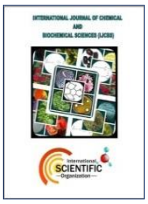
International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html



Prediction of Milk Productivity Based on Conformation Traits in Cows

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Abstract

The representation of individual animals and herds as a whole can be carried out based on their linear assessment. This allows organizing corrective selection aimed at eliminating specific exterior deficiencies in cows and influencing their body conformation, which is intricately linked with productive traits. Enhancing dairy cow productivity and its predictability is undeniably a relevant topic. Forecasting models may be employed to assess the productive potential of animals. In the breeding farm of the Novosibirsk region (Russia), a linear exterior assessment of first-calving Holstein cows (n = 35) from 30 to 150 days of lactation was conducted using a methodology combining traits utilized in the evaluation of dual-purpose dairy and beef cattle, as defined by ICAR standards: Stature, Body Depth, Chest Width, Rib Structure, Rump Length, Rump Angle, Rump Width, Muscularity, Rear Legs Set, Foot Angle, Fore Udder Attachment, Fore Udder Length, Rear Udder Height, Rear udder width, Central Ligament, Udder Depth, Front Teat Placement, Teat Length, Rear Teat Placement, Udder Balance, Rear Legs Rear View, Udder Texture. The calculation of regression coefficients was conducted using the least squares method. Selection of the most accurate and effective model was based on a comprehensive assessment of internal and external quality criteria. The dependent variable values corresponded to a Gaussian distribution. A high correlation was identified between the independent variables. As a result of selection based on internal and external quality criteria, an optimal milk yield prediction model for cows was identified, comprising four predictors: muscularity, rear legs set, fore udder length, udder depth. The model adheres to the necessary assumptions, namely: the residuals are normally distributed, there is an absence of autocorrelation, and influential observations. The obtained model can be utilized in the selection of cattle for predicting cows' milk yield based on their linear assessment.

Keywords: Holstein breed, first-calving heifers, linear assessment, milk productivity, modeling

Full length article

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1. Introduction

The animal's exterior type should be considered comprehensively in a complex relationship with productive qualities [1-3]. Scientists have proven a positive correlation between exterior indicators of dairy cows and their productivity [4-6]. Therefore, defining optimal body conformation is a pertinent focus in the selection of dairy cattle [7], as it primarily provides an understanding of the expression of the production type and its alignment with productivity goals [8-10]. Through a linear assessment of the exterior, insights into individual animals and herds as a whole can be obtained [2], enabling corrective selection to rectify individual exterior deficiencies in cows and influence their body conformation [11, 12]. The considerable variability of linear traits allows for effective selection and matching [13-15]. The genetic potential of dairy cows is significantly influenced by the sires used in the herd [11, 16], transmitting exterior features, milk productivity, health, and ease of calving to their first-calving daughters [17-19]. They can improve characteristics related to limb structure and udder quality by up to 25% [20]. For dairy cattle, it is necessary that the head be light, dry, and elongated; the chest deep and elongated; the abdomen capacious, well-developed but not pendulous; the hindquarters well-developed; the udder large, well-attached to the abdominal wall, highly developed, cup-shaped, or tub-shaped, with teats correctly positioned (squarely); the legs strong and relatively long [21, 22]. Additionally, a crucial aspect in the linear classification system is the evaluation based on the qualitative properties of the udder [23, 24]. This is primarily associated with adapting the udder to existing machine milking technologies [25], and the correlation between linear udder traits and indicators of milk productivity and cow longevity [26-28].

The major part of the phenotypic variability in cows' lifelong productivity is influenced by paratypical factors [29, 30]. Creating favorable housing and feeding conditions while excluding early heifer breeding increases the likelihood of successfully combining reproductive capacity indicators, high productivity, and long-term economic utilization in cows [31-33].

The research objective is to identify an optimal and effective model for predicting cows' milk yield based on linear assessment characteristics of animal exterior.

2. Methods and materials

The study was conducted in the industrial complex of the Novosibirsk region, Russian Federation. Linear assessment of exterior characteristics in primiparous Holstein cows (n = 35) between 30 and 150 days post-calving was performed using a methodology that combines features utilized in assessing the dual-purpose productivity of dairy and beef cattle as per the ICAR guidelines and: Stature, Body Depth, Chest Width, Rib Structure, Rump Length*, Rump Angle, Pin Width, Muscularity, Rear Legs Set, Foot Angle, Fore Udder Attachment, Fore Udder Length*, Rear Udder Height, Rear udder width, Central Ligament, Udder Depth, Front Teat Placement и Teat Length, Rear Teat Placement, Udder Balance**, Rear Legs Rear View, Udder Texture***. [ICAR. The standard trait definition for dairy cattle. Version june 2023, *ICAR. The standard trait definition for dual purpose cattle. Version march 2022, **ICAR. The standard trait definition for beef breed. Version march 2022, ***Holstein Canada]

Each characteristic was assessed independently of others on a linear scale from 1 to 9 points, with an average score of 5. Ratings of 1 and 9 represent extreme deviations of the trait. Statistical processing of the raw data was carried out using the R programming language. Model fitting conditions were examined in accordance with the exploratory data analysis protocol. Potential outliers were examined using the Grubbs test. The conformity of data distributions to a Gaussian distribution was assessed using the Shapiro-Wilk test. Calculation of correlation coefficients between variables was performed using the Spearman criterion. Assessment of multicollinearity was conducted by computing the variance inflation factor for each parameter, supplemented by graphical methods utilizing scatterplot matrices of regression model variables. Model coefficients were determined using the least squares method. Multiple comparisons of influential observations were conducted with the Bonferroni correction. The independence of model residuals was checked using the Durbin-Watson test [34].

To identify a milk yield forecasting model based on linear exterior assessment features of Holstein cows, a complex of independent variables was utilized (Table 1).

3. Results and discussion

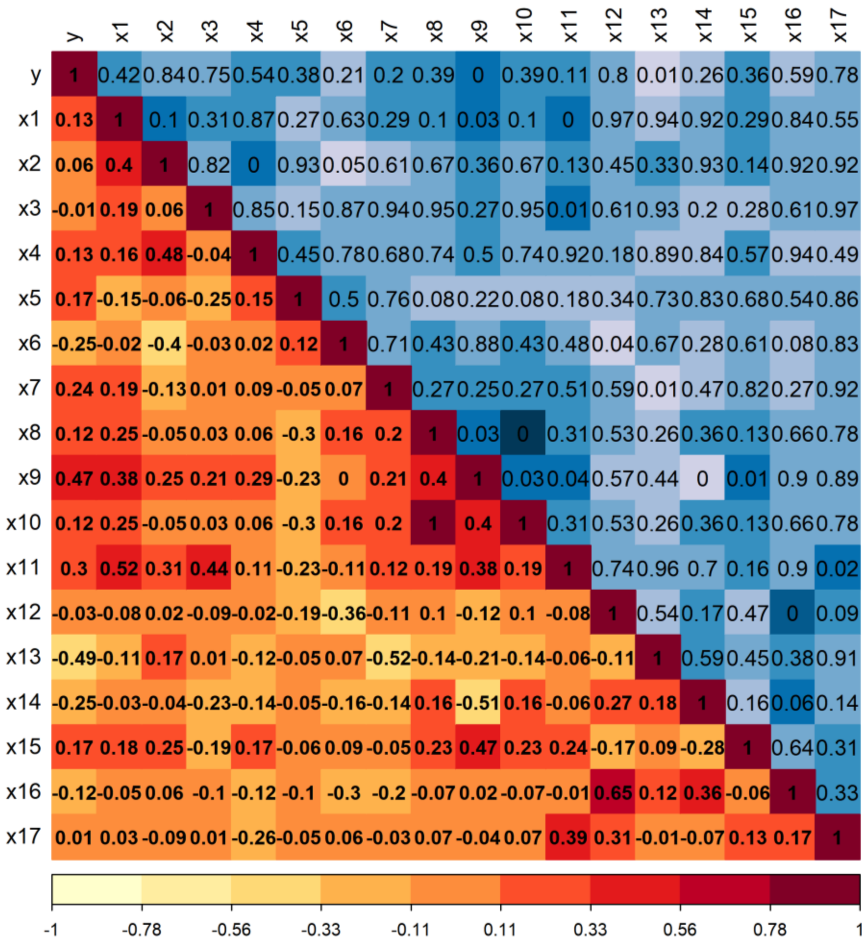
When analyzing the results as a preparatory step in constructing the optimal regression model, the assessment of interdependence between variables was crucial. For this purpose, correlation coefficient values and their significance levels were calculated. The data obtained, presented in the lower triangular part, represent correlation coefficients, while the upper triangular part shows the significance levels for these coefficients. As a result of the analysis, two statistically significant correlations were identified among linear traits (front udder attachment length and udder depth) with 305-day milk yield in the cows' first lactation. This may be associated with the fact that animals with optimal breed-related exterior traits are less susceptible to udder and limb diseases, which significantly affect productivity [23-26]. Furthermore, the larger the udder volume of a cow, the more milk it is capable of producing. This is supported by the statistically significant correlation coefficient we found ($r = 0.47$) between milk yield and front udder attachment length. The inverse relationships discovered between certain linear assessment traits were mostly insignificant or close to zero, or weak ($r \leq -0.4$), except for two significant inverse correlation coefficients between udder depth and hoof angle ($r = -0.52$) and between front teat placement and front udder attachment length ($r = -0.51$).

During model construction, three optimal variants were selected. The model with the highest adjusted coefficient of determination (R2adj) incorporating 7 variables was chosen (Table 2). The second contender model was selected based on the Mallows criterion (Table 3), and the last model was identified as the most compact based on the Bayesian Information Criterion (BIC) value (Table 4). The visualization of model rankings with complex coefficients is presented in Fig. 2. To identify the most effective forecasting model, external quality criteria must be used. As a result of cross-validation with observations divided into 3 blocks, the best approximation is observed in the model with four predictors (Fig. 3, far right), although it is evident that the slope angle of the regression lines does not significantly differ from other models. This is further supported by the mean square calculation through the cross-validation method (Table 6). By using cross-validation, unbiased estimations of the coefficient of determination can also be obtained (Table 6). Thus, all external quality assessments of the models indicate that the optimal and most suitable model for predicting cow milk yield based on linear assessment is the model with four predictors (x5, x6, x9, x13).

Evaluating the variance inflation factor for candidate models, it should be noted that multicollinearity was absent in all models (Table 5). The final step involves verifying assumptions regarding the residuals of the selected model to ensure its suitability for estimation. Primarily, the distribution was tested for conformity to a normal distribution using formal Anderson-Darling ($A = 0.21$; $p = 0.86$) and Shapiro-Wilk ($W = 0.99$; $p = 0.94$) tests. As the multiple regression model represents a specific case of general linear models, assumptions are made about the residuals adhering to the conditions of the Gauss-Markov theorem. Additionally, visualizing the residual distribution confirms the assumption of Gaussian distribution (Figs. 4 and 5, upper right). In Fig. 5 (upper left and lower plots), the scatter of residuals and square root of standardized residuals is shown in relation to predicted model values, indicating constant residual variance. The lower right plot displays influential observations, identified by ordinal numbers corresponding to observations with high Cook's distances, which may represent potential outliers. Utilizing a formal Bonferroni-corrected test of residuals, the maximum studentized residual value will be tested for conformity to a t-distribution. The maximum studentized residual value was found to be -2.52, corresponding to an adjusted significance level (p) of 0.61, confirming the absence of outliers and homogeneity of residuals. Based on the above, there are no grounds to consider potentially influential observations as outliers. Residual independence was assessed by testing for autocorrelation. The Durbin-Watson criterion was employed, resulting in a value of $d=1.41$, corresponding to an autocorrelation coefficient of -0.29 ($p>0.05$). Thus, the null hypothesis of no autocorrelation in model residuals is supported.

Table 1. Deciphering of independent variables used in regression models and other notations used in the article

Indicator	Variable in the model	Designation	Decoding
305-day milk yield, kg	y	Int.	Intersept
Rib Structure	x1	RSE	Residual standard error
Rump Length	x2	F-statistic	Fisher test value
Rump Angle	x3		
Rump Width	x4	Pt	Statistical significance t-statistic
Muscularity	x5		
Rear Legs Set	x6	df	Degrees of freedom
Foot Angle	x7		
Fore Udder Attachment	x8	BIC	Bayesian information criterion
Fore Udder Length	x9		
Rear Udder Height	x10	Cp	Mallow's Cp
Rear udder width	x11		
Central Ligament	x12	AIC	Akaike information criterion
Udder Depth	x13		
Front Teat Placement	x14	R2	Coefficient of determination
Teat Length	x15		
Rear Teat Placement	x16	R2cv	Cross-validation coefficient of determination
Udder Balance	x17		



	y	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16	x17
y	1	0.42	0.84	0.75	0.54	0.38	0.21	0.2	0.39	0	0.39	0.11	0.8	0.01	0.26	0.36	0.59	0.78
x1	0.13	1	0.1	0.31	0.87	0.27	0.63	0.29	0.1	0.03	0.1	0	0.97	0.94	0.92	0.29	0.84	0.55
x2	0.06	0.4	1	0.82	0	0.93	0.05	0.61	0.67	0.36	0.67	0.13	0.45	0.33	0.93	0.14	0.92	0.92
x3	-0.01	0.19	0.06	1	0.85	0.15	0.87	0.94	0.95	0.27	0.95	0.01	0.61	0.93	0.2	0.28	0.61	0.97
x4	0.13	0.16	0.48	-0.04	1	0.45	0.78	0.68	0.74	0.5	0.74	0.92	0.18	0.89	0.84	0.57	0.94	0.49
x5	0.17	-0.15	-0.06	-0.25	0.15	1	0.5	0.76	0.08	0.22	0.08	0.18	0.34	0.73	0.83	0.68	0.54	0.86
x6	-0.25	-0.02	-0.4	-0.03	0.02	0.12	1	0.71	0.43	0.88	0.43	0.48	0.04	0.67	0.28	0.61	0.08	0.83
x7	0.24	0.19	-0.13	0.01	0.09	-0.05	0.07	1	0.27	0.25	0.27	0.51	0.59	0.01	0.47	0.82	0.27	0.92
x8	0.12	0.25	-0.05	0.03	0.06	-0.3	0.16	0.2	1	0.03	0	0.31	0.53	0.26	0.36	0.13	0.66	0.78
x9	0.47	0.38	0.25	0.21	0.29	-0.23	0	0.21	0.4	1	0.03	0.04	0.57	0.44	0	0.01	0.9	0.89
x10	0.12	0.25	-0.05	0.03	0.06	-0.3	0.16	0.2	1	0.4	1	0.31	0.53	0.26	0.36	0.13	0.66	0.78
x11	0.3	0.52	0.31	0.44	0.11	-0.23	-0.11	0.12	0.19	0.38	0.19	1	0.74	0.96	0.7	0.16	0.9	0.02
x12	-0.03	-0.08	0.02	-0.09	-0.02	-0.19	-0.36	-0.11	0.1	-0.12	0.1	-0.08	1	0.54	0.17	0.47	0	0.09
x13	-0.49	-0.11	0.17	0.01	-0.12	-0.05	0.07	-0.52	-0.14	-0.21	-0.14	-0.06	-0.11	1	0.59	0.45	0.38	0.91
x14	-0.25	-0.03	-0.04	-0.23	-0.14	-0.05	-0.16	-0.14	0.16	-0.51	0.16	-0.06	0.27	0.18	1	0.16	0.06	0.14
x15	0.17	0.18	0.25	-0.19	0.17	-0.06	0.09	-0.05	0.23	0.47	0.23	0.24	-0.17	0.09	-0.28	1	0.64	0.31
x16	-0.12	-0.05	0.06	-0.1	-0.12	-0.1	-0.3	-0.2	-0.07	0.02	-0.07	-0.01	0.65	0.12	0.36	-0.06	1	0.33
x17	0.01	0.03	-0.09	0.01	-0.26	-0.05	0.06	-0.03	0.07	-0.04	0.07	0.39	0.31	-0.01	-0.07	0.13	0.17	1

Figure 1. Correlation matrix of regression model variables

Table 2. Parameter assessment of coefficients for the contender model based on the adjusted coefficient of determination

Coefficients designation	Coefficients estimates	Standard errors of coefficients	t-statistics	P_t
Int.	5529,766	6253,424	0,884	0,384
x3	-606,62	457,397	-1,326	0,196
x4	-427,794	258,664	-1,654	0,11
x5	1274,18	585,902	2,175	0,039
x6	-563,784	349,244	-1,614	0,118
x9	1098,841	313,732	3,502	0,002
x11	608,593	388,933	1,565	0,129
x13	-951,461	353,929	-2,688	0,012
RSE – 902,3; R^2_{adj} – 0,465; F- statistics – 5,231; p <0,0007.				

Table 3. Parameter estimation of the candidate model with the best value according to the Mallows criterion

Coefficients designation	Coefficients estimates	Standard errors of coefficients	t-statistics	P_t
(Intercept)	4714,05	5460,56	0,86	0,4
x5	1152,61	589,45	1,96	0,06
x6	-647,14	361,19	-1,79	0,08
x9	1134,77	306,24	3,71	<0,001
x13	-942,17	369,06	-2,55	0,02
RSE – 941,7; R2adj – 0.418; F- statistics – 7,104; p <0,0004.				

Table 4. Coefficients Estimation Parameters of the Candidate Model by the Bayesian Information Criterion

Coefficients designation	Coefficients estimates	Standard errors of coefficients	t-statistics	P_t
Int.	9580,111	4079,868	2,348	0,025
x9	980,955	316,938	3,095	0,004
x13	-1060,902	389,264	-2,725	0,01
RSE – 1002; F- statistics – 9,816; p <0,0004.				

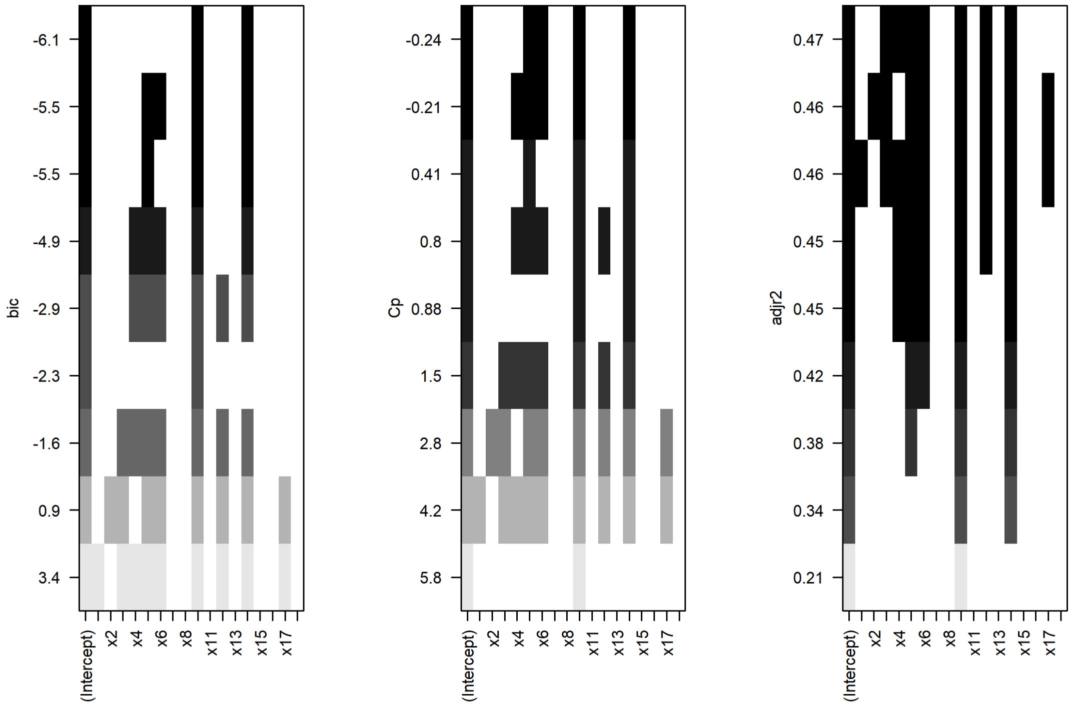


Figure 2. Ranking of milk yield forecasting models by BIC, Cp Mallows Criterion, and adjusted coefficient of determination (left to right)

Table 5. Values of the variance inflation factor for regression model coefficients of milk yield estimation

Predictors	y~1+x3+x4+x5+x6+x9+x13	y~1+x5+x6+x9+x13	y~1+x9+x13
x3	1,28	-	-
x4	1,04	-	-
x5	1,16	1,07	-
x6	1,04	1,03	-
x9	1,23	1,08	1,02
x11	1,4	-	-
x13	1,04	1,04	1,02

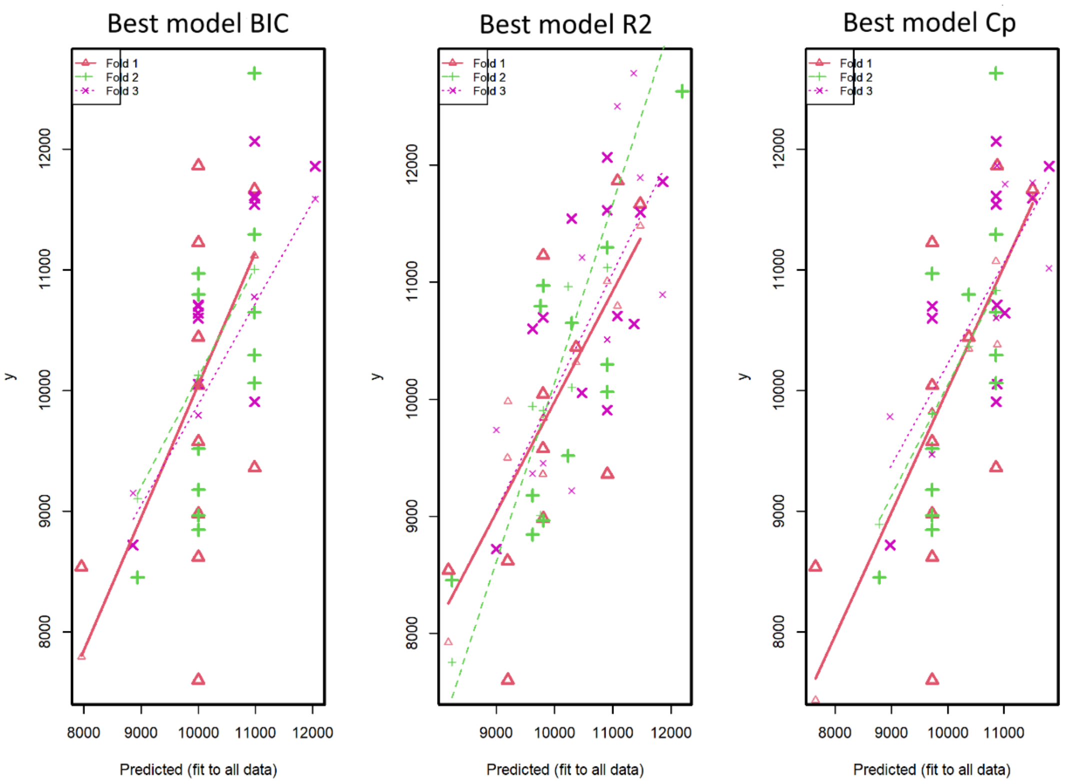


Figure 3. Visualization of candidate models for milk yield estimation by cross-validation with division into 3 blocks

Table 6. Assessment of error in cross-validation of regression models for milk yield prediction

Model formula	SS	df	MS	R^2	R^2_{cv}
y~1+x9+x13	33032196	35	943777	0,38	0,18
y~1+x5+x6+x9+x13	32650853	35	932882	0,49	0,37
y~1+x2+x3+x5+x6+x9+x11+x13+x16	34984715	35	999563	0,58	0,28

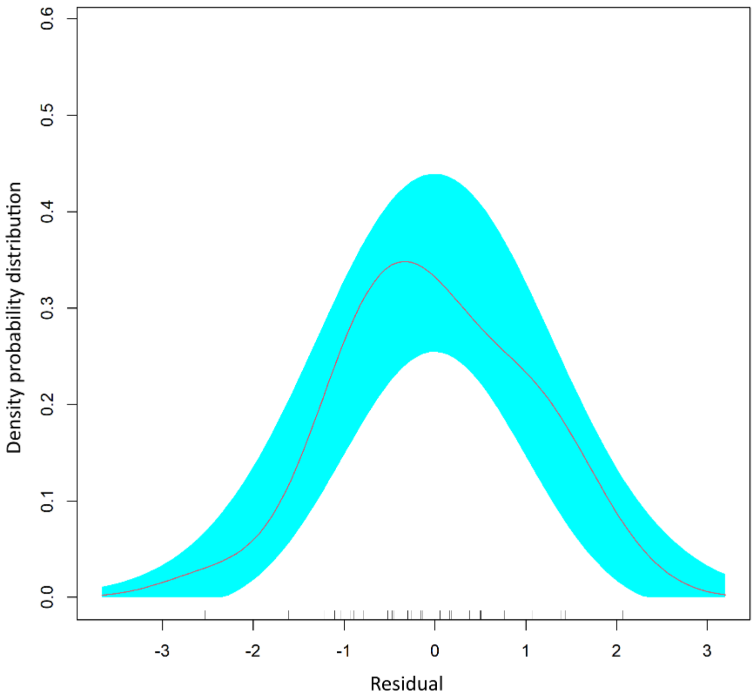


Figure 4. Distribution of residuals in the regression model for predicting milk yield based on linear assessment

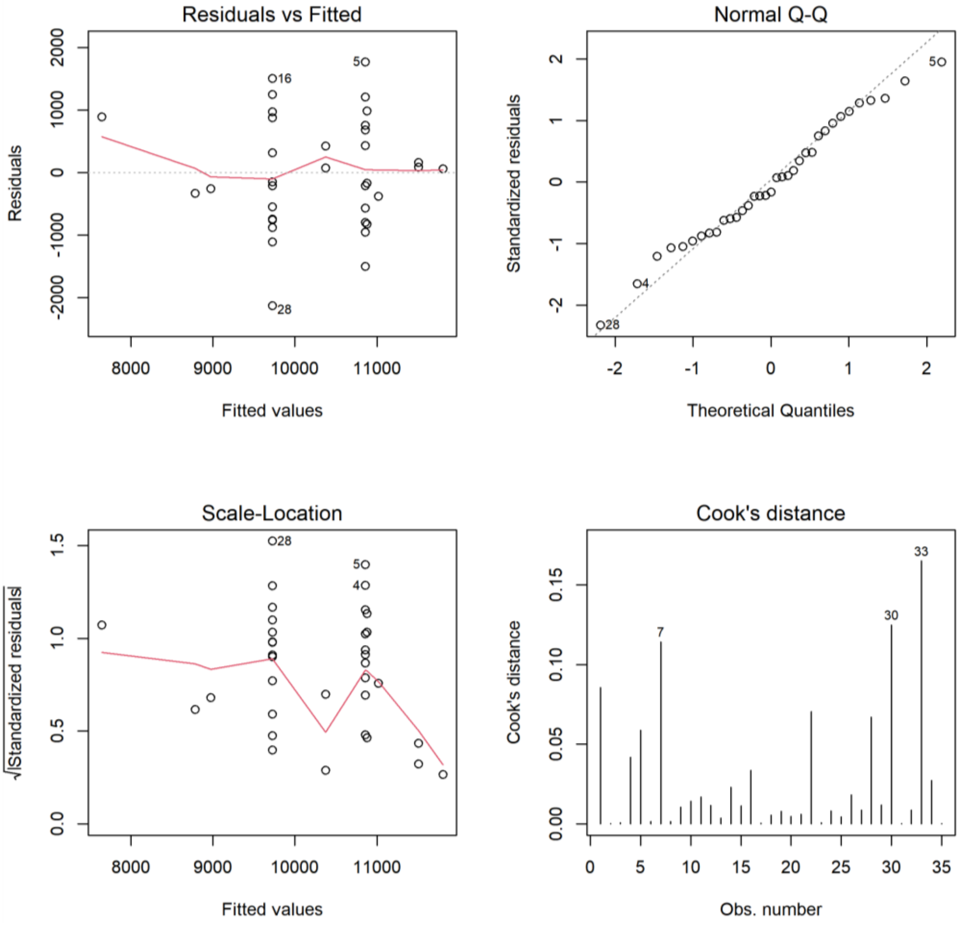


Figure 5. Residuals in relation to the response, quantile plot, square root of standardized residuals in relation to the response, and Cook's distances (from left to right)

To enhance the predictive accuracy of the milk yield model, it is advisable to determine the musculature, hind leg stance (side view), length of fore udder attachment, and udder bottom position in cows and incorporate these values into the regression equation:

$$y = x5+x6+x9+x13,$$

where y – 305-day milk yield, kg; x5 – Muscularity; x6 – Rear Legs Set; x9 – Fore Udder Length; x13 – Udder Depth.

4. Conclusions

The proposed model can be applied to other datasets to validate its effectiveness. The findings from this study are expected to be instrumental in cattle breeding programs for predicting cows' milk yield based on their linear assessment. Moreover, future research should consider using mixed linear models to account for additional random effects.

5. Funding

The work was carried out within the framework of the scientific project "Development of an Information-Analytical System for the Improvement of the Genetic Potential of Dairy Cattle," registration number 1022041100071-3-4.2.1.

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