvärdering (NAV) innehållande avelsvärden för egenskaperna livslängd och ben- och klövhälsa, för Holstein tjurar med minst 20 döttrar. Avelsvärden för exteriöregenskaper samt ben- och klövhälsa återfanns hos 610 tjurar medan avelsvärden för livslängd återfanns hos 606 av dem. Avelsvärdenas säkerhet för egenskaperna som erhölls från NAV var inkluderade i datafilen medan säkerhet för exteriöregenskaperna från USA beräknades genom att använda medelvärdet för antalet döttrar och arvbarheterna för de olika exteriöregenskaperna. Säkerhetsvärden användes sedan för att justera korrelationen mellan avelsvärden och skatta den genetiska korrelationen. Genetiska korrelationer som var signifikant skilda från noll testades för linjära och kvadratiska samband.

Majoriteten av de skattade genetiska korrelationerna var låga och nära noll. Genetiska korrelationer som skilde sig signifikant från noll var de mellan: Livslängd i laktation 1 – 5 (L1 – L5) och Bröstbredd (Strength) (0,10 – 0,12), Klövsulesår (SU) och Strength (0,13), Klövindex (CI) and Strength (0.12), SU and Kroppsdjup (BD) (0.16), CI and BD (0.16), Korkskruvsklöv (CSC) and Juverdjup (UD) (0.13), CSC and Spenplacering fram (FTP) (-0.17) and CSC and Spenplacering bak (RTP) (-0.13). För alla positiva genetiska korrelationer innebär högre poäng för exteriöregenskapen en ökad livslängd eller resistens för ben- och klövsjukdomar. För negativa genetiska korrelationer gäller det motsatta, högre poäng för exteriöregenskapen medför kortare livslängd eller minskad resistens mot ben- och klövsjukdomar. Noterbart är att ingen exteriöregenskap inom gruppen för ben och klövar uppvisade signifikanta resultat med någon av egenskaperna för ben- och klövhälsa. Däremot erhölls signifikanta resultat mellan egenskaper för juverexteriör och ben- och klövhälsa. Signifikanta resultat återfanns inte i analysen för linjära och kvadratiska samband.

Resultaten från denna studie visar att avelsvärden för exteriöregenskaper skattade i USA inte är användbara som indirekta egenskaper i hänseende att förbättra ben- och klövhälsa i de Nordiska länderna. Det genetiska framsteget inom ben- och klövhälsa kan försämras om import av tjurar, som saknar avelsvärdering för ben- och klövhälsa, används i avel i de nordiska länderna. Därför är det fördelaktigt om fler länder inkluderar ett selektionsindex för ben- och klövhälsa.

Abbreviations

- BComp – Body composite
- BD – Body depth
- BS – Bone structure
- CI –Claw index
- CSC – Corkscrew claw
- DComp – Dairy composite
- DE – Digital and interdigital dermatitis
- DF – Dairy form
- EBV – Estimated breeding values
- FA – Foot angle
- FLComp – Feet and leg composite
- FLS – Feet and leg score
- FTP – Front teat placement
- FUA –Fore udder attachment
- HH – Heel horn erosion
- HQ – Hook quality
- L1 – Longevity lactation 1
- L2 – Longevity lactation 2
- L3 – Longevity lactation 3
- L4 – Longevity lactation 4
- L5 – Longevity lactation 5
- NAV – Nordic Cattle Genetic Evaluation
- NTM – Nordic Total Merit index
- RA – Rump angle
- RLRV – Rear leg rear view
- RLSV – Rear leg side view
- RTP – Rear teat placement
- RUH – Rear udder height
- RUW – Rear udder width
- RW – Rump width
- SH – Sole hemorrhage
- SP –Verrucose dermatitis and interdigital hyperplasia
- SU – Sole ulcer
- TL – Teat length
- TPI – Total Performance Index
- UC – Udder cleft
- UComp – Udder composite
- UD – Udder depth
- WLS – Double sole and whiteline separation

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Introduction

Traits in breeding programs for dairy cows are divided into production and functional traits, where the latter consist of the traits health, fertility, milkability etc. Unlike production traits that are intended to increase output, functional traits are aimed to increase the efficiency by reduced costs (Groen et al., 1997). During the past 40 years, milk yield has nearly doubled (Dobson et al., 2007) and the Holstein breed is known for its high milk yield, mostly achieved by exclusive selection for high production with a loss in fertility and impaired health (Berry, 2012) and reduced longevity (Groen et al., 1997) as consequences. Today, when a Swedish dairy cow is productive on average 2.5 lactations and she only achieves an age of five years on average (Carlén & Eriksson, 2013) it is questionable whether this is sustainable.

The trend in Swedish dairy production indicates that the number of herds are decreasing while the herd size increases (Statistics Sweden, 2014). The same trend can be seen in many other parts of the world, for example in USA (MacDonald & Newton, 2014). The housing systems are also changing, shifting from tie stalls towards free stalls. This change could partly be explained by the Swedish animal legislation, saying that newly built stalls for cattle should be built as free stalls, which means that all dairy cows in Sweden will be housed in free stalls in the future (SJVFS 2010: 15). Free stalls have been associated with higher rates of lameness compared with tie stalls (Sogstad et al., 2005) and lameness in cows is associated with increased risk of being culled (Esslemont & Kossaibati, 1997). Claw and leg problems are the fourth most common reason for culling in both conventional and organic dairy herds in Sweden (Ahlman et al., 2011).

The changes that take place in the dairy production (the intensification, and housing in free stalls with concrete flooring) put higher demands on claw and leg health (Somers et al., 2003; Cook & Nordlund, 2009). Genetic progress in longevity can be hard to achieve because of a low heritability (Jairath et al., 1998), but type traits can be used as indirect measures of longevity (Sewalem et al., 2004). Type traits are also useful as indirect measures for disease resistance (Rogers et al., 1999). If selection shall be performed among Holstein bulls from USA, which lack information about claw disorders, would it be possible to use type traits evaluated in USA to select for improved claw and leg health and thereby also increase the longevity in the Nordic countries (Sweden, Denmark and Finland)?

The aim of this study was to estimate genetic correlations between, on one hand, estimated breeding values (EBV) for type traits obtained from USA, with, on the other hand, EBVs for longevity, claw and leg health obtained from the Nordic Cattle Genetic Evaluation (NAV) for Holstein dairy cattle. The results will be interpreted and discussed from the perspective to improve Holstein cow longevity and claw and leg health under Nordic conditions.

Literature Review

Breeding Goal for the Holstein Breed

Increasing the milk production has been the main goal for many breeding organisations all around the world. Miglior et al. (2005) compared selection indices from 15 countries and concluded that the average relative emphasis on production was 59.5%. In that study, Denmark represented Scandinavia and stood out by having the lowest relative emphasis on production, 34%, while two selection indexes from USA had relative emphasis of 54 and 55%, respectively. Breeding for high milk yield has had its consequences: impaired fertility due to an unfavorable genetic correlation between these traits (Kadarmideen et al., 2000) and also impaired health in terms of mastitis, milk fever and lameness (Dobson et al., 2007). The appearance of the Holstein dairy cow has undergone a change: cows nowadays are much taller, heavier and show more angularity. This is due to the selection for high milk yield combined with selection for angularity (Hansen, 2000). Carlén (2014) has expressed that dairy cows born between the years 1995 to 2009 in the Nordic countries have increased in height, from 4 up to 6 cm, despite the fact that the height/stature is not included in the Nordic Total Merit index (NTM). On the other hand, the importation of semen from North American bulls could have had an effect, because there focus has been placed on conformation and size of the dairy cow. Carlén (2014) pointed out that the change in size is not only dependent on genetic factors, it is also due to environmental factors, such as feeding and management. Another reason could also be that some farmers actually prefer larger cows and therefore choose bulls that are large.

A study that has been going on since 1966 in Northwest Experiment Station, Crookston, University of Minnesota, has created an experimental herd of two Holstein selection lines, selected for small or large body size. Becker et al. (2012) found that cows selected for large body size had higher costs for health care and veterinary treatments, one of which being treatments for locomotion disorders. Hansen et al. (1999) showed that cows in the selection line for small body size had longer productive life and better reproductive performance. Both Becker et al. (2012) and Hansen et al. (1999) concluded that cows with small body size were more profitable: they had lower maintenance costs and lower health costs, but no significant difference regarding milk production compared to the larger cows. According to Carlén (2014), there is a positive correlation between body size and milk production. However, the selection for increased body size is unfavorably correlated with many traits of economic importance, such as health and durability. Alban (1995) studied lameness in Danish cattle and suggested that the incidence of lameness could increase in breeds that are heavier, because the Danish Jersey breed, a light breed, showed lower prevalence of lameness compared with heavier breeds like the Danish Black and White.

Selection for high milk production and larger cows are both associated with a decline in health (e.g., lameness and mastitis), reproductive performance and longevity (Hansen et al., 1999; Kadarmideen et al., 2000; Dobson et al., 2007; Carlén, 2014), which also becomes a welfare problem (Oltenacu & Algers, 2005). Lameness and longevity have been pointed out as two important indicators of measuring welfare in dairy cows (Anonymous, 2001). According to Essl (1998) it is necessary to strive for dairy cows that have good health and thereby are sustainable to be able to increase the longevity.

Total Performance Index – USA

Holstein Association USA, the largest dairy breed association in the world, is using a selection index called total performance index (TPI, a service mark of Holstein Association USA Inc.). The genetic evaluation program estimates the predicted transmitting abilities (PTA, which corresponds to ½ EBV), showing an animal's ability to transfer its superiority or inferiority to its offspring (Holstein Foundation, 2015).

Selection for milk yield and type traits (udder, angularity, feet and legs, body size and overall conformation) has been the main focus for Holstein breeding in USA (Hansen, 2000). The study by Miglior et al. (2005), which contained selection indexes from 2003, showed that some other functional traits had been added. Longevity and udder health existed in both indexes, USA Net merit index and the USA TPI. Additional traits, fertility and calving ease were included in the USA Net merit index. Today TPI consists of 12 sub-indexes (see list below) that are categorized and weighted as follows: Production 46%, Health and fertility 28% and Conformation 26% (Holstein Association USA Inc., 2015).

1. Protein
2. Fat
3. Feed Efficiency
4. Type
5. Dairy Form
6. Udder Composite
7. Feet and Legs Composite
8. Productive Life
9. Somatic Cell Score
10. Fertility Index
11. Daughter Calving Ease
12. Daughter Stillbirth

Nordic Total Merit index

Sweden, Denmark and Finland are affiliated to NAV since 2002. NAV estimates breeding values for Nordic dairy cattle and a Nordic selection index, NTM, was introduced in 2008 (NAV, 2015). The NTM index consists of 14 sub-indexes (see list below) but no categorization similar to the TPI in the USA was found, instead a calculation according to the economic weights have been made: Production 28%, Health, fertility and longevity 52%, and Conformation 20% (NAV, 2013).

1. Yield
2. Growth (only evaluated for bull calves)
3. Fertility
4. Calving Direct
5. Calving Maternal
6. Udder Health
7. Other Diseases
8. Claw Health
9. Body
10. Feet and Legs
11. Udder
12. Longevity
13. Milking Speed
14. Temperament

Recording systems regarding functional traits (reproduction and health) started already in the 1960s in the Nordic countries. It started with data from milk recording and artificial insemination (AI) services and later data regarding health from veterinary services were incorporated into the database. A shift regarding the breeding objectives occurred, where much more emphasis and focus was given to functional traits instead of production traits (Philipsson & Lindhé, 2003). This was shown in the study of Miglior et al. (2005) where Denmark stood out by having the most balanced selection index, concerning the emphasis placed on production, health and longevity. Interestingly, the decline in fertility has not been as severe for the red breeds as in the Holstein breeds in the Nordic countries. It is something that the authors attribute to the absence of a breed replacement event, like “Holsteinisation” in the Holstein breed, in the red breeds; “Holsteinisations” means that many of the Holstein bulls used were derived from North America, where there was no recording of data on daughter fertility (Philipsson & Lindhé, 2003). The AI industry in USA grew in the early 1980s, mostly because of the large export of Holstein semen to Europe (Funk, 2006). Therefore, breeding and selection for Holstein in USA have had an impact on the Holstein populations in other countries (Hansen, 2000).

Longevity

A cow’s ability to survive in the herd is called longevity (Vollema, 1998). There are three main definitions of longevity: functional longevity, residual longevity and true longevity. The first definition refers to an adjustment for milk yield and shows the ability to prevent involuntary culling. The second definition refers to an adjustment for all traits that are included in the breeding goal, while the third is unadjusted and therefore shows the ability to prevent all culling, both voluntary and involuntary (Mark, 2004). The most common reasons for culling are low production, diseases and low fertility. A cow culled because of low production is classified as voluntary culling whereas a cow culled because of disease or low fertility is classified as involuntary culling (Vollema, 1998).

Longevity is affected by many factors, like management (feeding regimes, housing conditions etc.), access to heifers, milk prices and also the herd’s breeding strategy and the cow’s genetic ability, to mention some. One of the largest costs in milk production is the cost for replacement: a low replacement rate lowers the costs and the average age of the cows increases and thereby also the milk yield. A high replacement rate may seem to be beneficial in the respect that younger cows, with higher genetic level, replace older cows with lower genetic level. On the other hand, a high replacement rate could lead to that all heifers, both with high and low genetic level replace older cows, which in turn could impair the herd’s total genetic level. The fact that it takes a number of lactations before the cow has paid back the cost of the rearing period and until she starts to generate a surplus also indicates that a low replacement rate is economically beneficial (Carlén & Eriksson, 2013). For a cow to attain its full production capacity she requires a certain level of maturity and therefore also a longer herd life (Essl, 1998) and it takes four lactations for the dairy cow to become profitable (Esslemont & Kossaibati, 1997). Longevity is a trait of great importance regarding dairy cow profitability and that means to keep healthy cows that continues to be productive (Schneider et al., 1999).

One part of involuntary culling is mortality. To be able to keep a low replacement rate, it is advantageous if the involuntary culling is low and a high mortality leads to a higher replacement rate (Alvåsen et al., 2012). On-farm mortality has steadily increased throughout the years, this has been reported from Denmark (Thomsen et al., 2004), Sweden (Alvåsen et al., 2012) and USA (Miller et al., 2008). Alvåsen et al. (2012) concluded that Holstein cows and a larger herd size were two factors that were associated with higher mortality.

Cows should be replaced by younger cows based on production level, not because of impaired health, fertility or other problems. In Sweden, almost 50% of all culled cows are culled due to infertility, udder disease and high somatic cell count, showing that the involuntary culling is high (Carlén & Eriksson, 2013).

Selection for Longevity

The longevity index within the TPI is called productive life and indicate if the daughter is expected to live more or fewer months than average. A cow's productive life is calculated by giving credits for every month in lactation: the credit for a month in lactation is higher for later lactations, and for months when the cow achieves its peak production (Holstein Foundation, 2015).

Longevity index in NTM includes five traits: days from 1st calving to end of 1st lactation and similarly for the 2nd, 3rd, 4th and 5th lactation with a maximum of 365 days per lactation period. The heritabilities range from 0.035 to 0.072 for Holstein. The EBVs are expressed such that the animals in the base population have an average index of 100 and a higher longevity index implies that the daughters of the bulls will have a longer productive life. The economic weight of longevity in NTM is 0.11 for Holstein bulls (NAV, 2013), compared with 0.75 for yield.

Claw Health and Lameness

Claw disorders often cause lameness in dairy cows with accompanying pain and anxiety (Phillips, 2010). It has been reported that over 90% of the lameness incidents are caused by claw disorders (Shearer, 1997). Lameness also complicates the intake of feed and water because the ability to move is impaired (Metz & Bracke, 2005), and thus lameness clearly interferes with the welfare in dairy cows (Boelling & Pollott, 1998). Regarding the economically most important disorders in dairy cows, mastitis, infertility and claw and leg disorders are listed (Politiek et al., 1986; Enting et al., 1997; Växa Sverige, 2016). The main loss in income is due to decreased milk production, longer calving interval, veterinary treatments and earlier culling (Enting et al., 1997). Therefore, an improved claw health would lead to reduced involuntary culling and thereby improved longevity (Distl et al., 1990).

Claw disorders are classified according to origin: trauma (injury), infectious (hygiene related) and systemic (nutrition related) (Politiek et al., 1986; van der Spek et al., 2013). Some common claw disorders are presented in Table 1. Because claw disorders are partly affected by management factors (housing conditions, type of floor etc.), one way of improving claw health should be by applying different management methods, but improvement in claw health can in the long term also be achieved through genetics (Politiek et al., 1986).

The frequency of claw disorders in dairy cattle differs between countries; 69% in the Netherlands (Van der Linde et al., 2010), 47.8% (housed in tie stalls) and 71.8% (housed in free stalls) in Norway (Sogstad et al., 2005), and 72% in Sweden (Manske et al., 2002). Sole hemorrhage had the highest frequency in Dutch dairy cattle (Van der Linde et al., 2010), while heel horn erosion, 42%, was the most common disorder in Swedish dairy cattle (Manske et al., 2002). It has also been found that the rear claws are affected more frequently than the front claws (Manske et al., 2002; Sogstad et al., 2005). The frequency of lameness was found to be low: only 5% of cows suffering from any claw disorder showed signs of lameness among the Swedish dairy cattle, but the authors believe that the number might be underestimated (Manske et al., 2002). The claw disorder that is most strongly associated with lameness was found to be sole ulcers (Manske et al., 2002; Sogstad et al., 2005).

The proportion of Swedish Holstein culled because of claw and leg problems was between 8.4% and 8.9% during 2011 to 2014 (Swedish Dairy Association, 2012; Växa Sverige, 2013, 2014, 2015).

Table 1. Description of some claw disorders (modified from Växa Sverige, 2013b)

Claw disorder	Description
Heel horn erosion	Erosions of the bulbs
Digital dermatitis	Severe inflammation of the skin, wounds and bleedings
Interdigital dermatitis	Moderate dermatitis around the claw and that is not classified as digital dermatitis
Verrucose dermatitis	Wart like outgrowth, often a chronic stage of digital dermatitis
Interdigital hyperplasia	Growth of fibrous tissue, interdigital
Double sole	One or more layers of undermined sole horn
White line separation	A separation of the white line
Sole ulcer	Openings of the sole horn, fresh or necrotic corium are exposed. Often located in the rear part of the sole
Sole hemorrhage	Shallow or deep bleeding, or yellowish discoloration, bruising, of the sole and/or the white line
Corkscrew claw	Outer or inner claw goes inwards, the front wall deviates from a straight line

Selection for Claw Health

Eriksson (2006) concluded that it is possible to use data recorded by claw trimmers for the genetic evaluation of bulls and that these data are an important source of information because the correlation between EBVs for claw disorders and claw and leg conformation traits were found to be low in this study performed in Sweden. The author implicates the need of adding more traits into the genetic evaluation to achieve improvements regarding claw health. Johansson et al. (2011) presented the development of a new claw health index that was included in the NTM in August 2011. It contains seven traits that are described further in Table 2. Sweden was first with routine recording claw health data. Initially handwritten reports were used as data source, but claw health data and treatments are nowadays reported by claw trimmers using a computer program. Denmark started using the program in 2010, and a year later, both Sweden and Finland started to use the program as well (NAV, 2015b). Registrations from the first three lactations are included and cows are usually trimmed twice a year, which means that one cow can have several recordings during one lactation (Johansson et al., 2011). In Sweden, claw trimmers have recorded claw trimming traits for several years (Eriksson, 2006)

The economic weight of the claw health index in the NTM is 0.10 and the breeding values for claw health show the daughter's genetic ability to resist claw disorders, calculated for the first three lactations (NAV, 2013).

Table 2. The seven groups (HH, DE, SP, WLS, SU, SH and CSC) of claw disorders in the claw health index in NTM, how they are recorded and heritabilities, h^2, for Holstein in third lactation (Modified from NAV, 2013; Johansson et al., 2011)

Classified by origin:	**Claw disorder & Abbreviation**	**Type of recording**	**h^2 in 3rd lactation**
Infection related	Heel Horn Erosion, *HH*	No, mild or severe disease	0.05
	Digital Dermatitis, *DE*	No, mild or severe disease	0.04
	Interdigital Dermatitis, *DE*	No, mild or severe disease	0.04
	Verrucose Dermatitis, *SP*	No disease or disease	0.06
	Interdigital Hyperplasia, *SP*	No disease or disease	0.06
Feed related	Double sole, *WLS*	No disease or disease	0.02
	Whiteline separation, *WLS*	No disease or disease	0.02
	Sole Ulcer, *SU*	No, mild or severe disease	0.05
	Sole Hemorrhage, *SH*	No, mild or severe disease	0.04
Malformation	Corkscrew claw, *CSC*	No disease or disease	0.02

Type Traits Recording

Type classifications are very common in cattle breeding and are performed in many dairy cattle breeds (Simm, 2002; Haas et al., 2007). At first, the assessments were based on subjective opinions and were not that easily interpretable. In the early 1980s, the type classification changed to more objective measures and the system was called linear assessment and developed in North America. The linear assessments are now used in many countries (Simm, 2002). A few traits are measured in a particular unit, like stature is measured in centimeters. Still the majority of type traits are assessed visually but the linear assessment provides the degree of a certain trait and not what is desirable (Simm, 2002; ICAR, 2015).

The conformation assessment that are conducted by the Holstein Association USA, Inc. consists of two parts. First, the classifier assesses 20 type traits (Table 3) separately and gives each trait a score on a scale of 1 – 50 points. Thereafter in a new assessment and scoring according to five categories (Table 4), the classifier gives for each category a score on a scale of 1 – 100, based on how well the cow or bull reaches the desired conformation. A final score is then calculated according to the different categories' weight in percentage and the cow/ bull will then receive a grade based on the total score as follows: Poor (50 – 64), Fair (65 – 74), Good (75 – 79), Good Plus (80 – 84), Very Good (85 – 89) and Excellent (90 – 97) (Holstein Association USA Inc., 2014).

Table 3. The linear assessment in USA, first part of the assessment, the type traits scoring (Holstein Association USA Inc. 2014) and heritabilities, h^2 (Holstein Association USA Inc. 2016)

Category	*Type trait*	*Scoring*	h^2
Body	Stature	1 = short, 50 = tall	0.42
	Strength	1 = narrow, 50 = wide	0.31
	DF	1 = tight, 50 = open	0.29
	BD	1 = shallow, 50 = deep	0.37
	RW	1 = narrow, 50 = open	0.26
	RA	1 = pins higher than hooks, 50 = sloped	0.33
Feet & legs	RLSV	1 = straight, 50 = sickled	0.21
	RLRV	1 = toe out, 50 = no toe out	0.11
	FA	1 = low angle, 50 = steep angle	0.15
Udder	FUA	1 = loose, 50 = snug and strong	0.29
	RUH	1 = low, 50 = high	0.28
	RUW	1 = narrow, 50 = wide	0.23
	UC	1 = weak cleft, 50 = strong cleft	0.24
	UD	1 = below hooks, 50 = high above hooks	0.28
Teats	FTP	1 = wide, outside quarter, 50 = inside of quarter	0.26
	RTP	1 = wide, outside quarter, 50 = inside of quarter	0.32
	TL	1 = short, 50 = long	0.26
Other	Body condition	1 = thin, 50 = round	-
	Locomotion	1 = short stride, 50 = long stride	-

Table 4. Linear assessment according to five categories and the type traits included in each category (modified from Holstein Association USA Inc., 2014)

Category	*Front end & body capacity*	*Dairy strength*	*Rump*	*Feet & legs*	*Udder*
Type Traits	Front end Chest Barrel Back/Loin Stature Breed - characteristic	Ribs Width - of chest Spring - of fore rib Thighs Witters Neck Skin	Rump - angle Rump – width Vulva Tail - head	Rear legs - rear view Locomotion Rear legs - Side view Feet Thurl position Hooks Bone Pasterns	Udder depth Fore udder Rear udder Teat placement Udder cleft Teats Udder balance - & texture

The conformation assessment conducted by certified classifiers in the Nordic countries consists of 24 type traits and in addition, the cow's temperament and milkability are assessed (ICAR, 2015). The total for each category are weighted (weight factor for the different categories are presented in Table 5) and the final score is achieved by summing up the different values of each category. The cow/bull receives a final score on a scale from 60 – 99 and the average final score is 80 (SEGES, 2015). The differences between the linear assessment conducted in USA and within NAV are, among other, what type traits that are included in the recording. Top line, Hook quality (HQ), Bone structure (BS), udder balance and teat thickness are traits that are found in the assessment in NAV (ICAR, 2015), and not in USA. The greatest difference is the three categories front end and capacity, rump and dairy strength in USA, that all are included in the category body in NAV. This also makes a difference concerning the percentage: body stands for 30% in Denmark while the other three categories together constitutes for 40% in USA. This leaves less percentage for the category feet and legs in USA, only 20% in contrast to 30% in Denmark (Holstein Association USA, Inc. 2014; SEGES 2015b).

Table 5. The different categories for type classification and the categories percentage in the total type classification index in the Nordic countries (NAV) and in USA

	Category	**Total, %**
NAV[1]	Body	30
	Feet and legs	30
	Udder (including teat traits)	40
USA[2]	Front end and capacity	15
	Dairy strength	20
	Rump	5
	Feet and legs	20
	Udder (including teat traits)	40

[1] SEGES, 2015b [2] Holstein Association USA Inc., 2014

Genetic Correlations

To predict the effects of a breeding programme, the genetic correlations between traits included in the selection index and the breeding goal must be estimated (Lehrman, 2014). Genetic correlations between traits indicate that they are influenced either indirectly or directly by the same genes, and that the influence is either in the same direction for both traits (positive correlation) or in different directions (negative correlation). If strong (favourable) genetic correlations prevail it is possible to use indirect selection (Simm, 2002).

Type Traits and Longevity

Zavadilová & Štípková (2012) found positive genetic correlations between longevity and the type traits: Body condition score (0.14 – 0.19), rump angle (RA) (0.15 – 0.21), and Hook quality (0.05 – 0.19). The majority of the type traits evaluated in the study were negatively correlated with longevity. Strongest genetic correlation were found with the type traits: Angularity (-0.31 – 0.06), Capacity (-0.27 – -0.21), Stature (-0.27 – -0.18), Body depth (BD) (-0.26 – -0.21), Rump width (-0.27 – -0.14), Rear leg side view (RLSV) (-0.24 – -0.11), and Rear teat placement (RTP) (-0.28 – -0.21); somewhat weaker correlations were found for Final score (-0.13 – 0.02). In this study, both true and functional longevity were tested and the type traits showed stronger genetic correlations with functional longevity. Kern et al. (2015) found similar results for the type traits: Angularity (-0.29 – -0.13), Stature (-0.31 – -0.18), BD (-0,28 – -0.21), and Final score (-0.08 – 0.04), and somewhat higher correlations for Rump width (-0.18 – 0.08). Correlations between longevity and Foot angle (FA) were in the same range, -0.18 – 0.08 (Kern et al., 2015) and -0.10 – 0.10 (Zavadilová & Štípková, 2012), while the results for longevity and Rear udder width (RUW) differed somewhat, -0.30 – -0.15 (Kern et al., 2015) compared to -0.22 – 0.06 (Zavadilová & Štípková, 2012). In the study by Kern et al. (2015), five longevity traits were included, where strongest correlations were found with longevity measured as time from birth to last milk record and time from first calving to last milk record.

Rogers et al. (1989) found negative genetic correlations among functional longevity (measured as survival, age in months and adjusted for milk yield) and Stature (-0.18 – -0.02), BD (-0.23 – -0.08), and Strength (-0.20 – 0.01). They concluded that genetic selection for increased value of these traits could affect the fitness of the dairy cow negatively. The estimated values for Rump width and RUW were also negative but not as strong, -0.11 – -0.03 and -0.05 – -0.02 respectively. Genetic correlations for Angularity and RLSV were close to zero (-0.01 – 0.06 and 0.03 – 0.08), this was in contrast to the results in the studies by Zavadilová & Štípková (2012) and Kern et al. (2015).

The type trait Udder depth (UD) has been shown to be positively correlated with longevity traits, 0.20 – 0.27 (i.e. a higher udder is associated with longer life) (Rogers et al. 1989), 0.04 – 0.11 (Zavadilová & Štípková 2012) and 0.17 – 0.31 (Kern et al. 2015). Zavadilová & Štípková (2012) found a negative correlation for the type traits central ligament (-0.19) while Rogers et al. (1989) found a positive correlation (0.28) for the type trait udder support, it can be assumed that it is the same trait as central ligament. Rogers et al. (1989) also found a positive correlation for the type trait Teats rear view (0.17 – 0.29).

Rogers et al. (1989) also estimated the genetic correlation between true longevity (not adjusted for milk yield) and type traits, and strong negative correlations were found for the type traits: Stature (-0.32 – -0.09), Strength (-0.35 – -0.08), and BD (-0.36 – -0.15). For Rear udder height (RUH) and RUW, genetic correlations were also negative (-0.13 – -0.05 and -0.17 – -0.12, respectively).

In a study where the relationship between type traits and functional survival on Holstein in Canada was studied, it was clear that the Final score had the largest influence on survival. A cow with a Final score lower than 65 had 3.7 times higher risk of being culled compared to a cow with a Final score of 80. Except for the Final score of type classification, udder traits and feet and legs were the two most important traits for longevity. In the category feet and legs, Heel depth (depth of heel on outside claw) and Bone quality affected functional survival the most. In the same study both extremely small and extremely large cows seemed to be at risk for a shorter productive life (Sewalem et al., 2004).

Culling for reasons other than production, like type traits, has been shown to be both udder type traits and cows with extremely deep chests. These results were found in a study by Larroque & Ducrocq (2001) in the French Holstein population.

Type Traits and Claw and Leg Health

Several studies have been conducted regarding the genetic relationship between type traits and claw disorders, with dispersed results. In Finnish Holstein, the strongest genetic correlations found were between FA and Sole Ulcer (SU), -0.51, FA and Corkscrew claw (CSC), -0.50 and between FA and Heel horn erosion (HH), 0.45 (Häggman & Juga, 2013). This indicates that a cow with a high score for FA, with a steeper foot angle, is at lower risk of suffering from SU and CSC but more likely to suffer from HH, since the prevalence of claw disorders were analyzed in this study. Rogers et al. (1999) found genetic correlations in similar range, 0.39 and 0.40 with a combined trait of claw and leg health traits in lactation one and two. Weaker correlations were found between FA and Double sole and whiteline separation (WLS), -0.24 and between FA and Sole hemorrhage (SH), -0.08 (Häggman & Juga, 2013). Uggla et al. (2008) found considerably weaker genetic correlations for the type trait FA with the claw disorders SU and HH, -0.03 and 0.07 respectively, in Swedish Holstein. However, significant results were shown between FA and a combined trait of dermatitis and HH, 0.16. In USA Holstein cows, Dhakal et al. (2015) found the genetic correlation between FA and noninfectious claw disorders (CSC, SH etc.) to be 0.10. Genetic correlations close to zero have also been found, Laursen et al. (2009) reported a genetic correlation between FA and claw health traits to be 0.02 in Danish Holstein and Odegard et al. (2014) found correlations in the range from 0.09 – 0.17 in Norwegian Red cattle between the same traits. Note that in the study by Laursen et al. (2009), claw health traits are defined as the absence of claw disorders, and not the prevalence, as it is done in the study by Odegard et al. (2014).

The type trait RLSV has been shown to be genetically correlated with many claw health traits. Uggla et al. (2008) reported genetic correlations ranging from 0.13 – 0.28; the strongest correlation was found with SU. Van der Linde et al. (2010) found a stronger correlation, 0.41, between the same traits and 0.25 between RLSV and interdigital dermatitis in first parity cows. Dhakal et al. (2015) reported a positive genetic correlation with both noninfectious and infectious claw disorders, 0.13 and 0.14, respectively, meaning that lower scores for RLSV, aiming for cows with straighter legs, would lead to reduced incidence of claw disorders. Others have found weaker correlations, -0.07 (Laursen et al., 2009), -0.07 and -0.02 for cows in lactation one and two, respectively (Rogers et al., 1999).

Genetic correlations between Rear leg rear view (RLRV) and claw health traits have been reported to be in the range -0.32 – -0.23 (Van der Linde et al., 2010), -0.08 – 0.16 (Uggla et al., 2008) and -0.29 – 0.33 (Häggman & Juga, 2013). Strongest correlation found in each study were with the claw health traits: Dermatitis (0.32), CSC (0.33), and SU (0.16). Dhakal et al.

(2015) found the genetic correlation between RLRV and infectious claw disorders to be -0.25 and with noninfectious claw disorders -0.09. Also a positive correlation has been reported for RLRV with a group of claw health traits, 0.21 (Laursen et al. 2009).

For the type trait HQ, Uggla et al. (2008) found genetic correlations in the range from -0.08 – 0.00 where the strongest negative correlation was found to be with SH and SU (-0.08 for both traits). Laursen et al. (2009) found a positive correlation of 0.12 with a group of claw health traits. Slightly different results has also been shown between the type trait BS, -0.02 – 0.10 (Uggla et al. 2008) and 0.14 (Laursen et al. 2009).

For the combined score of feet and legs (FLS) genetic correlations with various claw health traits were in the range from -0.51 – 0.07. Strongest correlations were with digital dermatitis (-0.51 for cows in first parity and -0.27 in multiparous cows) and interdigital dermatitis (-0.44 for cows in first parity and -0.34 in multiparous cows) (Van der Linde et al., 2010).

Rogers et al. (1999) estimated genetic correlations between claw and leg health traits (combined) and various type traits. The significant results from that study were found for the type traits: Dairy form (DF) (-0.50 in first lactation and -0.38 in second lactation), RA (0.39 in first lactation and 0.40 in second lactation) and BD (-0.28 in first lactation). For Rump width, Strength and Stature the genetic correlations were in the range from -0.20 – -0.05, -0.20 – -0.08 and -0.13 – -0.02, respectively.

In the studies mentioned above, there are differences regarding which type traits that were included in the study and only one of them, Rogers et al. (1999), estimated genetic correlations between the final score of the linear descriptive assessment and claw and leg health traits. The genetic correlations were -0.09 in first lactation and -0.02 in second lactation. Also, the authors' final conclusions regarding the usefulness of type traits as indirect traits for improving claw and leg health are different. The general conclusions from these studies were that type traits were not that strongly correlated with claw and leg health traits, which means that using type traits for indirect selection is not efficient for improving claw and leg health. Records from claw trimmers of claw health are preferred over type traits (Uggla et al., 2008) and similar statements were made by Van der Linde (2010) and also Odegard et al. (2014). There are, however exceptions where a few type traits showed stronger correlations with claw and leg health. Laursen et al. (2009) stated that HQ and BS could be useful as indicator traits, Rogers et al. (1999) emphasizes RA and DF, which both showed stronger correlations than other type traits. Higher scores for RA, cows that are more sloped from hooks to pins, would reduce the risk of claw and leg disorders, while DF showed an unfavorable correlation and this would therefore have to be considered in the breeding program, according to Rogers et al. (1999).

According to Van der Linde et al. (2010) the progress that can be seen regarding the decreased prevalence of lameness was estimated up to 0.7% per year if a claw health index is included in the selection index. The most effective approach would be to continuously register claw disorders and combine that with type traits to select for improved claw health. Dhakal et al. (2015) is in agreement with Van der Linde et al. (2010), suggesting that a claw health index should be included in the index, like the Nordic countries already have done, because the claw disorders recorded by producers show a reasonable heritability. However, the authors also suggests that type traits regarding the feet could be used in cases where the disorders are hard to record, like infectious claw disorders.

Material and methods

Literature Review

The search for literature was done using the following databases: PubMed, ScienceDirect, Web of Knowledge and Google Scholar and the key words: dairy, cow, longevity, conformation, type traits, lameness, claw/hoof, health, correlation/relationship. Information has also been taken from web sites of different breeding companies etc.

Data

The data file containing EBVs of type traits for Holstein bulls in USA was received from Holstein Association USA Inc. The file contained 84,928 Holstein bulls, all originating from USA and their birth year were in the range between 1988 and 2015. Birth year information was missing for some of the bulls. EBVs for the following type traits included in the file were: Stature, Strength, BD, DF, RA, Rump width (RW), RLSV, RLRV, FA, Feet and FLS, Front udder attachment (FUA), RUH, UD, Udder cleft (UC), Front teat placement (FTP), RTP, Teat length (TL), Body composite (BComp), Dairy composite (DComp), Feet and leg composite (FLComp), Udder composite (UComp). Reliabilities for individual bull EBVs were not available, but number of daughters in the evaluation was known.

The data file containing EBVs of claw and leg health and longevity for Holstein bulls in the Nordic countries was received from NAV. A criterion for creating this data file was that the bulls originated from the USA, and had an international identity number and EBVs for some longevity and claw and leg health traits estimated in the Nordic countries. The file contained 1984 bulls with EBVs and reliability values for the following traits: SU, SH, Heel horn erosion (HH), Digital and interdigital dermatitis (DE), Verrucose dermatitis and interdigital hyperplasia (SP), WLS, CSC, Claw index (CI), Longevity lactation 1 (L1), Longevity lactation 2 (L2), Longevity lactation 3 (L3), Longevity lactation 4 (L4) and Longevity lactation 5 (L5). Regarding the claw health traits, SU to CSC, the data file contained EBVs for each lactation from first to the third plus EBV for an index over all lactations. The reliabilities for claw and leg health traits were estimated for the index over the lactations only, not for SU for the first lactation for example, therefore genetic correlations were only estimated from the EBVs for the index over lactations.

Statistical Analyses

All statistical analyses were performed with the program Statistical Analysis Software, version 9.4 (SAS Institute, 2014). At first, the SUBSTR function was used to replace the Nordic identity number with the international identity number in the file from NAV and the file was then sorted by the bulls international identity number by PROC SORT. PROC SORT procedure was also used to sort the file from USA on international identity number. Thereafter, the files were merged and the merged file contained 755 bulls.

The PROC CORR procedure was used to measure the relationship between USA type traits on one hand and longevity traits and claw and leg health traits from NAV on the other hand. Pearson correlations between EBVs were adjusted according to the method described by Calo et al. (1973), where the mean of the reliabilities of the traits are included in the equation. Reliabilities for type traits were missing in the USA data file and were therefore calculated based on the number of daughters of each bull and the heritability of the trait. Number of daughters was included in the USA data file and the heritabilities were obtained from Holstein

Association USA Inc. (2016). Reliabilities were calculated as (Blanchard et al., 1983):

$$b_{i=}\frac{n}{\left(n+\left(\frac{(4-h^2)}{h^2}\right)\right)}$$

where

b_i= reliability of the trait
n = number of daughters of the bull
h^2= heritability of the trait

Heritabilities were only found for the type traits included in the first step of the linear assessment and EBVs for the type trait final score were missing. Genetic correlations could therefor only be calculated with the type traits presented in Table 3, and also for Feet and leg score (h^2 = 0.17; Holstein Association USA Inc. 2016).

The reliabilities from NAV were divided by 100, because they were expressed in percent. The mean value of all reliabilities was obtained for each trait in the merged data set using PROC MEANS procedure.

The adjustment of the correlation between EBVs was done following the equation by Calo et al. (1973):

$$r_{g1,2}=\frac{r(EBV_1,EBV_2)}{\left(\left(\sqrt{\overline{b_1}}\right)\left(\sqrt{\overline{b_2}}\right)\right)}$$

where

$r_{g1,2}$ = estimated genetic correlation between trait 1 and 2
$r(EBV_1, EBV_2)$ = correlation value of EBVs for traits 1 and 2
$\sqrt{\overline{b_1}}$ = square root of mean value of reliability for trait 1
$\sqrt{\overline{b_2}}$ = square root of mean value of reliability for trait 2

A minimum value for number of daughters was set to 20 because the equation used to adjust the Pearson correlation between EBVs involves reliability values and if bulls with few daughters are included, the reliabilities will be lower, which in turn could lead to an overestimation of the genetic correlation. A similar approach was used by Rogers et al. (1999). The PROC CORR procedure was done for the data set containing bulls with ≥20 daughters, which resulted in a total of 610 bulls: only 606 of them with EBVs for longevity. When determining whether a correlation was significantly different from zero, the P-value (5% level) from estimated Pearson correlation between EBVs was used.

The association between Stature – L1, Strength – SU, Strength – CI, BD – SU, BD – CI, UD – WLS, FTP – CSC and RTP – CSC was further investigated for linear and quadratic regressions with PROC REG and PROC GLM procedure in SAS. Longevity and claw and leg health traits were set as the dependent variable and type traits as the independent variable.

Results

Calculations regarding the reliabilities for the different type traits are presented in Table 7. In general, the reliabilities for claw and leg health traits were lower compared to reliabilities for type – and longevity traits. The matching of bulls with the setting of ≥ 20 daughters per bull resulted in the smallest number of bulls for longevity traits, 606 bulls compared to 610 for claw and leg health, and type traits.

Genetic correlations among longevity traits and type traits are presented in Table 8. The only significant result exist between Stature and all five longevity traits, L1 – L5, the correlations are positive and ranging from 0.10 to 0.12. Genetic correlations among type traits from USA and claw and leg health traits from NAV are presented in Table 9. In general the genetic correlations are close to zero. The significant results are found for the type traits Strength, BD, UD, FTP and RTP, ranging from -0.17 to 0.16.

Since reliabilities were missing for the type traits UComp, FLComp, BComp and DComp the estimation of genetic correlations among these type traits with longevity and claw and leg health traits was not possible to conduct. However, the Pearson correlation betweens EBVs gives an indication of how these traits correlate with each other. Significant results from estimation of correlations between EBVs are presented in Table 10. Only two type traits, BComp and DComp showed some correlations that were different from zero with longevity and claw and leg health traits.

Associations that were tested for linear and quadratic regressions (stature – L1; strength – SU,CI; BD – SU, CI; UD – WLS, FTP – CSC and RTP – CSC) did not show any significant results. R^2 were approximately 0.01 for all traits analyzed, which means that only 1% of the variation in, for example, SU could be explained by BD.

Table 7. Average reliabilities for type traits from USA, and claw and leg health and longevity traits from NAV

Type trait (USA)[1]		*Claw health trait (NAV)*[1]		*Longevity trait (NAV)*[2]	
Stature	0.83	SU	0.55	L1	0.94
Strength	0.78	SH	0.52	L2	0.92
BD	0.81	HH	0.51	L3	0.91
DF	0.77	DE	0.53	L4	0.91
RA	0.79	SP	0.41	L5	0.91
RW	0.75	WLS	0.55		
RLSV	0.71	CSC	0.48		
RLRV	0.57	CI	0.54		
FA	0.64				
FLS	0.66				
FUA	0.77				
RUH	0.76				
RUW	0.73				
UC	0.73				
UD	0.76				
FTP	0.75				
RTP	0.79				
TL	0.77				

[1] 610 bulls [2] 606 bulls

Table 8. Estimated genetic correlations between type traits from USA and longevity traits from NAV in lactations 1 – 5. Correlations between EBVs different from zero (P<0.05) shown in bold

Type Traits, USA	**Longevity traits, NAV**				
	L1	L2	L3	L4	L5
Stature	**0.12**	**0.11**	**0.10**	**0.11**	**0.11**
Strength	0.07	0.07	0.07	0.07	0.07
BD	0.07	0.08	0.08	0.08	0.08
DF	0.00	0.01	0.02	0.02	0.02
RA	0.03	0.01	0.00	-0.01	-0.01
RW	0.05	0.05	0.06	0.06	0.07
RLSV	-0.03	-0.02	-0.01	-0.01	-0.01
RLRV	0.09	0.08	0.08	0.07	0.07
FA	0.06	0.05	0.04	0.04	0.04
FLS	0.02	0.01	0.01	0.01	0.00
FUA	0.02	0.01	0.01	0.01	0.01
RUH	-0.03	-0.02	-0.02	-0.02	-0.02
RUW	-0.04	-0.04	-0.03	-0.03	-0.03
UC	-0.02	-0.03	-0.03	-0.03	-0.03
UD	0.08	0.06	0.06	0.06	0.06
FTP	-0.06	-0.08	-0.09	-0.09	-0.09
RTP	-0.06	-0.08	-0.08	-0.08	-0.08
TL	-0.01	0.02	0.04	0.04	0.05

Table 9. Estimated genetic correlations among type traits from USA and claw health traits from NAV[1]. Claw health traits SU – CSC are indexes over the lactations. Genetic correlations different from zero (P<0.05) shown in bold

Type Traits, USA	**Claw Health Traits, NAV**							
	SU	SH	HH	DE	SP	WLS	CSC	CI
Stature	0.10	0.04	0.07	0.04	0.11	0.05	-0.02	0.11
Strength	**0.13**	0.07	0.05	0.03	0.09	0.08	0.01	**0.12**
BD	**0.16**	0.08	0.07	0.06	0.11	0.11	0.01	**0.16**
DF	0.08	0.04	0.06	0.10	0.09	0.06	-0.01	0.11
RA	-0.01	0.01	-0.04	-0.04	-0.07	-0.05	0.02	-0.03
RW	0.11	0.02	0.04	0.01	0.13	0.04	-0.03	0.11
RLSV	0.00	-0.04	-0.06	-0.06	-0.03	0.02	-0.04	-0.03
RLRV	0.08	0.08	0.04	0.04	0.00	0.08	0.08	0.08
FA	0.07	0.07	0.06	0.08	0.05	0.04	0.03	0.09
FLS	0.10	0.11	0.06	0.05	-0.01	0.08	0.10	0.10
FUA	-0.05	-0.07	-0.03	-0.01	0.02	-0.06	-0.09	-0.05
RUH	0.03	0.03	0.01	-0.01	-0.01	0.02	0.06	0.02
RUW	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.05
UC	0.02	-0.01	0.04	0.03	0.01	-0.05	-0.08	0.03
UD	-0.10	-0.11	-0.03	-0.06	-0.02	**-0.13**	-0.10	-0.10
FTP	-0.08	-0.11	0.01	0.07	0.01	-0.10	**-0.17**	-0.06
RTP	-0.03	-0.06	0.02	0.07	0.03	-0.06	**-0.13**	-0.01
TL	0.08	0.05	0.07	0.02	0.11	0.08	0.09	0.10

Table 10. Significant results (P<0.05) from estimation of Pearson correlation coefficients between EBVs

	Longevity and claw health traits, NAV						
Type traits, USA	L1	L2	L3	L4	L5	SU	CI
BComp	0.08	0.08	0.08	0.08	0.08	0.09	0.09
DComp						0.10	

Discussion

Type traits and Longevity

All genetic correlations estimated in this study were low and close to zero, and only a few significant results were obtained. Among them, positive genetic correlations were found between Stature and all five longevity traits, ranging from 0.10 to 0.12. This result indicates that higher scores for Stature, taller cows, could lead to increased longevity. This is, however, not in line with the results found by Zavadilová & Štípková (2012) and Rogers et al. (1989) who both found negative correlations (-0.27 – -0.18 and -0.18 – -0,02, respectively). Sewalem et al. (2004) stated that extremely large or extremely small cows are more likely to live a shorter productive life. This indicates that there may be an optimum size of the cow in relation to longevity._However, the test for quadratic regression between L1 and Stature was not significant.

Positive genetic correlations (albeit not significant) were also found for the type traits Strength, BD and RLRVranging from 0.07 – 0.09 and this result is not in line with results from other studies. Both Rogers et al. (1989) and (Zavadilová & Štípková, 2012) found negative and stronger correlations for the type trait BD, and negative correlations were also found for Strength (Rogers et al., 1989) and for RLRV (Zavadilová & Štípková, 2012). The type trait Strength could be considered to be the same as chest width, and according to Larroque & Ducrocq (2001), cows with a deep chest are at greater risk of being culled, which is in contrast to the result found in this study.

According to Sewalem et al. (2004), the most important type traits affecting the longevity are udder type traits and feet and leg type traits. It is not consistent with the results found in the current study because no significant result were found for these type traits and longevity. Genetic correlations for UD and longevity traits ranged from 0.06 to 0.08 which is in line with the results presented by Zavadilová & Štípková (2012), genetic correlations were in the range 0.04 – 0.11. Higher scores for the type trait UD could affect the cow’s longevity positively. Negative correlations were found for the type traits RUH (-0.03 – -0.02) and RUW (-0.03 – -0.04) with longevity traits, and these results were in the same range found by Rogers et al. (1989) for functional longevity (-0.03 – 0.06 and -0.05 – -0.02, respectively) but not if compared with the results for true longevity (-0.13 – -0.05 and -0.17 – -0.02, respectively). Other udder type traits that have been shown to be negatively correlated with longevity are UC (-0.03 – -0.02), FTP (-0.09 – -0.06) and RTP (-0.08 – -0.06). For TL, the results were not consistently positive or negative (-0.01 – 0.05) and for FUA, weak genetic correlations were found (0.01 – 0.02). Rogers et al. (1989) reported positive correlations for the type trait Teats rear view (0.17 – 0.29), and assuming that Teats rear view are assessed similar to FTP and RTP, the results are inconsistent. According to results presented in the current study, genetic selection for high scores of udder type traits would not result in a strong correlated response for longevity. However, high scores for FTP and RTP could affect longevity negatively, while high scores for UD would be positive.

Among feet and leg type traits, all genetic correlations were positive except for RLSV (-0.03 – -0.01) which is not as strong compared to results found by Zavadilová & Štípková (2012) (-0.25 – -0.17), these correlations suggest that lower scores for RLSV would increase longevity. Positive genetic correlations were found for RLRV (0.07 – 0.09, discussed earlier), FA (0.04 – 0.06) and FLS (0.00 – 0.02), and similar to the type traits of the udder, feet and leg type traits would not result in much correlated response for longevity.

Type traits and Claw and Leg Health

The type trait Strength showed a positive and favorable genetic correlation with both SU (0.13) and CI (0.12). This would mean that a cow with a strong and wide chest is more resistant to SU and all disorders included in the trait CI. In contrast, Rogers et al. (1999) found negative and unfavorable genetic correlations, -0.20 in first lactation and -0.08 in second lactation, among Strength and claw and leg health traits, which in this case means that genetic selection for Strength could reduce resistance for claw disorders. In the study by Rogers et al. (1999), all type traits were analyzed with one combined trait of claw and leg disorders and that could be the reason for the different results, however, the trait CI could be compared with the combined trait in the study by Rogers et al. (1999) and the different results are not easily explained. Nevertheless, a more accurate comparison would be if each of the different claw disorders were represented.

Similar results were found for BD, which showed a genetic correlation of 0.16 with both SU and CI. A cow with wider chest and a deeper body would be more resistant to claw disorders in general, compared with a cow that is narrow and shallow. This result is also in contrast to what has been found by Rogers et al. (1999), -0.28 for cows in first lactation and -0.12 in second lactation. There are doubts regarding the size of the cow, if smaller or larger cows are preferable from the perspective to increase the resistance for claw disorders. Rogers et al. (1999) stated that none of the type traits regarding the size of the cow would have a positive impact on claw and leg health; in fact, higher scores for DF would likely reduce disease resistance. In contrast, in this study, DF showed genetic correlation in the range -0.01 – 0.11 with claw health traits and positive correlations means that higher scores for DF would increase the resistance for claw disorders.

Genetic correlations for RA (-0.07 – 0.02) and RW (-0.03 – 0.11) were inconsistently positive or negative and differed from the results by Rogers et al. (1999) (0.39 – 0.40 and -0.20 – -0.05).

Genetic correlations regarding RLSV with claw health traits were in the range -0.06 – 0.02. A negative correlation would mean that lower scores, aiming for straighter legs, decreases the incidence of claw disorders. This is in line with results by Dhakal et al. (2015). Negative correlations were found between RLSV and SH, HH, DE, SP, CSC and CI but not very strong, however, it indicates that straight legs would be positive for claw and leg health. Dhakal et al. (2015) found a genetic correlation with infectious claw disorders and RLRV to be -0.25, higher scores means straighter legs and reduced incidence of claw disorders. The positive correlations found between RLRV (0.00 – 0.08) and claw health traits indicate the same, that higher score for the type trait RLRV increase the resistance for claw disorders. Once again, the genetic correlations are not as strong as found by Dhakal et al. (2015).

Other type traits within the group of feet and legs showed mostly positive genetic correlations to claw health traits. FA showed genetic correlation in the range 0.04 – 0.09, and the strongest correlation was found with CI (0.09) and DE (0.08), indicating that a steeper foot angle would increase the resistance for claw disorders. This is in line with the results found by Laursen et al. (2009), 0.02, and Odegard et al. (2014), 0.09 – 0.17. Laursen et al. (2009) defined claw health trait as the absence of claw disorder, which is in line with the definition of claw health traits used in this study and therefore comparable. Odegard et al. (2014) measured the prevalence which means that positive correlations indicate that higher scores for FA increase the prevalence of claw disorders. Between FLS and claw health traits, genetic correlations were in the range -0.01 – 0.11, and the strongest correlation was found for the claw disorder SH. Van der Linde et al. (2010) found genetic correlations in a wider range, -0.51 – 0.07, and the correlation between FLS and SH was -0.20 in first lactation and -0.12 in second lactation. Between FLS and WLS the genetic correlation was 0.08, which is in line with the results found by Van der Linde et al. (2010), 0.05 in first lactation and 0.07 in second lactation. However, Van der Linde et al. (2010) analysed the prevalence of claw disorder, which means that higher scores for FLS would increase the prevalence of the claw disorder WLS. That is the opposite to the result in the current study, where higher scores for FLS would instead increase the disease resistance.

Of what has been found in the literature, there is not a single study that has included udder type traits in the estimation of genetic correlations with claw and leg health. Because of curiosity and the opportunity, all type traits that was included in the data file from USA were included in this study. Unexpectedly, UD, FTP and RTP were significantly, negatively correlated with some of the claw health traits. Unfavorable correlations existed between UD and WLS, -0.13, FTP and CSC, -0.17 and for RTP and CSC, -0.13. Based on these results, selection for udders that are above the hooks and teats located inside the quarter of the udder would decrease the resistance of cows being affected by WLS and CSC. More research has to be carried out regarding how udder type traits correlate with claw health traits and if strong correlations are found future research may focus on identifying the genes. It is also interesting to estimate genetic correlations between udder type traits estimated by NAV with claw and leg health traits in the Nordic Holstein population.

Correlation between Estimated Breeding Values

Certainly it would have been preferable to obtain reliability values for all EBVs for the type traits from USA but that was not possible and the values were instead estimated using heritability values and information on number of daughters. Heritabilities for the five composites in the conformation assessment were not found and the correlations between EBVs that included these type traits could not be further adjusted. However, correlations estimated between EBVs showed that the genetic correlations would be weak and close to zero with some exceptions, where BComp and DComp were positively correlated with some of the traits from NAV (Table 10). BComp could affect the longevity positively and thus also the resistance for SU. DComp seems to be positively correlated with SU. Interesting is also that FLComp did not seem to be correlated with any of the claw and leg health traits, which could be expected.

The importance of a Claw and Leg Health Index

It is clear that genetic selection for improved claw and leg health is of great importance, because of the large negative impact that claw disorders have on the cow's and the producer's profitability. Breeding for functional cows that can fit into the modern dairy production, regarding free stalls and concrete flooring (Somers et al., 2003; Cook & Nordlund, 2009), that will stay productive longer than 2.5 lactations (Carlén & Eriksson, 2013), and that will not be culled because of diseases are of great importance in many aspects (welfare, sustainability, economic etc.). Type traits have higher heritabilities compared to claw and leg health traits, and type traits are good indicators when selecting for cows with functional conformation. However, using EBVs for type traits estimated in USA will not be an effective way of breeding for claw health in the Nordic countries, according to the low genetic correlations found in this study. The comparison made by Miglior et al. (2005) showed that the Nordic countries have been a step ahead regarding breeding for functional traits, and hopefully, more countries will include an index for claw health traits. Philipsson & Lindé (2003) write about the "Holsteinisation", and how the fertility may have declined within the Holstein breed partly because the use of import semen from North American bulls. With that in mind, the genetic progress for claw health could be hampered in the Nordic countries if importation of bulls, lacking EBVs for claw health traits, occurs. On the other hand, the North American bulls that are imported to the Nordic countries are genomic tested and genomic breeding values for claw health are estimated. Then it could be questioned if the majority or just a small part of the North American bulls are genomically tested and obtain genomic breeding values for claw health?

Certainly, there are some differences regarding some of the significant results within this study compared to other studies, however, all the genetic correlations are low which is in line with some other studies (Rogers et al., 1999; Uggla et al., 2008; Odegard et al., 2014). There is an inherent problem with the methodology as well: if a correlation between EBVs is close to zero, and by chance is estimated as positive or negative, that correlation is then scaled up by dividing by the respective reliabilities. In the literature, results from estimated genetic correlations both between type traits and longevity, and type traits and claw health traits seems to differ regarding population and breed. Despite contradictory results, low correlations indicate that type traits are not that useful in the perspective to increase claw and leg health within the Holstein breed in the Nordic countries.

Conclusion

Using EBVs for type traits estimated in USA will not be an effective way to select US bulls with good claw health in the Nordic countries, according to the low genetic correlations found in this study. Neither is the use of type traits for indirect selection for improved longevity. A claw health index based on recording by claw trimmers is preferable. Using bulls from other countries that lack EBVs for claw health in the Nordic countries may result in a decrease of the genetic progress for both claw and leg health and potentially also longevity within the Holstein population in the Nordic countries.

References

Ahlman, T., Berglund, B., Rydhmer, L. & Strandberg, E. (2011). Culling reasons in organic and conventional dairy herds and genotype by environment interaction for longevity. *Journal of Dairy Science*, 94, 1568 – 1575

Alban, L. (1995). Lameness in Danish dairy cows: frequency and possible risk factors. *Preventive Veterinary Medicine*, 22, 213 – 225

Alvåsen, K., Jansson Mörk, M., Hallén Sandgren, C., Thomsen, P.T. & Emanuelson, U. (2012). Herd-level risk factors associated with cow mortality in Swedish dairy herds. *Journal of Dairy Science,* 95, 4352 – 4362

Anonymous. (2001). Scientists' Assessment of the Impact of Housing and Management on Animal Welfare. *Journal of Applied Animal Welfare Science*, 4, 3 – 52

Becker, J.C., Heins, B.J. & Hansen, L.B. (2012). Costs for health care of Holstein cows selected for large versus small body size. *Journal of Dairy Science*, 95, 5384 – 5392

Berry, D.P., Bastiaansen, J.W.M., Veerkamp, R.F., Wijga, S., Wall, E., Berglund, B. & Calus, M.P.L. Genome-wide associations for fertility traits in Holstein–Friesian dairy cows using data from experimental research herds infour European countries. *Animal*, 6:8, 1206 – 1215

Blanchard, P.J., Everett, R.W. & Searle, R. (1983). Estimation of Genetic Trends and Correlations for Jersey Cattle. *Journal of Dairy Science*, 66, 1947 – 1954

Boelling, D. & Pollott, G.E. (1998). Locomotion, lameness, hoof and leg traits in cattleI. Phenotypic influences and relationships. *Livestock Production Science*, 54, 193 – 203

Calo, L.L., McDowell, R.E., Dale Van Vleck, L. & Miller, P.D. (1973). Genetic aspects of beef production among Holstein-Friesians pedigree selected for milk production. *Journal of Animal Science*, 3, 676 – 682

Carlén, E. & Eriksson, J.Å. (2013). Kornas livslängd –hur påverkas gårdens resultat?. Djurhälso- och Utfodringskonferensen 2013. Skövde, Sweden 27 – 28 August. Available: http://www.vxa.se/Global/Dokument/Dokument/Konferenser/DU/Kornas_livslangd_hur_paverkas_gardens_resultat.pdf [2015-09-03]

Carlén, E. (2014). Har storleken betydelse?. Djurhälso- och Utfodringskonferensen 2014. Linköping, Sweden 27 – 28 August. Available: http://www.vxa.se/Global/Dokument/Dokument/Konferenser/DU/DU2014/Har_storleken_betydelse.pdf [2015 - 09 - 04]

Cook, N.B. & Nordlund, K.V. (2009). The influence of the environment on dairy cow behavior, claw health and herd lameness dynamics. *The Veterinary Journal*, 3, 360 – 369

Dhakal, K., Tiezzi, F., Clay, J.S. & Maltecca, C. (2015). Short communication: Genomic selection for hoof lesions in first-parity US Holsteins. *Journal of Dairy Science*, 98, 3502 – 3507

Distl, O., Koorn, D.S., McDaniel, B.T., Peterse, D., Politiek, R.D. & Reurink, A. (1990). Claw traits in cattle breeding programs: Report of the E.A.A.P. working group "Claw quality in cattle". *Livestock Production Science*, 25, 1 – 13

Dobson, H., Smith, R.F., Royal, M.D., Knight, C.H. & Sheldon, I.M. (2007). The high-producing dairy cow and its reproductive performance. *Reproduction in Domestic Animals*, 42, 17 – 23

Enting, H., Kooij, D., Dijkhuzien, A.A., Huirne, R.B.M. & Noordhuzien – Stassen, E.N. (1997). Economic losses due to clinical lameness in dairy cattle. *Livestock Production Science*, 49, 259 – 267

Eriksson, J.Å. (2006). Swedish sire evalutation of hoof diseases based on hoof trimming records. *Interbull Bulletin*, 35

Essl, A. (1998). Longevity in dairy cattle breeding: a review. *Livestock Production Science*, 57, 79 – 89

Esslemont, R.J. & Kossaibati, M.A. (1997). Culling in 50 dairy herds in England. *The Veterinary Record,* 140, 36 – 39

Funk, D.A. (2006). Major Advances in Globalization and Consolidation of the Artificial Insemination Industry. *Journal of Dairy Science,* 89, 1362 – 1368

Groen, Ab.F., Steine, T., Colleau, J-J., Pedersen, J., Pribyl, J. & Reinsen, N. (1997). Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. *Livestock Production Science,* 49, 1 – 21

Haas, de. Y., Janss, L.L.G. & Kadarmideen, H.N. (2007). Genetic and phenotypic parameters for conformation and yield traits in three Swiss dairy cattle breeds. *Journal of Animal Breeding and Genetics,* 124, 12 – 19

Hansen, L.B., Cole, J.B., Marx, G.D. & Seykora, A.J. (1999). Productive Life and Reasons for Disposal of Holstein Cows Selected for Large Versus Small Body Size. *Journal of Dairy Science,* 82, 795 – 801

Hansen, L.B. (2000). SYMPOSIUM: SELECTION FOR MILK YIELD Consequences of Selection for Milk Yield from a Geneticist's Viewpoint. *Journal of Dairy Science,* 83, 1145 – 1150

Holstein Association USA Inc. (2014). *Linear Descriptive Traits.* Available: http://www.holsteinusa.com/pdf/print_material/linear_traits.pdf [2015-09-15]

Holstein Association USA Inc. (2015). *TPI Formula – April 2015*. Available: http://www.holsteinusa.com/genetic_evaluations/ss_tpi_formula.html [2015-10-10]

Holstein Association USA Inc. (2016). *Linear Type Evaluations.* Available: http://www.holsteinusa.com/genetic_evaluations/ss_linear.html [2016-01-14]

Holstein Foundation. (2015). *Understanding Genetics and the Sire Summaries.* Available: http://www.holsteinfoundation.org/pdf_doc/workbooks/Gen_Sire_WKBK.pdf

Häggman, J. & Juga, J. (2013). Genetic parameters for hoof disorders and feet and leg conformation traits in Finnish Holstein Cattle. *Journal of Dairy Science,* 96, 3319 – 3325

International Committee for Animal Recording, ICAR (2015).*Conformation Recording Dairy and Beef Cattle.* Available: http://www.icar.org/Documents/Rules%20and%20regulations/Guidelines/Krakow_2015/Conformation%20Recording%20(CR%20WG).pdf [2015-09-15]

Jairath, L., Dekkers, J.C.M., Schaeffer, L.R., Liu, Z., Burnside, E.B. & Kolstad, B. (1998). Genetic Evaluation for Herd Life in Canada. *Journal of Dairy Science,* 81, 550 – 562

Johansson, K., Eriksson, J.Å., Nielsen, U.S., Pösö, J. & Aamand, G.P. (2011). Genetic Evaluation of Claw Health in Denmark, Finland and Sweden. *Interbull Bulletin,* 44, 224 – 228

Kadarmideen, H.N., Thompson, R. & Simm, G. (2000). Linear and threshold model genetic parameters for disease, fertility and milk production in dairy cattle. *Animal science,* 71, 411 – 419

Kern, E.L., Cobuci, J.A., Costa, C.N., McManus, C.M. & Neto, J.B. (2015). Genetic association between longevity and linear type traits of Holstein cows. *Scienta Agricola,* 72, 203 – 209

Larroque, H. & Ducrocq, V. (2001). Relationship between type and longevity in the Holstein breed. *Genetics Selection Evolution,* 33, 39 – 59

Lehrman, A. (2014). *Shaping our food – an overview of crop and livestock production.* Available: http://www.slu.se/Documents/externwebben/centrumbildningar-projekt/Mistra%20Biotech%20-%20dokument/publikationer/ShapingOurFood_MistraBiotech_WEB_140625.pdf [2015-12-20]

Laursen, M.V., Boelling, D. & Mark, T. (2009). Genetic parameters for claw and leg health, foot and leg conformation, and locomotion in Danish Holsteins. *Journal of Dairy Science,* 92, 1770 – 1777

MacDonald, J. & Newton, D. (2014). *Milk Production Continues Shifting to Large-Scale Farms.* Available: http://www.ers.usda.gov/amber-waves/2014-december/milk-production-continues-shifting-to-large-scale-farms.aspx#.VeVUIvmqqkp [2015-09-01]

Manske, T., Hultgren, J. & Bergsten, C. (2002). Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. *Preventive Veterinary Medicine,* 54, 247 – 263

Mark, T. (2004). Applied genetic evaluations for production and functional traits in dairy cattle. *Journal of Dairy Science,* 87, 2641 – 2652

Metz, J.H.M. & Bracke, M.B.M. (2005). Assessment of the impact of locomotion on animal welfare, 54th annual meeting of the EEAP, Rome 2003. *Stoýarvsto,* 59, 31 – 38

Miglior, F., Muir, B.L. & Van Doormaal, B.J. (2005). Selection indices in Holstein cattle of various countries. *Journal of dairy science,* 88, 1255 – 1263

Miller, R.H., Kuhn, M.T., Norman, H.D. & Wright, J.R. (2008). Death losses for lactating cows in herds enrolled in dairy herd improvement testplans. *Journal of Dairy Science,* 91, 3710 – 3715

NAV – Nordic Cattle Genetic Evaluation. (2013). *NAV routine genetic evaluation of Dairy Cattle – data and genetic models*. Available: http://www.nordicebv.info/wp-content/uploads/2015/04/General-description_from-old-homepage_06052015.pdf [2015-10-10]

NAV – Nordic Cattle Genetic Evaluation. (2015). *About NAV.* Available: http://www.nordicebv.info/about-nav/ [2015-10-10]

NAV – Nordic Cattle Genetic Evaluation.(2015b). *Electronic claw health registration – now also in Finland and Sweden.* Available: http://www.nordicebv.info/health/ or: http://www.nordicebv.info/wp-content/uploads/2015/04/Registrations-from-hoof-health_Eng_final.pdf [2015-11-09]

Odegard, C., Svendsen, M. & Heringstad, B. (2014). Genetic correlation between claw health and feet and leg conformation in Norwegian Red Cows. *Journal of Dairy Science,* 97, 4522 – 4529

Oltenacu, P.A. & Algers, B. (2005). Selection for Increased Production and the Welfare of Dairy Cows: Are NewBreeding Goals Needed?. *AMBIO: A Journal of the Human Environment,* 34, 311 – 315

Philipsson, J. & Lindhé, B. (2003). Experiences of including reproduction and health traits in Scandinavian dairy cattle breeding programmes. *Livestock Production Science,* 83, 99 – 112

Phillips, C.J.C. (2010). *Principles of cattle production.* 2nd. Ed. Oxfordshire: CABI Publishing

Politiek, R.D., Distl, O., Fjeldaas, T., Heeres, J., McDaniel, B.T., Nielsen, E., Peterse, D.J., Reurink, A. & Strandberg, P. (1986). Importance of claw quality in cattle: Review and recommendations to achieve genetic improvement. Report of the E.A.A.P. working group on "Claw Quality in Cattle". *Livestock Production Science,* 15, 133 – 152

Rogers, G.W., Banos, G. & Sander-Nielsen, U. (1999). Genetic Correlations Among Protein Yield, Productive Life, and Type Traits from the United States and Diseases Other than Mastitis from Denmark and Sweden. *Journal of Dairy Science,* 82, 1331 – 1338

Rogers, G.W., McDaniel, B.T., Dentine, M.R. & Funk, D.A. (1989). Genetic Correlations Between Survival and Linear Type Traits Measured in First Lactation. *Journal of Dairy Science,* 72, 523 – 527

SAS Institute. (2014). SAS/STAT Software. Release 9.4 SAS Institute. Inc., Cary, North Carolina.

Schneider, M.D.P., Monardes, H.G. & Cue, R.I. (1999). Effects of Type traits on Functional Herd Life in Holstein Cows. *Interbull Bulletin,* 21, 111 – 116

SEGES. (2015). *Correction of Linear Assessments of Dairy Cattle*. Available: https://www.landbrugsinfo.dk/Kvaeg/Avl/Kaaring-og-eksterioertal/Sider/Correction_of_Linear_Assessments_of_Dair.aspx [2015-11-11]

SEGES, (2015b). *Optimum, average and weighing factor of traits for: Holstein*. Available: https://www.landbrugsinfo.dk/Kvaeg/Avl/Kaaring-og-eksterioertal/Sider/Classification_of_Dairy_Cattle.aspx [2015-11-11]

Sewalem, A., Kistemaker, G.J., Miglior, F. &Van Doormaal, B.J. (2004). Analysis of the Relationship Between Type Traits and Functional Survival in Canadian Holsteins Using a Weibull Proportional Hazards Model. *Journal of Dairy Science*, 87, 3938 – 3946

Shearer, J.K.. (1997).Lameness of dairy cattle: consequences and causes. *University of Minnesota Digital Conservancy*, Available: http://purl.umn.edu/118848

Simm, G. (2002). Genetic improvement of cattle and sheep. Oxfordshire: CABI publishing.

Sogstad, A.M., Fjeldaas, T., Østera, O. & Plym Forshell, K. (2005). Prevalence of claw lesions in Norwegian dairy cattle housed in tie stalls and free stalls. *Preventive Veterinary Medicine*, 70, 191 – 209

Somers. J.G.C.J., Frankena, K., Noordhulzen – Stassen, N. & Metz, J.H.M. (2003). Prevalence of Claw Disorders in Dutch Dairy Cows Exposed to Several Floor Systems. *Journal of Dairy Science,* 86, 2082 – 2093

Statens jordbruksverks föreskrifter och allmänna råd om djurhållning inom lantbruket m.m. (2010). Jönköping. (SJVFS 2010:15)

Statistics Sweden. (2014). *Yearbook of agriculture statistics 2014.* Örebro: SCB – Tryck.

Swedish Dairy Association. (2012). *Cattle Statistics 2012*. Available: http://www.gardochdjurhalsan.se/upload/documents/Dokument/Startsida_Not/Kunskapsbank/Statistik/Husdjursstatistik_Svensk_Mjolk_2012.pdf [2016-01-30]

Thomsen, P.T., Kjeldsen, A.M., Sorensen, J.T. & Houe, H. (2004). Mortality (including euthanasia) among Danish dairy cows (1990 – 2001). *Preventive Veterinary Medicine,* 62, 19 – 33

Uggla, E., Jakobsen, J.H., Bergsten, C., Eriksson, J-Å. & Strandberg, E. (2008). Genetic correlations between Claw health and Feet and Leg conformation traits in Swedish Dairy Cows. *Interbull Bull,* 38, 91 – 95

Van der Linde, C., de Jong, G., Koenen, E.P.C. & Eding, H. (2010). Claw health index for Dutch dairy cattle based on claw trimming and conformation data. *Journal of Dairy Science*, 93, 4883 – 4891

Van der Spek, D., Van Arendonk, J.A.M., Vallée, A.A.A. & Bovenhuis, H. (2013). Genetic parameters for claw disorders and the effect of preselecting cows for trimming. *Journal of Dairy Science,* 96, 6070 – 6078

Vollema, A.R. (1998). *Selection for longevity in dairy cattle.* Doctoral thesis. Wageningen: Wageningen Agricultural University. Available: http://edepot.wur.nl/206306 [2015-09-29]

Växa Sverige. (2013). *Cattle Statistics 2013.* Available: http://www.gardochdjurhalsan.se/upload/documents/Dokument/Startsida_Not/Kunskapsbank/Statistik/Husdjursstatistik_Svensk_Mjolk_2013.pdf [2016-01-30]

Växa Sverige. (2013b). *Nordic claw atlas – Defenitions of clawdisorders, Nordisk klövatlas – Definitioner av klövdiagnoser.* Available: http://www.vxa.se/Documents/Rapporter/SE%20Claw%20Atlas%202013-08-29%20webb.pdf?epslanguage=sv [2015-11-09]

Växa Sverige. (2014). *Cattle Statistics 2014.* Available: http://www.gardochdjurhalsan.se/upload/documents/Dokument/Startsida_Not/Kunskapsbank/Statistik/husdjursstatistik_2014_slutl.pdf [2016-01-30]

Växa Sverige. (2015). *Cattle Statistics 2015.* Available: http://www.vxa.se/Documents/Husdjursstatistik2015_ver2015-02-11.pdf [2016-02-09]

Växa Sverige. (2016). *Cattle Statistics 2016.* Available: http://www.vxa.se/Global/Dokument/Dokument/%c3%96vrigt/Husdjursstatistik2016.pdf [2016-12-21]

Zavadilová. L. & Štípková. M. (2012). Genetic correlations between longevity and conformation traits in the Czech Holstein population. *Czech Journal of Animal Science,* 3, 125 – 136