Asian Agricultural Research 2013, 5(7): 114 – 118

Variation Regulation and Models of Raw Milk Composition of Chinese Holstein Cattle in Tianjin

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Abstract Based on raw milk DHI data of Chinese Holstein cattle in northern China, milk composition (milk protein percentage and milk fat percentage) of lactating cow is grouped into parity 1 to 4. After preprocessing original data, 6114 data records of milk protein percentage and 5871 data records of milk fat percentage were obtained. This study discusses effects of natural months, lactation parity and their interaction on changes of milk protein percentage and milk fat percentage, and the model is established using GLM procedure of SAS software. At last, results are as follows: (i) Duncan multiple comparison of natural months, regardless of parity (only parity 1 to 4), indicates that milk composition takes on significant difference between different months ($P<0.05$). And milk protein percentage reaches highest in September (3.187%), drops to the lowest in July (3.016%); the milk fat percentage reaches highest in February (4.137%), and drops to the lowest in July (3.845%). (ii) Duncan multiple comparison of different parity, regardless months (January to December), shows that milk composition of different parity also takes on significant difference ($P<0.05$) although the difference between parities are not significant; milk protein percentage reaches highest in the 2nd parity (3.114%) and drops to the lowest in the 4th parity (3.066%); milk fat percentage reaches highest in the 2nd and 3rd parity (3.983% and 3.973%), and drops to the lowest in the 4th parity (3.923%). (iii) Using Wood model, the relational expression between milk protein percentage (MPP, %) and milk fat percentage (MFP, %) of different parity and natural month, *i. e.* MPP $=3.094x^{-0.0464}\times e^{0.0117x}$ and MFP $=4.2116x^{-0.0344}\times e^{0.0276x}$ (x stands for month). According to the above results, it is concluded that natural months, lactation parity and their interaction significantly influence milk protein percentage and milk fat percentage ($P<0.001$), and milk protein percentage and milk fat percentage take on Wood model change characteristics with natural months respectively. This study is intended to explore change regulation of milk composition, and to provide decision reference for properly regulating feeding management and nutrition supply of cattle, and thereby guaranteeing the quality of raw milk in certain month reach sales standard.

Key words Chinese Holstein cattle, Milk composition, Natural month, Lactation parity, Model

1 Introduction

The major milk components in raw milk (milk protein, milk fat, milk sugar and solids, *etc.*), coupled with principal health indicators (somatic cell count and total bacterial count, *etc.*), not only manifest the hereditary features and nutritional conditions of cattle, but also exert great effect on the quality and economic performance of fresh milk and processed dairy produce, thereby ultimately scathing consumers' interests and benefits[1]. In fact, the feeding of Chinese dairy cattle is always plagued by restrictions of variety, such as management, nutrient supply and seasonal change, leading to inevitably large fluctuation in the quality of raw and fresh milk. Since the Melamine Incident in 2008, the import volume of milk powder has been ascending constantly, and the retail price is also rising all the way[2]. Therefore, going into the details of current breeding of Chinese dairy cattle, together with statistical analysis of lactation rules of different parity and different seasons, will be definitely of great significance to providing theoretical basis for breed management and nutrition regulation[3].

Based on the essential data derived from DHI measurement (such as daily output, milk fat, milk protein, milk sugar, total solids, blood urea nitrogen and somatic cell count), the researches on seasonal changes in milk composition and health indicators of raw milk just fall within the sphere of our study. In foreign countries, Heck *et al.*[4] studied seasonal change characteristics of milk composition; Maurice – Van Eijndhoven *et al.*[5] compared changes of milk fat percentage, proportion of saturated fatty acid and non – saturated fatty acid in milk fat of 4 varieties of dairy cattle in the Netherlands; Quist *et al.*[6] studied change characteristics and correlation through combining milk output, milk composition, somatic cell count (SCC) and milking frequency. Obviously, researching the influence of nutrient on formation of milk composition is an ancient topic which has never been interrupted[7-8]. In China, Chang Lingling *et al.*[9] studied change characteristics of milk composition in southern diary farms with intensive management; Bai Yunfeng *et al.*[10-12] studied establishing dairy cattle management expert system and lactation curve of Chinese Holstein cattle through exploring DHI data, and evaluated feeding management and balance of nutrient supply through evaluating percentage of milk fat and milk protein. Through records, management and analysis of DHI data, the problem could be found timely, and then solved by improving management and nutrition strategy. However, there is less number of dairy cows and observation data[7-9]. Thus, it is difficult for results from these researches to be univer-

Received: April 3, 2013 Accepted: June 14, 2013
Supported by Task of 863 Research Team (2012AA101905-01); Post Expert Task of Beijing's Innovation Team for Dairy Industry and Technology System (bjcystx-ny-1); Basic Scientific Research Project of Institute of Animal Sciences of Chinese Academy of Agricultural Sciences (2013ywf-zd-3).
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sally applicable. In addition to greater difference in management level of dairy farms, and difference in climatic change of northern and southern breeding regions, especially big difference in performance of individual milk cow, only through using large sample number of dairy cows and observation data of corresponding index, can we obtain general change regulation of milk composition. This study takes Chinese Holstein cattle in typical dairy farms of Tianjin as an example, and explores change characteristics of natural months, lactation parity and milk composition, hoping to establish seasonal change model of milk composition and provide theoretical basis for dairy farm managers to change management and adjust nutrition supplement to guarantee raw milk accepted in the whole year.

2 Materials and Methods

2.1 Daily ration and feeding of lactating dairy cows In this study, 1 100 mature cows come from the 5th Dairy Cattle Farm of Tianjin. These cows were enrolled in DHI program in 2009. The daily ration adopts total mixed ration (TMR). Dairy cows of different lactation period adopt the same TMR formula, but voluntary feed intake (VFI) is different to meet the difference in nutrition demand. TMR formula of lactating dairy cow was designed mainly with reference to *Nutrient Requirements of Dairy Cattle* issued by NRC in 2001[13] and *Feeding Standard for Dairy Cattle*[14], and major composition of feed mainly referred to *Tables of Feed Composition and Nutritive Values in China* (the 19th edition)[15]. The TMR (feed basis) were formulated by 19% of concentrate supplements, 50% of corn silage, 10% of hay and 21% of DDG, while the concentrate supplements contain corn (52%), wheat bran (8%), wheat middling and red dog (10%), soybean meal (13%), cottonseed meal (5%), rapeseed meal (5%), bone meal (1%), technical grade salt (1%) and pre-mixed (5%). The ratio of concentrate to forage was 4:6. All cows were fed more than 45 kg TMR for 20 h/day at least.

2.2 Lactation data and preprocessing Lactation data for this study were collected from the 5th Dairy Cattle Farm in Tianjin. 1 100 lactating cows from the parity 1 to 4 were surveyed. The parities greater than 4 were deleted from original data because the number of those cows is few. Table 1 and Table 2 list the mean value $\bar{x}$ of milk protein and milk fat data arranged as per natural month and parity, as well as sample number. It also lists standard deviation (SD) of each mean value. Obviously, mean value of different parities and months in the milk protein and milk fat, due to gradual decrease in lactating cows along with increase of parities, and available data of each mean value have different frequency due to abnormal data, repetitive number n of each data point in Table 1 and 2 is different. As a result, we obtained 6 114 data items (sum of all n values) in Table 1, and obtained 5 871 data items (sum of all n values) in Table 2. Therefore, the volume of data participating in statistical analysis is ideal.

Table 1 Statistical data of natural month, lactating parity and milk protein

Month	1st Parity		2nd Parity		3rd Parity		4th Parity	
	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n
1	3.08 ±0.23	228	3.15 ±0.24	131	3.09 ±0.22	111	3.13 ±0.24	53
2	3.09 ±0.22	243	3.18 ±0.25	131	3.10 ±0.22	116	3.17 ±0.24	59
3	3.04 ±0.22	246	3.11 ±0.26	118	3.02 ±0.24	116	3.02 ±0.24	51
4	3.05 ±0.22	219	3.10 ±0.22	121	2.99 ±0.23	123	2.97 ±0.26	55
5	3.01 ±0.23	217	3.09 ±0.26	119	3.08 ±0.24	113	3.11 ±0.24	53
6	3.03 ±0.22	211	3.04 ±0.22	105	2.97 ±0.22	96	2.99 ±0.22	44
7	3.01 ±0.21	213	3.03 ±0.24	118	3.03 ±0.21	93	2.98 ±0.24	42
8	3.03 ±0.20	208	3.07 ±0.22	141	3.08 ±0.20	103	3.03 ±0.24	53
9	3.22 ±0.22	186	3.14 ±0.27	120	3.25 ±0.22	89	3.03 ±0.25	40
10	3.16 ±0.18	232	3.14 ±0.20	151	3.10 ±0.19	114	3.12 ±0.18	53
11	3.14 ±0.11	238	3.13 ±0.12	152	3.12 ±0.13	115	3.10 ±0.12	63
12	3.20 ±0.18	206	3.15 ±0.19	149	3.19 ±0.19	96	3.09 ±0.17	60

Note: $\bar{x}$ stands for mean value of samples, and SD refers to standard deviation. The same meaning is adopted in the following tables.

Table 2 Statistical data of natural month, lactating parity and milk fat

Month	1st Parity		2nd Parity		3rd Parity		4th Parity	
	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n	$\bar{x} \pm SD$	n
1	4.02 ±0.23	228	4.08 ±0.22	141	4.10 ±0.25	115	4.02 ±0.25	60
2	4.12 ±0.22	260	4.16 ±0.20	137	4.12 ±0.22	123	4.19 ±0.21	59
3	4.05 ±0.21	235	4.09 ±0.20	122	4.07 ±0.19	113	4.14 ±0.20	44
4	3.97 ±0.22	214	4.05 ±0.21	126	4.02 ±0.20	116	3.96 ±0.20	54
5	3.84 ±0.27	191	3.93 ±0.30	108	3.97 ±0.33	95	3.93 ±0.28	41
6	3.82 ±0.28	158	4.01 ±0.31	100	3.86 ±0.35	82	3.99 ±0.35	43
7	3.81 ±0.28	194	3.88 ±0.25	113	3.91 ±0.29	85	3.80 ±0.28	42
8	3.88 ±0.22	203	3.91 ±0.21	138	3.93 ±0.23	100	3.89 ±0.21	50
9	3.93 ±0.25	187	3.92 ±0.25	117	3.92 ±0.24	76	3.93 ±0.22	44
10	3.84 ±0.25	223	3.95 ±0.27	146	3.91 ±0.27	103	3.86 ±0.31	51
11	3.86 ±0.24	236	3.94 ±0.25	146	3.90 ±0.25	110	3.92 ±0.25	62
12	3.84 ±0.25	192	3.88 ±0.26	145	3.86 ±0.25	87	3.81 ±0.25	56

2.3 Data analysis This study is to explore variety regulation of milk composition in parity (factor 1), natural month (factor 2). In consideration of non-balance of original observation data, we adopted GLM procedure in SAS8.0[16], carried out non-balance variance analysis of factor 1 and factor 2 for observation data in Table 1 and Table 2, and analyzed interaction between lactating parity and natural month. On the basis of variance analysis, by Duncan multiple comparison method, we analyzed the difference in milk composition in different months, regardless of parity (1 - 4 parities). Finally, we established the lactating models which reflected the variety regulation of milk composition. Here, we mainly based on common lactating curve models, such as Wood model[17], Dijistra model, and Gompertz model[18].

3 Results

3.1 Effect of lactating parity, natural month and their interaction on milk protein and milk fat GLM variance analysis on data of milk protein of 4 parities and 12 months in Table 1 indicates that natural month, lactating parity (1 - 4 parity) and their interaction significantly influence milk protein percentage ($P < 0.001$); Duncan multiple comparison of milk protein percentage of mixed cattle, regardless of parity, indicates that milk protein percentage of milk produced from different month takes on discrete characteristic (Table 3, $P < 0.05$). From Table 3, it can be known that the milk protein percentage in September and December (3.187% and 3.169%) is significantly higher than that in other months ($P < 0.05$); in June and July, the milk protein percentage is 3.017% and 3.016% respectively, which are significantly lower than level of other months ($P < 0.05$). However, regardless of parity, based on the analysis of collected milk composition data, the milk protein percentage in whole herds of cattle is above 3%, higher than 2.8% specified in *Standards for the Qualification of Raw and Fresh Milk Received from Farms*. Similarly, regardless of natural month, Duncan multiple comparison analysis on milk protein percentage of milk in different parities indicates that the mean value of milk protein percentage of the second parity cows reaches the maximum value (3.114%), which is significantly higher than that of the first, third and fourth parity cows ($P < 0.05$). GLM variance analysis on the milk protein percentage of parities 1 to 4 and natural months in Table 2 indicates that natural month, parity and their interaction significantly influence milk fat percentage ($P < 0.001$); Duncan multiple comparison of milk fat percentage of mixed cattle indicates that milk fat percentage of milk produced from different month also takes on discrete characteristic (Table 4).

From Table 4, it can be known that the milk fat percentage of milk in February reaches 4.137%, which is significantly higher than other months ($P < 0.05$); in July, the milk protein percentage is 3.845%, which is significantly lower than level of other months ($P < 0.05$). If not considering natural month, the milk fat percentage of different parity reaches 3.9%, much higher than 3.1% level specified in *Standards for the Qualification of Raw and Fresh Milk Received from Farms*[19]. Similarly, regardless of natural month, Duncan multiple comparison analysis on milk fat percentage of milk produced by different parity of cows indicates that the milk fat percentage of the second and third parity cows reaches 3.983% and 3.973% respectively, so the difference between the second and third parity is not significant ($P > 0.05$), while the second and third parity were significantly higher than that of the first and fourth parity cows ($P < 0.05$).

Table 3 Comparison of changes in milk protein percentage of milk produced by 1 - 4 parity cows

No.	Month/parity	Milk protein percentage %	Standard error of the mean (SEM)	*P* value
	Month			
1	September	3.187a	0.01402	0.2214
2	December	3.169a	.	.
3	October	3.140b	0.01320	0.0251
4	November	3.126cb	0.01310	0.0009
5	February	3.122cb	0.01337	0.0004
6	January	3.102c	0.01243	<0.0001
7	May	3.058d	0.01350	<0.0001
8	August	3.053c	0.01348	<0.0001
9	March	3.047c	0.01321	0.2214
10	April	3.040de	0.01340	<0.0001
11	June	3.017e	0.01385	<0.0001
12	July	3.016e	0.01377	<0.0001
	Parity			
1	2nd	3.114a	0.01017	<0.0001
2	1st	3.087b	0.00955	0.0143
3	3rd	3.082cb	0.01047	0.0720
4	4th	3.066c	.	.

Note: the same letter in the same column means insignificant difference ($P > 0.05$). Following table adopts the same meaning.

Table 4 Comparison of changes in milk fat percentage of milk produced by 1 - 4 parity cows

No.	Month/parity	Milk protein percentage %	Standard error of the mean (SEM)	*P* value
	Month			
1	February	4.137a	0.01551	<0.0001
2	March	4.071b	0.01595	<0.0001
3	January	4.051b	0.01573	<0.0001
4	April	4.001c	0.01598	<0.0001
5	September	3.926d	0.01588	<0.0001
6	August	3.898ed	0.01612	0.0051
7	May	3.896ed	0.01664	0.0068
8	November	3.895ed	0.01566	0.0062
9	June	3.894ed	0.01721	0.0158
10	October	3.885ef	0.01588	0.0422
11	December	3.854eg	.	.
12	July	3.845g	0.01664	0.7218
	Parity			
1	2nd	3.983a	0.01204	0.0111
2	3rd	3.973ab	0.01251	0.3388
3	4th	3.956b	.	.
4	1st	3.923c	0.01137	0.0014

3.2 Building visual and simulation models for milk protein percentage and milk fat percentage Table 1 shows the milk protein percentage data obtained from parity 1 to 4 and January -

December. With the aid of Excel plotting tool, we drew the overall change trend of milk protein percentage in different paritis (as shown in Fig. 1). Through processing the mean value of milk protein percentage in 4 parities per each month, we obtained mean value of milk protein percentage in parities 1 to 4. with reference to wood model, through parameter estimation of NLIN procedure, we found that the model of parameter estimation was convergent, and then obtained the relational model of x and MPP as follows:

$$MPP = 3.094x^{-0.0464} \times e^{0.0117x} \quad (1)$$

where x stands for natural month, January, February, $\cdots$. December. Following table adopts the same meaning.

By the same method, we plotted the trend of milk fat percentage in different parities along with natural months, and obtained the relational model of natural month (x) – milk fat percentage (MFP):

$$MFP = 4.2116x^{-0.0344} \times e^{0.0276x} \quad (2)$$

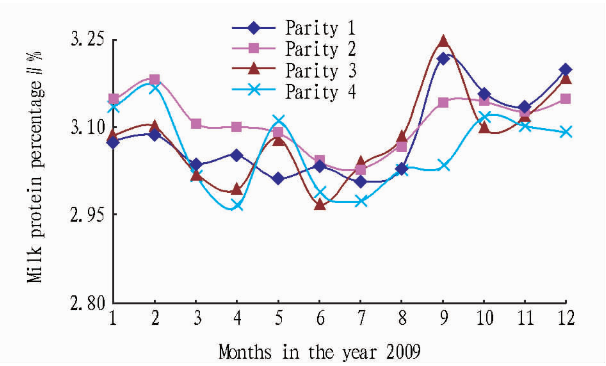

Fig. 1 Seasonal change of the milk protein percentage of 1 – 4 parity

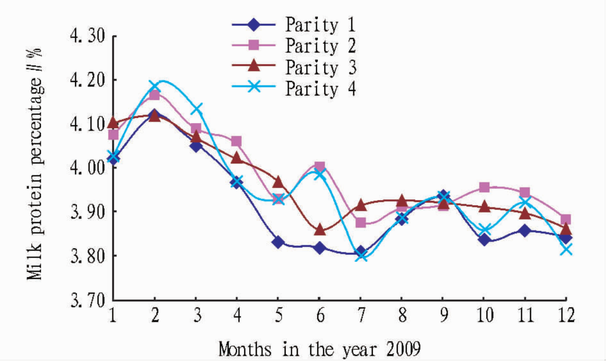

Fig. 2 Seasonal change of the milk fat percentage of 1 – 4 parity

4 Discussion

4.1 Effect of seasonal change on milk composition Data of the milk protein percentage and milk fat percentage were collected from an intensive dairy farm in Tianjin. It proves that natural month, lactating parity and their interaction significantly influence regulation of milk composition. Statistical analysis on the production data of this farm in 2007 and 2008 shows that the first to fourth cattle farms are consistent with the overall trend reported by Heck *et al*[4, 9]. However, in specific natural month, the milk protein percentage and milk fat protein reached the maximum value or lower to the minimum value. The difference in different years, changes of temperature and humidity, seasonal change and even the difference of latitude, will inevitably showed fluctuation of milk composition. Even so, the minimum value of both milk protein percentage and milk fat percentage appeared in June or July in both southern and northern regions of China, northern Europe (studied by Heck *et al*[4]), and northern America (studied by Quist *et al*[5]); the maximum value appeared in different months, such as February, April, September, and December.

4.2 Effect of parity on milk composition No special report has been seen on effect of parity on milk composition. Michiru *et al*[20] studied the effect of lactating and parity of Holstein cattle on cortisol concentration, but it didn't touch upon milk composition. Sevi *et al*[21] studied the effect of parity on milk yield, milk composition and somatic cell count of Comisana ewes, and found that effect of parity on milk composition is not significant, while the milk protein, casein protein and milk fat in the 3rd parity are significantly higher than that in 1st and 2nd parity. In this study, the effect of parity on milk composition is different, the milk protein percentage reached the highest in the 2nd parity, and it drops significantly along with increasing of parity. This is possibly because management and health lead to reduction of milk quality. This study indirectly shows the reason why most Chinese Holstein cows have to be rejected in the 3rd parity and 4th parity.

4.3 Models for seasonal changes of milk composition There is obvious relationship between the changes of milk composition and 12 natural months. As shown in Fig. 1, changes of milk protein percentage of 4 parities in natural months take on declining and then rising, while the milk fat percentage takes on reduction with fluctuation. Through MLIN procedure of SAS, it is found that Wood model[17] could be used to express seasonal changes of milk composition. It indicates that Wood model not only could be used to build lactating curve[12], but also could be used to simulate seasonal changes of milk composition. However, when conducting nonlinear regression processing of data by Dijstra model and Gompertz model[22], the convergent model could not be obtained. In addition, since observation data only considered parity 1 to 4, the parity data points are few, which is not suitable for building parity – milk composition regression model. Although we established the regression model for milk composition and natural month, the models need further verification, so as to prove the prediction effect of the regression model.

5 Conclusions

External (factor natural month), internal factor (lactating parity) and their interaction significantly influence both the milk protein percentage and milk fat percentage ($P < 0.001$), and the mean value of milk composition in different months and parities takes on discrete characteristic. The Wood model could quantitatively describe seasonal change regulation of milk composition. The conclusions and the models are directive significance for dairy farm managers to change the management practices and adjust nutrient supplement based on seasonal change and parity.

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