Animal and Veterinary Sciences
2023; 11(3): 64-70
http://www.sciencepublishinggroup.com/j/avs
doi: 10.11648/j.avs.20231103.12
ISSN: 2328-5842 (Print); ISSN: 2328-5850 (Online)

A Review of Genetic and Non-Genetic Parameter Estimates for Milk Composition of Cattle

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To cite this article:
Fikadu Wodajo Tirfie. A Review of Genetic and Non-Genetic Parameter Estimates for Milk Composition of Cattle. *Animal and Veterinary Sciences*. Vol. 11, No. 3, 2023, pp. 64-70. doi: 10.11648/j.avs.20231103.12

Received: February 27, 2023; **Accepted**: May 12, 2023; **Published**: May 29, 2023

Abstract: This review focuses on the genetic and non-genetic parameter estimation for dairy cattle milk composition. Milk is the most widely consumed food in the world, containing proteins, fats, lactose, and various vitamins and minerals. Milk's solids content has a direct impact on both its nutritional and economic value. The milk composition trait performances had obtained in the range from 3.5±0.0038 to 6.1±0.05 for fat percentage, 3.07±0.03 to 4.7±0.09 for protein percentage, 3.3 to 5.52±1.71 for lactose content, 12.16±0.14 to 16.02±0.05 for total solid content and 8.47±0.1 to 9.37±0.24 for the solid not fat content of cow milk, respectively. The composition of cow milk is influenced by breed, animal age and health, lactation phase, nutrition, season, milking method, number of lactations, and individual cows. The heritability of milk composition trait ranged from 0.24 to 0.49±0.03 for fat percentage, 0.28 to 0.53±0.009 for protein percentage, 0.41±0.04 to 0.59 for total solid content and 0.17 to 0.68 for the solid not fat content of cow milk, respectively. The repeatability of fat, protein, total solid and solid not fat percentage of bovine milk ranged between 3.9 to 0.98, 0.4 to 0.99, 0.49 to 0.99 and 0.23 to 0.78, respectively. The genetic and phenotypic correlation between fat and solid not fat of cow milk were weakly positive (0.16±0.15, 0.06 ±0.04), whereas a strong positive relationship was found between protein content and solid not fat of cow milk (0.99±0.05, 0.67±0.03), respectively. Enhancing milk compositional quality through genetic selection based on individual performance is successful.

Keywords: Correlation, Genetic Parameter, Milk, Milk Composition, Phenotypic Correlation

1. Introduction

Milk is the most widely consumed food in the world, containing proteins, fats, lactose, and various vitamins and minerals [1]. The nutritional value of milk is determined by its constituents. The composition of bovine milk protein is an important factor in the dairy industry's profitability [2]. The gains in milk components obtained through selection and breeding are permanent and accumulate from year to year [3].

Milk's solids content has a direct impact on both its nutritional and economic value. The higher the solids content, the higher the nutritional value and the more milk product produced [4]. In many countries, milk payments are primarily based on the quality determining criteria of protein content, whereas others are priced based on fat and solids-non-fat composition [5]. The yield of dairy products obtained from milk is determined by the amount of components (total solids) present, the more fat and protein in milk, the higher the yield of cheese, and milk with a high fat content yields more butter than milk with a lower fat content [6].

Depending on the particular animal, its breed, stage of lactation, age, and health status, the amounts of the main milk constituents can vary significantly [7]. In addition, the genetic parameters have not a biological constant due to the environmental/management variability, selection pressure, and use of different sires. Therefore, the estimates of the genetic and non-genetic parameters for the milk composition of dairy cattle are the focus of this review.

2. Milk Composition of Cow

All species milk has the same types of milk composition/constituents, but the amounts differ depending on the species, genetic factors, and external factors like temperature, physiological state, and genetic factors [8]. Besides milk yield, the composition of milk such as fat, protein, SNF, total solid, and lactose percentages have become more important due to the rise in the price of butter and cheese in recent years [9]. As a result, milk composition is becoming an important element in deciding the profitability of dairy production and requires attention. When compared to the Jersey, Ayrshire, and Guernsey types, Holsteins have the lowest proportion of milk composition [10]. The milk constituents of different cattle breeds are reviewed in Table 1.

2.1. Milk Fat Content

The fat content of milk for different breeds in this review (Table 1) is within the range for the milk composition standard requirement for cows. According to a research on cattle raised in a tropical climate by crossing Jersey breeds with Ghana Shorthorn and Sokoto Gudali, the locals had a considerably greater butterfat percentage than the crosses [11]. Differences in milk components were also observed among temperate breeds. Zebu cows produce milk with up to 7% fat, Jersey and Guernsey breeds produce milk with about 5% fat, and Shorthorn and Friesians produce milk with about 3.5% fat contents [6]. According to Farrington and Woll findings, the fat content of cow's milk ranged from 3 to 6 percent [12]. In comparison to Hariana-Brown Swiss and Hariana-Friesian crosses, the Hariana-Jersey crosses had 0.59% and 0.79% more milk fat content, respectively [13]. According to Myburgh findings, the milk fat percentages for Boran, Nguni, Tuli, Afrikane, Bonsmara, and Drakensberger were 2.6, 4.18, 2.01, 3.79, 3.76, and 3.63, respectively [14]. According to Aynalem's findings, bovine milk fat content was 4.58 ± 0.02% [7]. The milk fat percentages in Holstein and Jersey cow were 3.7% and 5.1%, respectively [9]. The difference in milk fat could be attributed to the genetics and physiological state of the cattle breeds.

2.2. Milk Protein Content

The reviewed milk protein content for different breeds is presented in Table 1. In the United States, the protein composition of whole Holstein and Jersey milk was 3.22±0.45% and 4.22±0.55%, respectively [15]. Other scholars also recorded a similar outcome (3.33± 0.02%) [7]. Protein content in Holstein and Jersey cows was 3.1% and 3.7%, respectively [9]. The protein percentage of indigenous Boran cows was 3.17 percent in Ethiopia [16]. The protein content of milk samples collected from various places in Ethiopia was 3.10 percent [17]. Protein content in milk samples taken from local cows, crossbred cows, and local Horro cows was recorded as 3.48%, 3.46±0.04%, 3.31%, and 3.42% by these scholars [18-21], respectively. The protein content of fresh milk from a local cow was 3.07±0.56%, which was greater than the 2.70±0.37% protein content of milk samples from crossbred cows [22]. Additionally, other scholars [23] found that milk samples taken from households that raise local and hybrid cows had a protein content of 3.46%. The main source of dairy cow feed in the region, the protein content of natural pasture (grass), and supplement concentrates all affect the milk's protein content [24].

2.3. Solid Not Fat (SNF) Content of Cow Milk

The average solid not fat (SNF) percentage obtained from fresh milk samples was 8.7 [25] and 8.96 percent [26] (Table 1). The solid not fat (SNF) content of fresh milk from Holstein Frisian crossbred cows in India was 9.13±0.16 [27]. A similar finding was found in Ethiopia for Holstein and Jersey cows, with 8.7% and 9.5% solid-not-fat, respectively [9]. According to study done in Ethiopia, the percentage of SNF in cow milk was 8.35±0.04% [7]. According to a research performed in Ethiopia, the solid not fat percentage of cow milk was 9.46% [28] and 10.7% [29]. Another SNF finding for milk from dairy farms was 8.75% [21]. The raw cow's milk purchased from market sellers and milk makers in and near Addis Abeba had a rage value of 8.3±0.36 to 8.7±0.36 SNF content [23].

2.4. Total Solid (TS) Content of Cow Milk

The total solids (TS) of local and crossbred bovine milk were 14.71±1.51% and 13.03±1.24%, respectively [22]. The milk of a Holstein Frisian crossbred cow in Indian had 13.29±0.19% total solid content, which was lower than the result for Borana cow milk (15.47%) in Ethiopia [28]. Furthermore, other scholars [30] found 14.31% TS in Horro cattle breed milk (Table 1). The cow milk total solids content were 4.58±0.02 percent [7]. Total solids content in Holstein and Jersey cow were 12.4% and 6%, respectively [9].

2.5. Lactose Percentage of Milk

According to a research performed in Brazil for the Gire cow breed, the lactose percentage of whole milk was 4.63±0.2 [31] (Table 1). The lactose content of the local cow and crossbred cow was 5.47±1.25% and 5.85±1.29%, respectively [22]. A study revealed 4.52% and 4.37% lactose content in milk collected from urban and peri-urban areas, respectively [32]. According to European Union Quality guidelines for unprocessed whole milk, the lactose content should not be less than 4.2 percent [33].

Table 1. *Milk constituents (%) of different cattle breeds.*

Breed	Fat %	Protein %	Lactose %	Total solid %	Solid nonfat %	Country	Source
Holstein Frisian	3.7±0.03	3.14±0.06	4.6±0.04	12.16±0.14	8.48±0.1		
50%Jersey x Horro	3.8±0.18	3.8±0.18	4.67±0.023	13.24±0.23	9.29±0.23		[34]
50% Holstein Frisian x25 Jersey x25Horro	4.7±0.08	4.7±0.09	4.17±0.04	13.68±0.02	8.98±0.09		
Ogaden	4.69±0.01	4.69±0.01	4.57±0.19	14.03±0.39	9.28±0.5	Ethiopia	
Unknown	3.76	3.1	5.08	12.24	8.56		[35]
Local	5.46±0.51	3.07±0.56	5.47±1.25	14.71±1.51	9.26±1.38		[22]
Crossbred	4.04±0.29	2.76±0.37	5.52±1.71	13.03±1.24	9.01±1.16		

Breed	Fat %	Protein %	Lactose %	Total solid %	Solid nonfat %	Country	Source
50%crossbred	4.36±0.09	3.9±0.05	12.94±0.12				
62.5 crossbred	4.45±0.12	3.44±0.06	13.14±0.11				[36]
75%crossbred	4.51±0.15	3.91±0.11	13.42±0.2				
Boran x Holstein Frisian	5.48±0.02	3.8±0.03	4.18±0.05	15.32±0.03			[9]
Boran	6.1±0.05	4.05±0.05	4±0.05	16.02±0.05			
Unknown	3.5±0.38	3.09±0.1		12.19±0.1			[5]
Boran	5.01±0.03	3.6±0.02		13.71±0.04	8.66±0.05		
50% Holstein Frisian x Boran	4.77±0.03	3.4±0.02		13.19±0.05	8.49±0.05		
62.5% Holstein Frisian x Boran	4.85±0.04	3.43±0.03		13.26±0.05	8.43±0.05		[7]
75% Holstein Frisian x Boran	4.21±0.05	3.07±0.03		12.44±0.08	8.09±0.06		
87.5% Holstein Frisian x Boran	4.04±0.08	3.13±0.02		12.27±0.13	8.66±0.11		
Friesian × Shahiwal	3.73±0.08	3.27±0.04	4.42±0.04	12.25±0.12	8.52±0.07	Bangladesh	[37]
Gire	4.12±0.99	3.26±0.3	4.63±0.2	12.93±1.05		Brazil	[31]
Guzerat	4.22±1	3.4±0.34	4.62±0.25	13.22±1.19			
Holstein Frisian crossbred	4.75±0.34	3.12±0.06	4.73±0.07	13.29±0.19	8.54±0.13		
Vechur	3.61±0.27	3.33±0.03	4.99±0.04	12.69±0.71	9.09±0.04	India	[38]
Sahiwal	4.36±0.29	3.04±0.04	4.62±0.07	12.72±0.41	8.35±0.12		
Kankrj	5.54±0.12	3.19±0.27	4.89±0.28	14.33±0.16	8.81±0.13		

***Table 1.** Continued.*

Breed	Fat %	Protein %	Lactose %	Total solid %	Solid nonfat %	Country	Source
Jersey crossbred	4.5±0.35	3.25±0.06	4.88±0.09		8.92±0.17	India	[27]
Holstein Frisian Crossbred	3.81±0.34	3.33±0.06	5.06±0.09		9.13±0.16		
Holstein	3.95	3.29	3.3			Italy	[39]
50%Sahiwal x Friesian (F1)	4.2±0.49			13.6±0.61	9.4±0.38		
50%Sahiwal x Friesian (F2)	3.99±0.3			13.01±0.39	9.02±0.23		
50%Sahiwal x Friesian (F3)	4.5±0.36			13.81±0.45	9.31±0.23	Malaysia	[40]
45.75%Sahiwal x 56.75% Friesian	4.17±0.46			13.42±0.56	9.25±0.29		
37.5%Sahiwal x 62.5% Friesian	4.09±0.43			13.46±0.54	9.37±0.24		
25%Sahiwal x 75% Friesian	3.96±0.42			13.16±0.44	9.2±0.2		
Holstein Frisian	4.63±0.05	3.7±0.02	4.86±0.01				
Jersey	5.38±0.06	3.97±0.02	4.89±0.01			New Zealand	[41]
Holstein Frisian x Jersey	5.11±0.005	3.86±0.02	4.88±0.01				
Friesian x Bunaj	4.22±0.04	4.15±0.03	4±0.06			Nigeria	[42]
Holstein	3.73±0.32	3.22±0.45	4.93±0.61				
Jersey	5.42±0.53	4.22±0.51	4.99±0.39				
Guernsey	4.76±0.44	3.7±0.55	4.66±0.34			USA	[15]
Ayrshire	4.12±0.22	3.47±0.55	4.67±0.34				
Brown Swiss	4.28±0.5	4.28±0.39	5.15±0.46				
Milking Shorthorn	3.58±0.26	3.42±0.51	4.8±0.31				

3. Non-Genetic Factors Affecting Milk Composition

The length of time between milking, the stage of lactation, the age and health of the cow, the food regimen, the thoroughness of milking, and microbial activities like the degradation of milk proteins and fats can all affect the content of milk [6]. A lack of crude protein in the diet may cause low milk protein composition as a result of underfeeding concentrates, low forage consumption, bad pasture quality, an unbalanced diet of protein and nutrients, or improperly ground cereals [43]. According to the same research, low body reserves will result in lower amounts of milk and milk products [6].

Almost all milk components are handled according to the variables that influence them. The nonfat solid component of milk varies with diet, but to a smaller extent than the fat percentage [44]. Milk's fat percentage and fatty acid composition are the most likely to shift, while lactose is the least sensitive and protein is in the middle [37]. The quantity and composition of dietary components had an impact on the content of milk fat. The microbial activity is adversely impacted by a protein supply that is low in carbohydrates, which disorders the production of acetate and reduces the synthesis of milk fat [44].

The season of calving impacted SNF percentage but had no effect on other components [45]. The milk constituents had highest value in the first parity and declined as parity increased. Another research revealed that parity significantly affected the components of milk [46]. The parity had a significant effect on fat and SNF percentages in crossbred dairy cattle and found that, fat percentage was not affected by parity, parity had a substantial effect on SNF percentage, with a decreasing trend across parities [13].

Generally, breed, age and the health condition of the animals, lactation period (early, mid, and late), feeding (type and quality), season, method of milking (manual or automatic), and the number of lactations, individual cows and environmental factors are the main determinant of milk composition [4, 35, 37].

4. Estimates of Genetic Parameters for Milk Composition Traits

Before a potential trait can be evaluated for selection in dairy cattle populations, it must meet several criteria. The considerations include either it should have an economic value, the trait must have sufficiently large genetic variation, measurable at a low cost, and consistently recorded and an indicator trait may be favored if it has a high genetic correlation with the economically important trait, reduces recording costs, has a higher heritability, or can be measured earlier in life [47]. Estimates of genetic parameters are needed for breeding program implementation and monitoring the development of ongoing programs [48-51].

The genetic parameters are useful for describing the selection strategy, predicting the direct and correlated response to selection, selecting the breeding strategy to be used for future advancement, and estimating genetic gain [52]. Estimates of genetic parameters for milk composition traits in dairy cattle are reviewed in Tables 2 and 3. The heritability (h^2) of cow milk's fat content ranged from 0.24 [53] for tropical cattle to 0.45±0.006 [41] for temperate cattle, respectively.

The heritability of milk protein content for the Boran breed in Ethiopia (0.260.05) [7] was lower than for Jersey in Zimbabwe (0.440.12) [54]. According to a study performed in the United States, the total sold percentage of bovine milk heritability for the Jersey cattle breed was 0.59 [55]. The lowest heritability values for bovine milk's total solid content (0.13) and solid not fat content (0.17) were recorded [45].

The repeatability of fat, protein, total solid and solid not fat percentage of bovine milk in Holstein calves was estimated to be 0.58, 0.55, 0.65, and 0.65, respectively [55]. The review of repeatability estimate for milk composition trait is presented in Table 2. This review found that genetic and phenotypic correlation between traits was common and significant, implying that the majority of traits had favorable interactions with one another. The phenotypic and genetic associations between fat and solid not fat of cow milk were weakly positive, whereas a strong positive relationship was found between protein content and solid not fat of cow milk (Table 3) [7].

Table 2. *Heritability (h^2) and repeatability (r) estimates of milk composition traits.*

Parameter	Breed	Fat %	Protein %	Lactose %	Total solid %	Solid nonfat %	Country	Source
Heritability (h^2)	Boran	0.49±0.03	0.26±0.05		0.45±0.04	0.46±0.04	Ethiopia	[7]
	Unknown	0.32±0.04	0.49±0.03		0.41±0.04	0.39±0.04		
	Jersey	0.39±0.009	0.53±0.009				South African	[56]
	HF, J, HF x J	0.45±0.006	0.4±0.05	0.35±0.06			New Zealand	[41]
	Jersey	0.42±0.11	0.44±0.12				Zimbabwe	[54]
	Holstein	0.89	0.7		0.9	0.63	USA	[55]
	Jersey	0.53	0.5		0.59	0.46		
	tropical cattle	0.24	0.2			0.68	Tropics	[53]
	Karana Fries	0.29	0.28		0.13	0.17	Indian	[45]
Permanent environmental effect (c^2)	Boran	0.49±0.03	0.33±0.04		0.54±0.03	0.47±0.04	Ethiopia	[7]
	Unknown	0.34±0.04	0.5±0.03		0.42±0.04	0.39±0.04		
	Jersey	0.14±0.008	0.13±0.008				South African	[56]
	Jersey	0.07±0.11	0.07±0.12				Zimbabwe	54]
Residual effect (e^2)	Jersey	0.47±0.004	0.34±0.004				South African	[56]
Repeatability (r)	Unknown	0.67	0.61					[57]
	Holstein	0.58	0.55		0.65	0.65	USA	[55]
	Jersey	0.68	0.63		0.7	0.6		
	Karana Fries	0.39	0.4		0.49	0.23	Indian	[45]
	Boran	0.98	0.59		0.99	0.93	Ethiopia	[7]
	Unknown	0.66	0.99		0.83	0.78		

Note: HF; Holstein Frisian, J; Jersey, HF x J; Holstein Frisian with Jersey crossbred.

Table 3. *Estimates of genetic (r_g) and phenotypic correlation (r_p) between milk composition traits in dairy cattle.*

Parameter	Breed	Genetic correlation (r_g)	Phenotypic correlation (r_p)	Source
Fat% -Protein%	Boran	0.51±0.12	0.2±0.05	[7]
Fat% -SNF%	Boran	0.16±0.15	0.06±0.04	
Fat% -TS%	Boran	0.92±0.15	0.36±0.04	
Protein%- SNF%	Boran	0.71±0.05	0.51±0.02	
Protein%- TF%	Boran	0.82±0.09	0.43±0.04	
SNF%-TS%	Boran	0.78±0.06	0.24±0.04	
Fat% -Protein%	Cross breed (HFxBo)	0.88±0.11	0.5±0.04	
Fat% -SNF%	Cross breed (HFxBo)	0.67±0.11	0.26±0.04	
Fat% -TS%	Cross breed (HFxBo)	0.92±0.12	0.45±0.04	
Protein%- SNF%	Cross breed (HFxBo)	0.92±0.05	0.67±0.03	
Protein%- TF%	Cross breed (HFxBo)	0.85±0.09	0.41±0.05	
SNF%-TS%	Cross breed (HFxBo)	0.99±0.05	0.19±0.05	

Note: HF x Boran; Holstein Frisian with Boran crossbred.

5. Conclusion

The revenue of the dairy business is significantly influenced by the composition of cow's milk. The review findings of milk composition performances differed significantly from genotype to genotype. The major determinants of milk composition are breed, age and health of the animals, lactation phase, feeding, season, technique of milking, and the number of lactations, individual cows, and environmental factors. The essential element of milk constituents (fat, SNF, protein, lactose, etc.) got little consideration in breed improvement programs (especially in tropics), but the nutritive value of milk is dependent on its constituents. Enhancing milk compositional quality through genetic selection based on individual performance is successful.

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