

Correlations among Milk Yield, Milk Composition, Serum Biochemical Indices, and Milk Calcium Content in Different Breeds of Dairy Cows

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Abstract

This study investigated the correlations among milk yield, milk composition, and serum biochemical indices with milk calcium content in different dairy cattle breeds, providing a theoretical basis for obtaining high-calcium milk sources. From four farms raising Jersey cattle, Simmental cattle, Simmental-Holstein crossbred cattle (Simmental-Holstein F1), and Holstein cattle, 50 healthy, disease-free cows with 100-150 days in milk and 1-3 parities were selected respectively, and samples were collected on a day with an ambient temperature of (14 ± 4) °C. The milk yield was recorded three times on that day, and milk samples were collected three times in the morning, noon, and evening; furthermore, 30 cows were randomly selected from them, and blood samples were collected three times in the morning, noon, and evening. That is, 150 milk samples were collected from each breed for milk composition analysis, and 90 blood samples were collected for biochemical index determination. The correlations between milk calcium content and milk yield, milk composition, and serum biochemical indices were analyzed across different breeds. The results showed: 1) Holstein cattle had significantly higher milk yield than other breeds ($P<0.05$), Jersey cattle had significantly higher milk protein percentage than other breeds ($P<0.05$), Jersey and Simmental cattle had significantly higher milk fat percentage and milk calcium, phosphorus, and zinc contents than Simmental-Holstein F1 and Holstein cattle ($P<0.05$), Simmental-Holstein F1 and Holstein cattle had significantly higher milk lactose percentage than Jersey cattle ($P<0.05$), and Jersey cattle had significantly higher milk magnesium content than Simmental and Simmental-Holstein F1 cattle ($P<0.05$). 2) Jersey and Simmental cattle had significantly higher serum alkaline phosphatase (ALP) activity than Simmental-Holstein F1 and Holstein cattle ($P<0.05$), Simmental-Holstein F1 cattle had significantly higher serum calcium and phosphorus contents than the other three breeds ($P<0.05$), Jersey and Holstein cattle had significantly higher serum phosphorus content than

Simmental cattle ($P < 0.05$), and Simmental-Holstein F1 and Holstein cattle had significantly higher serum vitamin D content than Jersey and Simmental cattle ($P < 0.05$). 3) Milk calcium content was significantly or extremely significantly positively correlated with milk protein percentage and milk zinc and phosphorus contents across the four breeds ($P < 0.05$ or $P < 0.01$), but showed no significant correlation with milk yield, milk fat percentage, milk lactose percentage, serum ALP activity, and parathyroid hormone (PTH), vitamin D, calcium, phosphorus, and magnesium contents ($P > 0.05$). In conclusion, breed has a substantial influence on milk calcium content, with Jersey and Simmental cattle having higher milk calcium content, while Holstein cattle had the lowest milk calcium content but the highest milk yield. Milk calcium content was positively correlated with milk protein percentage and milk zinc and phosphorus contents, but showed no correlation with serum ALP activity and PTH, vitamin D, calcium, phosphorus, and magnesium contents.

Full Text

Study on Correlations between Milk Yield, Milk Composition, Serum Biochemical Indices and Milk Calcium Content of Different Dairy Cow Breeds

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Abstract

This study investigated the correlations between milk yield, milk composition, serum biochemical indices, and milk calcium content across different dairy cow breeds to provide a theoretical basis for obtaining high-calcium milk sources. Fifty healthy dairy cows from each of four farms—raising Jersey, Simmental, Simmental×Holstein (S×H F1), and Holstein breeds—were selected based on 100–150 days in milk and parity 1–3. Samples were collected on a day when ambient temperature was (14 ± 4) °C. Milk yield was recorded three times daily, and milk samples were collected at morning, noon, and evening. From these, 30 cows per breed were randomly selected for blood collection at the same three time points. This yielded 150 milk samples and 90 blood samples per breed for analysis of milk composition and serum biochemical indices, respectively. The results showed: (1) Holstein cows had significantly higher milk yield than other breeds ($P < 0.05$). Jersey cows exhibited significantly higher milk protein percentage

than other breeds ($P < 0.05$). Jersey and Simmental cows showed significantly higher milk fat percentage and milk calcium, phosphorus, and zinc contents compared to S×H F1 and Holstein cows ($P < 0.05$). S×H F1 and Holstein cows had significantly higher lactose percentage than Jersey cows ($P < 0.05$). Jersey cows displayed significantly higher milk magnesium content than Simmental and S×H F1 cows ($P < 0.05$). (2) Serum alkaline phosphatase (ALP) activity in Jersey and Simmental cows was significantly higher than in S×H F1 and Holstein cows ($P < 0.05$). S×H F1 cows had significantly higher serum calcium and phosphorus contents than the other three breeds ($P < 0.05$). Serum phosphorus content in Jersey and Holstein cows was significantly higher than in Simmental cows ($P < 0.05$). Serum vitamin D content in S×H F1 and Holstein cows was significantly higher than in Jersey and Simmental cows ($P < 0.05$). (3) Across all four breeds, milk calcium content showed significant or highly significant positive correlations with milk protein percentage and milk zinc and phosphorus contents ($P < 0.05$ or $P < 0.01$). No significant correlations were observed between milk calcium content and milk yield, milk fat percentage, lactose percentage, serum ALP activity, or serum parathyroid hormone (PTH), vitamin D, calcium, phosphorus, or magnesium contents ($P > 0.05$). In conclusion, breed substantially influences milk calcium content, with Jersey and Simmental cows producing higher milk calcium levels while Holstein cows produce the lowest milk calcium but highest milk yield. Milk calcium content positively correlates with milk protein percentage and milk zinc and phosphorus contents, but shows no correlation with serum ALP activity or PTH, vitamin D, calcium, phosphorus, or magnesium contents.

Keywords: dairy cows; breed; milk composition; milk calcium; correlation

Introduction

Calcium is an essential macronutrient that plays a vital role in regulating normal physiological functions of body systems, tissues, and organs, and cellular activities are also regulated by calcium. Prolonged calcium deficiency can cause calcium metabolism disorders, leading to osteoporosis, endocrine disorders, cardiovascular and cerebrovascular diseases, and nervous system disorders. By 2011, the State Food and Drug Administration had approved over 1,740 calcium supplement products. Common calcium supplements have distinct characteristics: inorganic calcium such as calcium carbonate has high calcium content but low absorption rate and strongly irritates the stomach; organic calcium such as calcium lactate and calcium gluconate has better absorption and less gastrointestinal irritation, but lower calcium content, and after decomposition into calcium ions (Ca^{2+}) in the stomach, readily combines with oxalic acid to hinder absorption.

Milk serves as an excellent calcium source for humans, with a calcium-to-phosphorus ratio of approximately 1.3:1.0, which matches the ratio optimal for human absorption. Milk calcium content in China is typically 1,030 mg/kg, while European milk contains 1,020-2,200 mg/kg. Studies have reported signifi-

cant variation in protein, fat, lactose, and milk calcium content among different goat breeds. Although individual variation in mineral content is substantial within the same cattle breed, milk calcium content remains relatively stable throughout lactation for a given individual. Furthermore, research on 1,860 primiparous Dutch Holstein cows from 388 farms demonstrated that genetics exert greater influence than farm management on milk calcium, phosphorus, and magnesium contents. Therefore, milk calcium content is closely related to dairy cow breed, yet few studies have examined correlations between milk calcium content and milk yield, milk composition, and serum biochemical indices. This study selected four common dairy cow breeds in China to investigate these relationships, providing comprehensive theoretical support for obtaining high-calcium milk to meet human nutritional needs.

1. Materials and Methods

1.1 Experimental Design

Milk samples were collected from four farms: Farm 1 (a farm in Tangshan) with Jersey cows, Farm 2 (a farm in Xinjiang) with Simmental cows, Farm 3 (a farm in Tongliao) with Simmental×Holstein crossbred cows (S×H F1), and Farm 4 (a farm in Beijing) with Holstein cows. All farms had herds exceeding 1,000 head. Fifty healthy cows from each farm were selected based on 100-150 days in milk and parity 1-3. Samples were collected on a day when temperature was (14 ± 4) °C. Milk yield was recorded three times daily, and milk samples were collected at morning, noon, and evening. From these, 30 cows per breed were randomly selected for blood collection at the same three time points, yielding 150 milk samples and 90 blood samples per breed. Diets at all farms were formulated according to NRC (2001). Diet composition and nutrient levels are shown in Table 1 .

1.2 Sample Collection and Processing

1.2.1 Diet Samples Diet samples were collected, dried in a 65 °C oven for 48 h, rehydrated for 48 h, processed into air-dried samples, ground, and stored for analysis.

1.2.3 Milk Samples All farms employed a three-times-daily milking schedule. At each milking, 100 mL of milk was collected: 50 mL was refrigerated at -4 °C and transported to local Mengniu laboratories for routine testing of milk fat percentage and other conventional parameters, while the remaining 50 mL was stored at -20 °C for determination of milk calcium, phosphorus, magnesium, and zinc contents. All three daily milk samples were tested separately.

1.2.4 Blood Samples Concurrent with milk sampling, 10 mL of blood was collected. Samples were centrifuged at 4,000 r/min for 10 min, and the supernatant was aliquoted into 1.5 mL tubes and stored at -20 °C until analysis.

1.3 Analytical Methods

1.3.1 Dietary Nutrient Composition Dietary dry matter (DM), crude protein (CP), ether extract (EE), ash, calcium, and phosphorus contents were determined using GB/T 6435–2014, GB/T 6432–1994, GB/T 6433–2006, GB/T 6438–2007, ethylenediaminetetraacetic acid disodium titration, and molybdenum yellow colorimetry, respectively. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were measured according to Van Soest et al.

1.3.2 Milk Composition Milk protein, fat, and lactose percentages were measured using a Foss FT120 milk composition analyzer. Milk calcium, magnesium, and zinc contents were determined using a Hitachi ZA3000 atomic absorption spectrophotometer according to GB/T 5009.92–2003, GB/T 5009.90–2003, and GB/T 5009.14–2003, respectively. Milk phosphorus content was measured according to GB/T 5413.22-2010.

1.3.3 Serum Biochemical Indices Serum parathyroid hormone (PTH) content was measured by enzyme-linked immunosorbent assay (ELISA) using kits from Shanghai Langdun Biotechnology. Serum alkaline phosphatase (ALP) activity and calcium, phosphorus, and magnesium contents were measured using kits from Nanjing Jiancheng Bioengineering Institute. Serum vitamin D content was determined by high-performance liquid chromatography.

1.4 Statistical Analysis

Data were organized using Excel 2007. One-way ANOVA and general linear model (GLM) correlation analysis were performed using SPSS 19.0. Duncan's multiple comparison test was used for significance testing, with $P < 0.05$ indicating significant difference and $P < 0.01$ indicating highly significant difference. Results are expressed as mean \pm standard deviation.

2. Results

2.1 Milk Yield and Composition of Different Breeds

As shown in Table 2, Holstein cows had significantly higher milk yield than other breeds ($P < 0.05$), with no significant differences among the remaining three breeds ($P > 0.05$). Jersey cows exhibited significantly higher milk protein percentage than Simmental, S×H F1, and Holstein cows ($P < 0.05$), while Simmental and S×H F1 cows had significantly higher values than Holstein cows ($P < 0.05$) with no significant difference between them ($P > 0.05$). Jersey and Simmental cows showed significantly higher milk fat percentage and milk calcium, phosphorus, and zinc contents compared to S×H F1 and Holstein cows ($P < 0.05$). S×H F1 cows had higher milk calcium, phosphorus, and zinc contents than Holstein cows, but the difference was not significant ($P > 0.05$). S×H F1 and Holstein cows had significantly higher lactose percentage than Jersey cows ($P < 0.05$). Jersey cows displayed significantly higher milk magnesium content

than Simmental and S×H F1 cows ($P<0.05$), with no significant differences among Simmental, S×H F1, and Holstein cows ($P>0.05$).

2.2 Serum Biochemical Indices of Different Breeds

As shown in Table 3 , no significant differences were observed in serum PTH or magnesium content among breeds ($P>0.05$). Jersey and Simmental cows showed significantly higher serum ALP activity than S×H F1 and Holstein cows ($P<0.05$). S×H F1 cows had significantly higher serum calcium and phosphorus contents than the other three breeds ($P<0.05$), with no significant differences in serum calcium among the remaining three breeds ($P>0.05$). Serum phosphorus content in Jersey and Holstein cows was significantly higher than in Simmental cows ($P<0.05$), with no significant difference between Jersey and Holstein cows ($P>0.05$). S×H F1 and Holstein cows had significantly higher serum vitamin D content than Jersey and Simmental cows ($P<0.05$).

2.3 Correlation Analysis of Milk Calcium Content with Milk Yield, Composition, and Serum Biochemical Indices

As shown in Table 4 , milk calcium content was significantly or highly significantly positively correlated with milk protein percentage and milk zinc and phosphorus contents across all four breeds ($P<0.05$ or $P<0.01$). No significant correlations were found between milk calcium content and milk yield, milk fat percentage, lactose percentage, serum ALP activity, or serum PTH, vitamin D, calcium, phosphorus, or magnesium contents ($P>0.05$).

3. Discussion

3.1 Milk Yield and Composition of Different Breeds

Differences in production performance, body size, and physiological characteristics among breeds lead to varying requirements for feeding management, diet types, and milking equipment. Consequently, the four breeds could not be raised simultaneously under identical farm or nutritional conditions. The four sampling farms in this study employed management practices tailored to each breed' s specific physiological characteristics. Jersey cows from the same farm produced significantly less milk than Holstein cows, averaging 4.92 kg less per day. Annual milk yield differed significantly between Simmental and Holstein cows at 4.7 and 6.5 tonnes, respectively. Studies have shown that first-lactation crossbreeds (Mongolian×Holstein and Fleckvieh×Holstein) produced 398 and 538 kg less milk in 305 days than Holstein cows. In this study, Holstein cows had the highest daily milk yield among the four breeds, with no significant differences among the other three breeds.

Jersey cattle, originating from the Isle of Jersey in the English Channel, are renowned for high milk protein and fat percentages, with protein content approximately 20% higher than Holstein milk. Simmental milk protein percentage

of 4.02% is significantly higher than that of Holstein cows. S×H F1 cows show significantly higher milk protein percentage than Holstein cows, differing by 0.07%. Our results align with these reports, with Jersey, Simmental, and S×H F1 cows all showing significantly higher milk protein percentages than Holstein cows.

Regarding milk fat percentage, Jersey cows have significantly higher values than Holstein cows. Studies indicate Simmental milk fat percentage is significantly higher than Holstein, and S×H F1 milk fat percentage is also significantly higher than Holstein. No significant difference in lactose percentage has been reported between Jersey and Holstein cows, and Simmental and Holstein cows show similar lactose percentages. Research found no significant difference in lactose percentage between S×H F1 and Holstein cows (5.02% vs. 5.11%). Our results largely concur, except that S×H F1 and Holstein cows did not differ significantly in milk fat percentage, and Jersey lactose percentage was significantly lower than Holstein. No significant differences in lactose percentage were observed among Simmental, S×H F1, and Holstein cows.

A study of 1,860 primiparous Dutch Holstein cows across 388 farms demonstrated that genetics influence milk calcium, phosphorus, and magnesium contents more than farm management. Analysis of different breeds revealed Jersey and Holstein milk calcium contents of 150 and 120 mg/dL, magnesium contents of 12.5 and 10.1 mg/100 dL, and zinc contents of 0.40 and 0.42 mg/dL, respectively. Another study reported colostrum calcium contents of 147.07 and 106.49 mg/dL and magnesium contents of 24.7 and 13.77 mg/dL for multiparous Jersey and Holstein cows at 120 h postpartum. Limited data are available for Simmental and S×H F1 cows. In our study, Jersey and Simmental cows had significantly higher milk calcium, phosphorus, and zinc contents than S×H F1 and Holstein cows. Our magnesium results differ from previous reports, showing no significant difference between Jersey and Holstein cows.

3.2 Relationship Between Milk Calcium Content and Milk Composition

Gaucheron reported substantial variation in milk calcium content among breeds, with higher mineral content in milk with elevated protein percentages. Poulsen et al. analyzed approximately 275 suppliers (different breeds) throughout 2010 and concluded that milk calcium content was significantly positively correlated with milk protein percentage, likely due to shared metabolic pathways. Bijl et al. examined bulk tank milk samples from 20 dairies weekly and compared composition with data from the 1930s-1960s, finding a significant positive correlation between total milk calcium and protein percentage ($r=0.725$). Our results align with these findings, showing significant positive correlations between milk protein percentage and calcium content within individual breeds. Bijl et al. also found a significant positive correlation between milk calcium and phosphorus contents. Rodríguez et al. collected bulk tank milk samples from eight farms approximately every 15 days throughout 1995, analyzing mineral content and

finding significant correlation between milk calcium and zinc contents but not magnesium. In our study, milk calcium content was positively correlated with both milk phosphorus and zinc contents across all four breeds, indicating that breed differences did not affect the secretion of milk protein, calcium, and zinc.

The strong correlations among milk calcium, protein, phosphorus, and zinc can be explained by casein micelle structure. Milk protein comprises 80% casein, which exists not in isolation but as complexes intertwined with various ions—casein micelles. Approximately 72% of milk calcium and 48% of milk phosphorus reside in casein micelles, which also bind various cations [ferric ions (Fe^3), copper ions (Cu^2), Ca^2 , zinc ions (Zn^2), and magnesium ions (Mg^2)]. The binding affinity sequence for cations to casein micelles is $\text{Fe}^3 > \text{Zn}^2 > \text{Ca}^2 > \text{Cu}^2 > \text{Mg}^2$, indicating Zn^2 binds more strongly than Ca^2 . Therefore, milk calcium, protein, phosphorus, and zinc are all associated with casein micelles and distributed throughout milk protein, resulting in strong positive correlations.

3.3 Correlation Analysis of Serum Biochemical Indices with Milk Calcium Content

Parathyroid hormone (PTH) is a primary regulator of serum calcium and phosphorus levels. Studies found no significant difference in serum PTH content between S×H F1 and Holstein cows (66.25 vs. 76.08 nmol/L). Similarly, our study found no significant differences in serum PTH among breeds, and milk calcium content showed low correlation with serum PTH. Parathyroid hormone-related protein (PTHrP) shares homology with PTH and exerts similar biological effects through the same receptor. Research on goats and rodents indicates PTHrP is the primary factor increasing milk calcium content. Studies on Holstein cows concluded that PTHrP synthesis and secretion correlate closely with milk calcium content. However, whether the observed differences in milk calcium content in our study relate to PTHrP requires further investigation.

ALP is a glycoprotein that enters blood as part of the plasma membrane during milk fat globule formation, with higher activity during early and mid-lactation. Serum ALP activity is an important indicator of calcium and phosphorus metabolism and reflects osteoblastic activity and bone formation. Comparisons of water buffalo and Holstein cows showed significantly higher serum ALP activity in buffalo. In our study, Jersey and Simmental cows had significantly higher serum ALP activity than S×H F1 and Holstein cows, suggesting more active bone metabolism and calcium/phosphorus deposition in bone.

Milk calcium content is generally considered related to serum Ca^2 concentration. However, research demonstrated that adjusting dietary cation-anion difference (DCAD) to 400 reduced serum Ca^2 concentration while increasing milk Ca^2 concentration, confirming no correlation between serum and milk calcium. This occurs because when serum calcium decreases, lactating animals mobilize bone calcium to meet mammary gland requirements; when serum calcium increases, excess calcium is reabsorbed, with some deposited in bone and some excreted.

Therefore, serum calcium content minimally influences milk calcium content. Additionally, studies indicate that vitamin D, calcium, phosphorus, and magnesium in serum collectively promote bone growth. Our results confirm that milk calcium content shows no significant correlation with conventional serum calcium metabolism indicators.

4. Conclusion

Breed substantially influences milk calcium content, with Jersey and Simmental cows producing higher milk calcium levels while Holstein cows produce the lowest milk calcium but highest milk yield. Milk calcium content positively correlates with milk protein percentage and milk zinc and phosphorus contents, but shows no correlation with serum ALP activity or PTH, vitamin D, calcium, phosphorus, or magnesium contents.

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