Genetic parameters for milk coagulation properties in Estonian Holstein cows

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ABSTRACT

The objective of this study was to estimate heritabilities and repeatabilities for milk coagulation traits [milk coagulation time (RCT) and curd firmness (E_{30})] and genetic and phenotypic correlations between milk yield and composition traits (milk fat percentage and protein percentage, urea, somatic cell count, pH) in first-lactation Estonian Holstein dairy cattle. A total of 17,577 test-day records from 4,191 Estonian Holstein cows in 73 herds across the country were collected during routine milk recordings. Measurements of RCT and E_{30} determined with the Optigraph (Ysebaert, Frepillon, France) are based on an optical signal in the near-infrared region. The cows had at least 3 measurements taken during the period from April 2005 to January 2009. Data were analyzed using a repeatability animal model. There was substantial variation in milk coagulation traits with a coefficient of variation of 27% for E_{30} and 9% for the log-transformed RCT. The percentage of variation explained by herd was 3% for E_{30} and 4% for RCT, suggesting that milk coagulation traits are not strongly affected by herd conditions (e.g., feeding). Heritability was 0.28 for RCT and 0.41 for E_{30} , and repeatability estimates were 0.45 and 0.50, respectively. Genetic correlation between both milk coagulation traits was negligible, suggesting that RCT and E_{30} have genetically different foundations. Milk coagulation time had a moderately high positive genetic (0.69) and phenotypic (0.61) correlation with milk pH indicating that a high pH is related to a less favorable RCT. Curd firmness had a moderate positive genetic (0.48) and phenotypic (0.45) correlation with the protein percentage. Therefore, a high protein percentage is associated with favorable curd firmness. All reported genetic parameters were statistically significantly different from zero. Additional univariate random regression analysis for milk coagulation traits yielded slightly higher average heritabilities of 0.38 and 0.47 for RCT and E_{30}

compared with the heritabilities of the repeatability model.

Key words: milk coagulation, heritability, genetic correlation, Estonian Holstein dairy cattle

INTRODUCTION

Recent trends indicate that an increasing percentage of milk produced in European countries is used for manufacturing cheese (Eurostat, 2009). At present, in Italy more than 75% (De Marchi et al., 2008), in Scandinavian countries 33% (Wedholm et al., 2006), and in Estonia 60% (Statistics Estonia, 2009) of milk is being used for cheese production. Milk coagulation properties are important to the quality and yield of cheese (Leitner et al., 2006; Wedholm et al., 2006; De Marchi et al., 2009); therefore, these properties become more important if an increasing percentage of milk is used for cheese manufacturing. Milk coagulation properties are commonly defined by milk coagulation time and curd firmness. A short milk coagulation time and a firmer curd are favorable for cheese production. Shorter milk coagulation time may be beneficial to cheesemaking because it leaves more time for curd firming during the coagulation process. A firmer curd during clotting is positively correlated with cheese yield (Aleandri et al., 1989; Martin et al., 1997). Ikonen et al. (1999a) observed greater cheesemaking efficiency from milk with good coagulation properties.

Milk coagulation is a complex process and is not understood in detail, but studies have indicated that it is affected by numerous factors including casein composition (Okigbo et al., 1985a), SCC (Politis and Ng-Kwai-Hang, 1988), concentrations of total casein and calcium (Storry et al., 1983; Summer et al., 2002), pH (Najera et al., 2003), genetic polymorphism of milk proteins (Van den Berg et al., 1992; Mayer et al., 1997; Ikonen et al., 1999b), stage of lactation (Okigbo et al., 1985b; Ostersen et al., 1997), season (O'Brien et al., 1999), and breed (Auldist et al., 2002, 2004; De Marchi et al., 2008). Although it has been suggested that genetic factors affect milk coagulation, few studies have quantified the extent to which genetic factors play a

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role. Reported heritability estimates for milk coagulation traits range from 0.15 to 0.40 (Ikonen et al., 1999c, 2004; Tyrisev et al., 2004; Cassandro et al., 2008). Furthermore, only a few studies have reported genetic relationships between milk coagulation traits and milk production and composition traits (Ikonen et al., 1999c, 2004; Cassandro et al., 2008). Knowledge of the genetic parameters of milk coagulation traits and their associations with milk production is important when considering ways to improve milk coagulation by means of genetic selection. Before including milk coagulation traits in the breeding goal, the economic value of these traits needs to be determined. There is a large amount of information about the application of biotechnology to cheese manufacturing but very little about the feasibility of enhancing cheese production efficiency by the genetic improvement of milk coagulation.

The aim of this study was to estimate the heritability and repeatability for milk coagulation traits and their genetic correlation with milk yield and composition, SCS, urea, and pH levels.

MATERIALS AND METHODS

Data Collection

First-lactation milk samples were collected during routine milk recording as part of a development project for the Bio-Competence Centre of Healthy Dairy Products in Estonia during the period from April 2005 to January 2009. The herds were milked 2 or 3 times a day. The individual milk samples collected from the cows were a mixture of all test-day milkings or only the morning, afternoon, or evening milkings on the test-day. Milk samples were immediately preserved with Bronopol (Knoll Pharmaceuticals, Nottingham, UK) and stored at 4C during the transportation and analyzing periods. Milk samples with a pH <6.5, indicative of colostrum (Bhandari and Singh, 2002), and noncoagulated milk samples (n = 52) were excluded from the analysis. Additionally, farms with fewer than 10 cows and cows with fewer than 3 test-day records were removed. The final data set used for analyses consisted of 17,577 test-day records from 4,191 Estonian Holstein cows located in 73 herds across the country and that were daughters of 274 sires. The number of daughters per sire ranged from 1 to 267. Each cow has 3 to 6 measurements collected during the different stages (7 to 305 DIM) of the first lactation.

Information about the cows, herds, and pedigrees was obtained from the Estonian Animal Recording Centre (EARC) and the Animal Breeders' Association of Estonia, and entered into the database COAGEN of the Bio-Competence Centre of Healthy Dairy Products.

Laboratory Analysis

The test-day milk yield was recorded and individual milk samples were analyzed for fat percentage, protein percentage, and urea using the MilkoScan 4000 and MilkoScan FT6000, and for SCC using the Fossomatic 400 and Fossomatic 5000 cell counter (all equipment from Foss, Hillerd, Denmark) at the Milk Analysis Laboratory of EARC, using methods suggested by the International Committee for Animal Recording (2009). Values of SCC were log-transformed to SCS: $SCS = \log_2(SCC/100,000) + 3$.

The pH and milk coagulation properties were determined at the Laboratory of Milk Quality of the Estonian University of Life Sciences (Tartu, Estonia) generally 3 d after sampling. The proportion of milk samples with a maximum age of 7 d was very small (<1%). The pH level of the milk was determined using a pH meter (Seven Multi, Mettler Toledo GmbH, Greifensee, Switzerland) at a temperature of 20C before analyzing the milk coagulation properties. The latter were milk coagulation time (**RCT**, min) and curd firmness (**E**₃₀, mm). Before assessment of the milk coagulation properties, milk samples were heated to the renneting temperature (35C). The rennet (Milase MRS 750 international milk clotting units/mL; CSK Food Enrichment B.V., Ede, the Netherlands) used in the analyses was diluted 1:100 (vol/vol) with distilled water, and 0.2 mL of the solution was added to 10 mL of milk. The milk coagulation properties were determined using the Optigraph (Ysebaert, Frepillon, France), which was developed by Ysebaert Dairy Division in partnership with Institut National de la Recherche Agronomique, Laboratoire de Gnie et Microbiologie des Procds Alimentaires (Thiverval-Grignon, France), to define coagulation characteristics in the laboratory, especially to answer the needs of cheese makers (Ysebaert Dairy Division, 2009).

Measurements made with the Optigraph are not based on a rheological measures but on an optical signal in the near-infrared region. During a coagulation test, the light emitted through the milk gradually weakens because of changes in the micellar structure of casein. The Optigraph then calculates the coagulation parameters (coagulation time, curd firmness, and speed of aggregation) by means of particular feature points extracted from the optical information acquired in real time. Optigraph system parameters were set as follows: R slope = 1.784 and R offset = -2.303. Milk coagulation time was recorded directly based on the maximum first derivative of the signal. To determine the firmness of the curd, the Optigraph signal 30 min after the addition of the rennet was converted into millimeters using a calibration equation (Kubarsepp et al., 2005).

Table 1. Number of observations (n), means, and coefficients of variation (CV) for test-day milk coagulation, production, and composition traits

Trait	n	Mean	CV (%)
Curd firmness (E ₃₀) (mm)	17,577	27.0	27
Milk coagulation time (RCT) ¹ (min)	17,577	2.3	9
Milk yield (kg)	17,575	25.9	28
Fat (%)	17,536	4.05	17
Protein (%)	17,567	3.38	9
SCS ²	17,567	2.9	65
Urea (mg/L)	17,223	26.8	31
pH	17,577	6.6	1

¹Log-transformed.²SCS = [$\log_2(\text{SCC}/100,000) + 3$].

Statistical Analysis

Statistical analysis was carried out in ASReml (Gilmour et al., 2002) using the following repeatability animal model:

$$Y_{ijklmn} = \mu + \beta_1 DIM_i + \beta_2 DIM_i^2 + \beta_3 age + ys_j + cys_k + herd_l + animal_m + pe_n + e_{ijklmn},$$

where Y_{ijklmn} = dependent variable (log-transformed RCT, E₃₀, milk yield, milk protein and fat percentages, SCS, urea, pH); μ = overall mean; DIM_i = i th day in milk, modeled with quadratic polynomial; age = linear regression on age at calving; β_1 , β_2 , and β_3 = regression coefficients; ys_j = fixed effect of sampling year-season ($j = 1, \dots, 16$ with 3-mo classes from April 2005 to January 2009); cys_k = fixed effect of calving year-season ($k = 1, \dots, 15$ with 3-mo classes from December 2004 to August 2008); $herd_l$ = random effect of herd ($l = 1, \dots, 73$), $herd_l \sim N(0, \mathbf{I}\sigma_h^2)$; $\mathbf{I}$ = identity matrix; $animal_m$ = random effect of animal ($m = 1, \dots, 17,185$), $animal_m \sim N(0, \mathbf{A}\sigma_a^2)$; $\mathbf{A}$ = additive genetic relationship matrix; pe_n = random permanent environmental term ($n = 1, \dots, 4,191$), $pe_n \sim N(0, \mathbf{I}\sigma_{pe}^2)$; and e_{ijklmn} = residual random error term, $e_{ijklmn} \sim N(0, \mathbf{I}\sigma_e^2)$. For normality assumption, log-transformation of RCT was used.

Three generations of ancestors were included in the analysis and 17,185 animals were included in the relationship matrix. Heritabilities were estimated with univariate models, and genetic correlations were derived from bivariate models.

Heritability (h^2) was calculated as

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2},$$

repeatability (r) was calculated as

$$r = \frac{\sigma_a^2 + \sigma_{pe}^2}{\sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2},$$

and the proportion of variation due to herds (hrd) was calculated as

$$hrd = \frac{\sigma_h^2}{\sigma_h^2 + \sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2},$$

where σ_a^2 = additive genetic variation; σ_{pe}^2 = permanent environmental variation; σ_e^2 = residual variation; and σ_h^2 = herd variation.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 shows descriptive statistics of the milk coagulation traits, and milk production and composition traits. There was substantial variation in milk coagulation traits as indicated by the coefficient of variation (CV) of 27% for E₃₀ and 9% for the log-transformed RCT. Milk yield had a CV similar to that of E₃₀ (28%), whereas the CV was higher for urea (31%). There was little variation in pH (CV = 1%).

Systematic Environmental Effects

Table 2 shows the fraction of total phenotypic variance due to herd, reflecting the relative importance of differences between herds, probably mainly because of differences in feeding. Milk coagulation properties were not strongly influenced by differences between herds: the proportion of variation due to the herd was 0.04 for RCT and 0.03 for E₃₀. The proportion of the variance explained by herd was also low for milk composition traits. For milk yield, a substantial percentage of the variation was due to the herd (25%). Tyrisevä et al. (2004) reported slightly higher proportions of variation explained by herd for RCT (6%) and E₃₀ (9%). Ikonen et al. (2004) reported similar results as in the present study with a small fraction of the variation explained by herd (5%) for RCT and E₃₀. Herd effects for milk yield, fat percentage, and protein percentage in studies by Tyrisevä et al. (2004) and Ikonen et al. (2004) were higher (ranging from 15 to 48%) than our estimates. Milk coagulation properties therefore seem to be affected to a smaller extent by the herd environment than are milk composition traits. This suggests that it is difficult to improve milk coagulation properties by herd management factors such as nutrition.

The effect of DIM on milk coagulation properties is shown in Figure 1. Rennet coagulation time increased toward the end of lactation and stabilized after d 180 to less favorable values. Curd firmness showed a different pattern with less favorable values during the first part of lactation and more favorable (higher) values toward the end of the lactation.

Variation in the time between milk sampling and analysis may also have an effect on milk coagulation properties. Ikonen et al. (2004) reported a significant effect of the time between milk sampling and analysis on curd firmness. We were not able to adjust for this effect, because this information was not available for all samples. Based on the design of the current study, we may state that the time between milk sampling and analysis could have varied from 1 to 7 d. This variation was, however, much smaller than in the study by Ikonen et al. (2004) (0 – 27 d) and therefore is expected to have less effect on milk coagulation properties.

Heritabilities and Repeatabilities

Heritabilities and repeatabilities of all traits studied were statistically significantly different from zero ($P < 0.05$). Heritabilities of milk coagulation properties were 0.41 for curd firmness and 0.28 for milk coagulation time (Table 2). The heritability estimate for RCT was similar to that reported by Ikonen et al. (2004) but somewhat higher than other estimates (0.21 to 0.25) reported for Finnish and Italian dairy cattle populations (Ikonen et al., 1999c; Tyrisevä et al., 2004; Cassandro et al., 2008). Heritability of E_{30} was consistent with the estimate (0.4) reported by Ikonen et al. (1999c) but higher than other estimates (0.15 to 0.22) available in literature (Ikonen et al., 2004; Tyrisevä et al., 2004; Cassandro et al., 2008). These differences may be due to genetically different cattle populations. The differ-

Figure 1. Lactation curve of log-transformed milk coagulation time [log (RCT)] and curd firmness (E_{30}) during the lactation period 7 to 305 DIM.

ence in methods might also have influenced variation in milk coagulation traits. Coefficients of variation for milk coagulation traits in the studies (Ikonen et al., 1999c) using the Formagraph (Foss) or in the studies (Ikonen et al., 2004; Tyrisevä et al., 2004; Cassandro et al., 2008) using Computerized Renneting Meter (Polo Trade, Monselice, Italy) are larger than in our study (ranging from 27 to 50%). In our study, heritabilities for milk coagulation traits were higher than those for milk yield and composition traits. The highest heritability for a milk composition trait was for protein percentage (0.28); that for milk yield was 0.15. Heritability was low for SCS (0.05) and urea (0.07).

Repeatabilities for RCT (0.45) and E_{30} (0.50) were high and of the same order of magnitude as repeatabilities for milk yield (0.47) and protein percentage (0.46). Urea had a low repeatability of 0.19. The repeatability for SCS was moderately high (0.37).

Repeatabilities for RCT and E_{30} reported in Finnish studies by Ikonen et al. (1997) and Tyrisevä et al. (2003) are somewhat higher (from 0.57 to 0.68) than ours,

Table 2. The estimates of heritability (h^2), repeatability (r), proportion of variance due to herd (hrd), and total phenotypic variance (σ_P^2)¹ for the traits studied

Trait	h^2 (SE)	r (SE)	hrd (SE)	σ_P^2
Curd firmness (E_{30}) (mm)	0.41 (0.04)	0.50 (0.01)	0.03 (0.01)	49.27
Milk coagulation time (RCT) ² (min)	0.28 (0.04)	0.45 (0.01)	0.04 (0.01)	3.15
Milk yield (kg)	0.15 (0.03)	0.47 (0.01)	0.25 (0.03)	38.00
Fat (%)	0.19 (0.03)	0.32 (0.01)	0.06 (0.01)	0.47
Protein (%)	0.28 (0.04)	0.46 (0.01)	0.06 (0.01)	0.06
SCS ³	0.05 (0.02)	0.37 (0.01)	0.03 (0.01)	3.50
Urea (mg/L)	0.07 (0.02)	0.19 (0.01)	0.11 (0.02)	64.73
pH	0.24 (0.03)	0.36 (0.01)	0.06 (0.01)	0.31

¹ $\sigma_P^2 = \sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2$. σ_a = additive genetic variance, σ_{pe} = permanent environmental variance, and σ_e = residual variance.

²Log-transformed.

³SCS = [3 + log₂(SCC/100,000)].

Table 3. Phenotypic (above the diagonal) and genetic correlations (below the diagonal; SE in parentheses) between milk coagulation properties, production, and composition traits¹

Item	E ₃₀ (mm)	RCT	Milk yield (kg)	Fat (%)	Protein (%)	SCS	Urea (mg/L)	pH
Curd firmness (E ₃₀) (mm)		−0.22	−0.06	0.11	0.45	0.01	0.02	−0.15
Milk coagulation time (RCT) ² (min)	−0.16 (0.09)		−0.01	−0.04	0.15	0.10	0.03	0.61
Milk yield (kg)	−0.29 (0.11)	−0.07 (0.12)		−0.33	−0.18	−0.12	0.09	−0.08
Fat (%)	0.25 (0.09)	−0.10 (0.10)	−0.65 (0.09)		0.25	0.12	−0.03	−0.05
Protein (%)	0.48 (0.07)	0.19 (0.10)	−0.51 (0.09)	0.49 (0.08)		0.16	−0.11	−0.02
SCS ³	−0.04 (0.15)	−0.06 (0.15)	0.12 (0.18)	−0.05 (0.16)	−0.02 (0.15)		−0.17	0.12
Urea (mg/L)	0.19 (0.12)	−0.00 (0.12)	0.13 (0.15)	−0.21 (0.13)	−0.12 (0.13)	0.12 (0.19)		0.00
pH	−0.06 (0.09)	0.69 (0.05)	0.07 (0.12)	−0.26 (0.10)	−0.12 (0.10)	−0.22 (0.14)	0.07 (0.12)	

¹SE of phenotypic correlations were 0.01 to 0.02.²Log-transformed.³SCS = [$\log_2(\text{SCC}/100,000) + 3$].

which may also reflect the different measuring aspects of coagulation in these studies. The high repeatability estimates for RCT and E₃₀ in our study, however, show that only a few measurements are needed for reliable genetic estimation of milk coagulation properties.

Genetic and Phenotypic Correlations

Genetic correlation between the 2 milk coagulation properties (Table 3) was negligible, suggesting that milk coagulation time and curd firmness measured by the Optigraph are mainly influenced by different genes. Other correlations reported here were significantly different from zero ($P < 0.05$). Phenotypic correlation between the 2 milk coagulation properties was slightly higher (−0.22). Both estimates were lower than those reported in previous studies (Ikonen et al., 1999c, 2004; Tyrisevä et al., 2004; Cassandro et al., 2008), ranging from −0.89 to −0.96. This result may indicate that the Optigraph device used in our study measures somewhat different aspects of milk coagulation compared with the devices used in previous studies (Formagraph and Computerized Renneting Meter), whose measurements of coagulation traits are based on direct measurement of viscosity. In our research, the Optigraph uses an optical signal, which is transformed to values for E₃₀ (mm) by using a calibration equation (Kübarssepp et al., 2005).

Genetic correlations between milk coagulation and milk yield and composition traits were mainly low. Curd firmness had the highest genetic correlation with milk protein percentage (0.48), suggesting that a high protein percentage results in a favorable E₃₀. Cassandro et al. (2008) reported a correlation of 0.44 between E₃₀ and protein percentage, which is in agreement with our results. The genetic correlations of −0.24 and −0.07 reported by Ikonen et al. (1999c, 2004) on the same traits, however, are different. These inconsistencies in-

dicate that many factors may influence the relationship between E₃₀ and protein percentage, such as sample size, breed, model and devices, and variation in time between milk sampling and analysis.

Milk coagulation time had the strongest genetic correlation with pH (0.69). A high pH level is therefore associated with a less favorable RCT. This result is consistent with previous studies (Ikonen et al., 1999c, 2004; Cassandro et al., 2008), which also reported a moderate to high genetic correlation between RCT and pH (0.40 to 0.81). A moderate to high genetic correlation (−0.30 to −0.85) between E₃₀ and pH observed in previous studies (Ikonen et al., 1999c, 2004; Cassandro et al., 2008), however, was not found in our study; we estimated a zero genetic correlation between E₃₀ and pH.

Curd firmness showed a weak positive genetic correlation with milk fat percentage (0.25) and a weak negative genetic correlation with milk yield (−0.29). Therefore, selection for improved curd firmness may be associated with a somewhat higher fat percentage and slightly reduced milk production. Genetic correlations for E₃₀ with milk yield and fat percentage were negligible in previous studies (Ikonen et al., 1999c, 2004; Cassandro et al., 2008).

Phenotypic correlations between milk coagulation properties and milk composition traits were similar or somewhat lower than the corresponding genetic correlations, except for slightly stronger phenotypic correlations between coagulation properties (−0.22) and for E₃₀ with pH (−0.15). Previous studies (Ikonen et al., 1999c, 2004; Cassandro et al., 2008) reported weak phenotypic correlations between milk coagulation traits and milk yield and composition traits, except for a moderately strong correlation between milk coagulation traits and pH and a moderate correlation for E₃₀ with protein percentage. We found a somewhat higher

positive phenotypic correlation for protein percentage with both milk coagulation properties and a lower phenotypic correlation between E_{30} and pH level.

The association of E_{30} with protein percentage can be explained by the key role of caseins in the milk coagulation process. Aggregation of casein micelles, the second phase of rennet coagulation process, starts only after about 87% of κ -casein is enzymatically degraded (Lucey, 2002). Van Hooydonk et al. (1986) reported that the optimum pH for hydrolysis of κ -casein is in the range from 5.1 to 5.3. This could explain the positive phenotypic correlation between RCT and pH levels, suggesting that a lower pH shortens RCT.

To our knowledge, no genetic and phenotypic correlations between milk coagulation traits and urea have been published. All genetic and phenotypic correlations of urea with other milk composition traits and milk yield were low and nonsignificant in our study. Our results were of the same magnitude as the values reported by Stoop et al. (2007), except for the high genetic correlation between urea and SCS (0.85) reported by Stoop et al. (2007).

The average SCS in our study was slightly lower than the values derived from the monthly reported average SCC (Estonian Animal Recording Centre, 2008) for cows in milk recording during 2008 (92% of all cows in Estonia). For this reason, probably, we did not find any nonzero genetic correlations between SCS and milk coagulation traits. Ikonen et al. (2004) and Cassandro et al. (2008), however, reported that lower SCS are associated with improved milk coagulation properties. Some authors report that SCC has an unfavorable effect on milk coagulation properties at the phenotypic level (Politis and Ng-Kwai-Hang, 1988; O'Brien et al., 2001); Somers et al. (2002), however, did not find a significant effect of SCC on milk coagulation properties. To investigate a possible nonlinear relationship for SCS with RCT and E_{30} , we performed additional analyses in which SCS was included as a linear and as a quadratic covariate in the model. The results showed a small unfavorable effect of higher SCS ($P < 0.05$) on RCT and E_{30} . Adjusting for SCS differences in the model did not affect the estimated heritabilities.

In general, genetic and phenotypic correlations among milk yield and composition traits were in accordance with previous studies (Ikonen et al., 1999c, 2004; Cassandro et al., 2008).

Genetic Parameters with a Random Regression Analysis

In this article we used a repeatability model, which showed a good fit to the data (standard deviation of residuals was 1.17 for log-transformed RCT and 4.40 for

E_{30}) and residual independence of DIM (residual and squared residual correlations across DIM were <0.05 for both milk coagulation traits). Because residuals were independent of lactation stage, variation due to DIM was sufficiently described by a repeatability model. For milk coagulation traits, however, additional univariate random regression models with second-order Legendre polynomials for the additive genetic and permanent environmental effects (except for first-order Legendre polynomial for permanent environmental effect of RCT) were applied to compare heritability and repeatability estimates and residuals with results from repeatability model analysis. Residual standard deviations of the random regression model were somewhat smaller than residuals from the repeatability model (standard deviation of residuals from repeatability and random regression model were 1.17 and 1.06, respectively, for RCT and 4.40 and 3.40, respectively, for E_{30}). Based on monthly averages of residuals, differences between both models were small; however, the random regression model showed a somewhat better fit in the last 2 (mo 9 and 10) lactation months for curd firmness. Average heritability across lactation was 0.38 for RCT and 0.47 for E_{30} . Heritability of RCT increased toward the end of lactation and had a maximum of 0.44 in lactation mo 6 and 7. The heritability for E_{30} showed an increase during lactation and a maximum of 0.51 in mo 8 to 10 of lactation. Average repeatability estimates were 0.53 for RCT and 0.58 for E_{30} .

CONCLUSIONS

In our study of 17,577 test-day records from 4,191 first-lactation Estonian Holstein cows, we found RCT and E_{30} to be highly heritable. Genetic correlations of the milk coagulation traits with milk production and composition traits were weak; therefore, selection for milk coagulation properties is not expected to result in a strong deterioration of milk production and composition. Genetic and phenotypic correlations between milk coagulation time and curd firmness were different from those reported in previous studies, indicating that coagulation aspects measured by the new Optigraph device and other devices used may be different. Therefore, further research is needed to study the effect of the Optigraph milk coagulation measurements on cheese yield and quality.

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