Using the Wood Model to Fit Lactation Curves for Milk Yield and Milk Composition of Chinese Holstein Cattle in the Yangtze River Delta Region: A Postprint

Authors: Sun Xianzhi, An Pengpeng, Guo Mei, Sun Yongmei, Jin Ting, Liu Guanglei

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Abstract

This study aimed to employ the Wood model to fit the lactation curves of milk yield, milk fat percentage, milk protein percentage, and somatic cell score (SCS) in Chinese Holstein cows in the Yangtze River Delta region. Based on 104,368 records from Chinese Holstein cows (parities 1-3) in 10 large- and medium-scale dairy farms in the Yangtze River Delta region, the Wood model was utilized to fit curves for milk yield, milk fat percentage, milk protein percentage, and milk SCS data. The results showed that: 1) The milk yield of Chinese Holstein cows followed a standard lactation curve, while the changes in milk fat percentage, milk protein percentage, and SCS exhibited an inverted parabolic shape. 2) The Wood model achieved the highest goodness of fit for milk yield, with values above 0.98 for all parities, followed by milk SCS, with goodness of fit above 0.93 for all parities, while the goodness of fit for milk fat percentage in all parities was also above 0.92. 3) The timing of peak milk yield in parities 1 and 2 was similar to the timing of minimum SCS values, whereas the timing of minimum milk fat percentage occurred relatively later. 4) The peak milk yield in parity 1 (32.4263 kg/d) was lower than that in parities 2 and 3, while the persistence of high milk yield (4.98) and milk protein percentage (4.19) was stronger in parity 1 compared to parities 2 and 3. Based on comprehensive evaluation of all indicators, it can be concluded that the Wood model is suitable for fitting the lactation curves of milk yield, milk fat percentage, milk protein percentage, and milk SCS changes in Chinese Holstein cows in the Yangtze River Delta region.

Full Text

Fitting of Changing Curves of Milk Yield and Milk Composition of Chinese Holstein Dairy Cows in Yangtze River Delta using Wood' s Model

SUN Xianzhi[1], AN Pengpeng[1], GUO Mei[1], SUN Yongmei[1], JIN Ting[1], LIU Guanglei[1,2*]

[1]Shanghai Dairy Cow Breeding Center Co., Ltd., Shanghai 200436, China
[2]Guangming Animal Husbandry Co., Ltd., Shanghai 200436, China
*Corresponding author, senior engineer, E-mail: liuguanglei@brightdairy.com

Abstract

This study aimed to fit the changing curves of milk yield, milk fat percentage, milk protein percentage, and milk somatic cell score (SCS) of Chinese Holstein dairy cows in the Yangtze River Delta using Wood' s model. Based on 104,368 records from Chinese Holstein cows (parities 1-3) across ten medium-to-large-scale farms in the Yangtze River Delta region, Wood' s model was applied to curve fitting for milk yield, milk fat percentage, milk protein percentage, and SCS. The results showed that: (1) The milk yield curve followed a standard lactation curve, while milk fat percentage, milk protein percentage, and SCS exhibited inverted parabolic patterns. (2) Wood' s model achieved the highest goodness of fit for milk yield, with R^2 values above 0.98 for all parities, followed by SCS ($R^2 > 0.93$ for all parities). The goodness of fit for milk fat percentage exceeded 0.92 across all parities. (3) The timing of peak milk yield in first and second parity cows was similar to that of the lowest SCS values, whereas the minimum milk fat percentage occurred relatively later. (4) The peak milk yield of first-parity cows (32.4263 kg/d) was lower than that of second- and third-parity cows; however, first-parity cows demonstrated stronger persistence in maintaining high milk yield (4.98) and milk protein percentage (4.19) compared to later parities. Overall, Wood's model is suitable for fitting the changing curves of milk yield, milk fat percentage, milk protein percentage, and SCS in Chinese Holstein dairy cows in the Yangtze River Delta region.

Keywords: Wood' s model; milk yield; milk composition; somatic cell score; lactation curve; Chinese Holstein dairy cows in Yangtze River Delta

Introduction

The lactation curve describes how milk yield, milk fat percentage, milk protein percentage, and other traits change with lactation days during the lactation period. Lactation curve models provide valuable guidance in dairy production, offering not only individual animal lactation patterns but also enabling comparisons between individual and herd lactation periods. These models can even facilitate early detection of clinical diseases before overt symptoms appear, playing a crucial role in milk yield prediction, genetic potential estimation, and selection. Since Gains [?] first used mathematical models to describe the functional relationship between milk yield and lactation days, numerous studies on mathematical models of lactation curves have been conducted internationally. Typical lactation curve models include Wood’ s incomplete gamma function model (Wood’ s model), the Wilmink (WIL) model, the inverse polynomial (IQP) model, and the Ali-Schaeffer (AS) model [?]. For instance, Da Cunha et al. [?] compared the fitting performance of Wood’ s model, Wilmink’ s model, and Dijkstra’ s model, while Marek et al. [?] evaluated seven lactation curve models and found that Wood’ s model, Nelder’ s model, and Marek-Zelinkova’ s model performed well. Domestic researchers have also extensively studied dairy cow lactation curves using these models [?]. However, few models are available for describing changes in milk composition traits such as milk fat and protein percentages, and research findings have shown considerable variation. This study employed Wood’ s model to fit the changing curves of four major lactation traits—milk yield, milk fat percentage, milk protein percentage, and somatic cell score (SCS)—for Chinese Holstein cows from ten farms under Shanghai Dairy Cow Breeding Center Co., Ltd. in the Yangtze River Delta region, quantitatively describing their changing trends to provide a scientific basis for production management and trait prediction.

Materials and Methods

Data Sources

Data were collected from ten farms in the Yangtze River Delta region between 2014 and 2016, comprising 123,765 Dairy Herd Improvement (DHI) test-day records (recorded monthly) from Chinese Holstein cows in parities 1-3, provided by Shanghai Dairy Cow Breeding Center Co., Ltd. To ensure analytical reliability, incomplete records were excluded, and extreme outliers in milk yield and milk composition were removed. The DHI data were filtered according to the following criteria: lactation days 7-336, milk yield 5-60 kg, milk fat percentage 2%-7%, milk protein percentage 2%-6%, and somatic cell count (SCC) 1-5 × 10 cells/mL. Given the skewed distribution of SCC, it was transformed into SCS using the formula: SCS = log (SCC/100) + 3 [?]. The final dataset contained 104,368 qualified records. Basic information on the data is presented in Table 1 .

Lactation Curve Fitting

Wood’ s incomplete gamma function was used to fit the changes in milk yield, milk fat percentage, milk protein percentage, and SCS. The basic model is as follows [?]:

$$Y_t = at^b e^{ct}$$

where t represents lactation week, Y_t represents milk yield, milk fat percentage, milk protein percentage, or SCS at time t, and a, b, and c are model parameters: a is the initial value after calving, b is the slope parameter for reaching the peak, and c is the slope parameter for the declining phase. When parameter b is positive and c is negative, the model is suitable for milk yield analysis; when b is negative and c is positive, the model is appropriate for fitting milk fat percentage, milk protein percentage, and SCS. Initial parameter values for curve fitting were determined based on results from Oloria et al. [?]. The following secondary parameters were calculated:

- $T_{\text{max}} = b/c$: time to peak milk yield
- $T_{\text{min}} = b/c$: time to minimum values for milk fat percentage, milk protein percentage, and SCS
- $Y_{\text{max}} = a(b/c)^b e^{-b}$: peak milk yield
- $Y_{\text{min}} = a(b/c)^{-b} e^b$: minimum values for milk fat percentage, milk protein percentage, and SCS
- $\text{Per} = -(b+1)\ln c$: lactation persistence

Data Analysis

Given the substantial influence of parity on fitting performance, data were fitted separately for each parity. All milk yield data were initially processed in Excel, and curve fitting was performed using Matlab. The goodness of fit was evaluated using the coefficient of determination (R^2) and mean square error.

Results

Basic Characteristics of Milk Yield, Milk Fat Percentage, Milk Protein Percentage, and SCS Curves

The fitted curves for milk yield, milk fat percentage, milk protein percentage, and SCS in first-, second-, and third-parity Chinese Holstein cows using Wood's model are shown in Figures 1 [Figure 1: see original paper], 2 [Figure 2: see original paper], and 3 [Figure 3: see original paper], respectively. The test-day milk yield curves exhibited standard lactation patterns, showing an initial increase followed by a gradual decline. In contrast, the curves for milk fat percentage, milk protein percentage, and SCS displayed inverted parabolic patterns, decreasing from initial high values to minimum points before gradually increasing again.

Fitting Performance and Parameters for Different Parities

The fitting parameters, R^2 values, and mean square errors for milk yield, milk fat percentage, milk protein percentage, and SCS across parities are presented in Table 2 . The milk yield curves showed the highest fitting accuracy, with R^2 values exceeding 0.98 for all parities. The SCS curves ranked second, with R^2 values above 0.93 for all parities. For milk fat percentage, R^2 values were 0.96

for first and second parities and 0.92 for third parity. The R^2 values for milk protein percentage curves were above 0.88 across all parities.

Analysis of the fitted curves and secondary parameters revealed that first-parity cows reached peak milk yield latest and had the lowest peak yield but the strongest persistence. Second- and third-parity cows reached peak milk yield at 8.95 and 8.04 weeks, respectively, with higher peak yields but lower persistence. For milk fat percentage, second-parity cows reached the minimum value earliest. For milk protein percentage, all parities reached the minimum around 11 weeks, with similar persistence values across parities. For SCS, first-parity cows reached the minimum value latest, while second-parity cows reached it earliest.

Discussion

Comparative Analysis of Lactation Curve Fitting for Different Parities

This study found that first-parity cows reached peak milk yield at 12.92 weeks (90 days), while second- and third-parity cows peaked at 8.95 weeks (63 days) and 8.04 weeks (56 days), respectively. These results are consistent with Mao et al. [?], who reported peak milk yield times of 9.9 weeks (70 days), 7.4 weeks (58 days), and 7.6 weeks (53 days) for first, second, and third parities. However, our findings show later peak times compared to Xiong et al. [?], who reported peak milk yield at 67, 30, and 33 days for northern Chinese Holstein cows. This discrepancy may be attributed to differences in feeding environments and milk recording frequency. The cows in our Yangtze River Delta study were recorded monthly, potentially missing data points before the lactation peak or capturing only one record, which could delay the predicted peak time. Regarding lactation persistence, first-parity cows showed the highest persistence value (4.98), exceeding that of second- and third-parity cows, consistent with findings by Friggens et al. [?]. The R^2 values exceeding 0.98 for all parities demonstrate that Wood' s model provides excellent fit for milk yield curves.

Comparative Analysis of Milk Fat Percentage Curve Fitting

The R^2 values for milk fat percentage curves were 0.96 for first and second parities but only 0.92 for third parity, indicating that Wood' s model predicts milk fat percentage more accurately for first- and second-parity cows than for third-parity cows. Second-parity cows reached the minimum milk fat percentage earliest (15.65 weeks), while first-parity cows reached it latest (16.47 weeks), with third-parity cows intermediate. These findings align with those of Zhang et al. [?] and Luo et al. [?], suggesting that milk fat percentage varies less in first-parity cows, resulting in better curve fitting, whereas greater variation in second-parity cows leads to slightly lower accuracy. Overall, with R^2 values above 0.90 for all parities, Wood' s model can be used to predict milk fat percentage trends in Chinese Holstein cows.

Comparative Analysis of Milk Protein Percentage Curve Fitting

The R^2 values for milk protein percentage curves were highest for first parity (0.93), followed by second parity (0.90), and lowest for third parity (0.88), indicating that Wood' s model predicts milk protein percentage most accurately for first-parity cows and least accurately for third-parity cows. Second-parity cows reached the minimum milk protein percentage earliest (11.33 weeks), while third-parity cows reached it latest (11.59 weeks). The fitted curves for all parities showed a pattern of initial decrease followed by increase—high in early lactation, gradually declining, then rising again—similar to the pattern described by Steri et al. [?]. All parities reached the minimum around 11 weeks, which differs from Xiong et al. [?], who reported minima at 6-8 weeks. This variation may be due to differences in feeding management across different production environments.

Comparative Analysis of Milk SCS Curve Fitting

The R^2 values for SCS curves exceeded 0.93 for all parities, with relatively small mean square errors; second-parity cows showed the highest R^2 value (0.97). These results contrast with findings by Gołębiewski et al. [?] and Mao et al. [?], who concluded that Wood' s model was unsuitable for fitting SCS and SCC patterns. The discrepancy may be attributed to our use of large-scale, real-world production data, which may be more amenable to Wood' s model fitting.

Conclusions

1. Wood' s model provides excellent fit for lactation curves and satisfactory fit for SCS, milk protein percentage, and milk fat percentage curves in Chinese Holstein dairy cows.
2. Milk yield follows a standard lactation curve, whereas milk fat percentage, milk protein percentage, and SCS exhibit inverted parabolic patterns.

References

[1] GAINS 待补充 P. Algebraic model lactation curve cattle[J]. *Nature*, 1967, 216(5111): 164–165.

[3] WILMINK J B M. Adjustment of test day milk, fat and protein yield for age, season and stage of lactation[J]. *Livestock Production Science*, 1987, 16(4): 335–348.

NELDER J A. Inverse polynomials, a useful group of multifactor response fuctions[J]. *Biometrics*, 1966, 22(1): 128–141.

ALI T E, SCHAEFFER L R. Accounting for covariance among test day milk yields in dairy cow[J]. *Canadian Journal of Animal Science*, 1987, 67(3): 637–644.

DA CUNHA D D N F V, PEREIRA J C, CAMPOS O F, et al. Selection of models of lactation curves in milk production simulation systems[J]. *Revista Brasileira Zootecnia*, 2010, 39(4): 891–902.

[7] MAREK J, RAJMON R, HALOUN T. Critical evaluation of seven lactation curve estimation models[C]//ABRAHAM A, JIANG X, SNÁŠEL V, et al, Eds. *Intelligent data analysis applications*. Cham: Springer, 2015: 73–84.

[8] 赵智华, 彭顺清, 李凤翔, 等. 用 Wood 模型拟合四川地区黑白花奶牛泌乳曲线的研究 [J]. 四川畜牧兽医, 2000, 27(1S): 19–20.

[9] 毛永江, 张亚琴, 许兆君, 等. 中国荷斯坦牛泌乳曲线拟合研究 [J]. 畜牧兽医学报, 2011, 42(9): 1239–1248.

[10] 努尔比亚・吾布力, 付雪峰, 热西提・阿不都热依木, 等. 新疆农七师荷斯坦牛不同模型泌乳曲线拟合效果分析 [J]. 中国奶牛, 2012(17): 19–22.

POLOTT G E. Deconstructing milk yield and composition during lactation using biologically based lactation models[J]. *Journal of Dairy Science*, 2004, 87(8): 2375–2387.

TORSHIZI M E. Effects of season and age at first calving on genetic and phenotypic characteristics of lactation curve parameters in Holstein cows[J]. *Journal of Animal Science and Technology*, 2016, 58: 8.

[13] OLORIA V E, BROTHERSTONEA S, HILLA W G, et al. Fit of standard models of lactation curve to weekly records of milk production of cows in single herd[J]. *Livestock Production Science*, 1999, 58(1): 55–63.

[14] 毛永江, 张美荣, 许兆君, 等. 用 Wood 模型拟合南方中国荷斯坦牛产奶量、乳脂率、乳蛋白率和体细胞评分及其效果分析 [J]. 畜牧兽医学报, 2012, 43(12): 1904–1909.

[15] 熊本海, 杨亮, 杨琴, 等. 中国北方荷斯坦奶牛乳产量及乳成分变化的普适模型构建 [J]. 畜牧兽医学报, 2014, 45(12): 1939–1948.

FRIGGENS N C, EMMANS G C, KYRIAZAKIS I, et al. Feed intake relative to stage of lactation for dairy cows consuming total mixed diets with a high or low ratio of concentrate to forage[J]. *Journal of Dairy Science*, 1998, 81(8): 2228–2239.

[17] 张美荣, 廖想想, 陈丹, 等. 产犊季节、胎次及牛场对荷斯坦牛泌乳性能的影响 [J]. 中国牛业科学, 2012, 38(4): 6–9.

[18] 罗清尧, 熊本海, 马毅, 等. 中国荷斯坦奶牛第二泌乳期泌乳曲线模型的研究 [J]. 中国农业科学, 2010, 43(23): 4910–4916.

[19] STERI R, CAPPIO-BORLINO A, MACCIOTTA N P P. Modelling extended lactation curves for milk production traits Italian Holsteins[J]. *Italian Journal of Animal Science*, 2009, 8(2S): 165–167.

[20] GOŁĘBIEWSKI M, BRZOZOWSKI P, GOŁĘBIEWSKI L. Analysis of lactation curves, milk constituents, somatic cell count and urea in milk of cows

by the mathematical model of Wood[J]. *Acta Veterinaria Brno*, 2011, 80(1): 73-80.

Note: Figure translations are in progress. See original paper for figures.