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The influence of crossbreeding on the protein composition, nutritional and energy value of cow milk

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Abstract

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The use of crossbreeding as an element of improving livestock in commercial herds has affected the protein composition of milk and its nutritional and energy value. The cross of Ukrainian Black-Spotted and Brown Swiss cows have exceeded the purebred analogues in a mass fraction of fat by 0.08%, protein – by 0.05%, and the cross of Ukrainian Red-Spotted cows with Montbeliarde ones have significantly surpassed purebred analogues in the content of fat by 0.16%, protein – by 0.14%. It has been established that the milk protein of the crossbred first generation (F1) obtained as a result of the local Black- and Red-Spotted cows with Brown Swiss and Montbeliarde breeds crossing had a higher biological value. Milk protein of the local cows did not contain amino acids, which score was less than 100%. According to the coefficient of utility (assimilation) which characterizes the biological value of milk proteins, a significant advantage of crossbred cows over purebred counterparts has been observed.

Keywords: crossbreeding; cow milk; milk fat; milk protein; amino acids

Introduction

Along with many positive features Holsteinized cattle has a number of problems associated with lowering of the reproduction, productive longevity and product quality level (Heins et al., 2006; Heins and Hansen, 2012). One of the methods for improving of these dairy cattle characteristics in commodity herds is crossbreeding. It represents a system of crossbreeding, in which the offspring can expect higher rates of individual quantitative attributes than their parents due to their hetero-zygosity for many genes (Dechow et al., 2007). In the USA, among the breeding breeds for Holstein, the most common are Jersey, Brown Swiss, Ayrshire and Montbeliarde, and in the European Union and Scandinavia, Swedish, Norwegian and Danish red strains (Heins et al., 2012). It has been established that the following functional attributes of the first-generation crossbred animals such as productive longevity, qualitative composition of milk, reproduction rates have been significantly improved (Dezetter et al., 2015).

Today, the problem of rational use and processing of food resources to the full-fledged amino acid composition of food products is particularly urgent for the population (Rassin et al., 1978; Gandolfi et al., 1992; Bos et al., 2003; Chuang et al., 2005). Amino acids are among the most natural universal regulators of metabolism and life of the human body (Wu and Knabe, 1994; Li et al., 2007; Sabahelkheir et al., 2012; Rafiq et al., 2016). Biochemical compounds of this class are the most important elements of normal human nutrition (Moshel et al., 2006; Wu, 2009).

It is known that various amino acids are widely used in medicine and the national economy for balancing the protein nutrition, because a significant amount of food and feed products do not contain the necessary amount of essential amino acids in their structure (Broderick et al., 1974). To eliminate the possible imbalance of amino acids, they are used in pure form or introduced into the composition of combined products and fodders that are produced by the industry (Rogers et al., 1974; Niven et al., 1998; Stoll et al., 1998; Skeie et al., 2001; Appuhamy et al., 2011).

Milk is a complex polydisperse system in which the aqueous phase contains dissolved components of fat, protein, carbohydrate, mineral and others. One of the most important milk components are proteins, which are basically represented by casein and serum proteins (Rassin et al., 1978; Chuang et al., 2005; Wu, 2009). According to the chemical point of view, proteins are high-molecular compounds that consist of amino acids. In the functional activity of the body, amino acids perform substrate and regulatory functions in protein biosynthesis. Amino acids are actively involved in energy processes, they are the source of physiologically active amines and are involved in the formation of nucleic acids, lipids, hormones (Bos et al., 2003; Moshel et al., 2006; Li et al., 2007). The main importance of proteins is their irreplaceability with other nutrients (Schaafsma, 2000). In the human body, food proteins are split to amino acids, some of them are split to organic keto acids, from which new amino acids are synthesized in the body, and then the required proteins for the body. These are the so-called substitutable amino acids. However, 8 amino acids, namely: isoleucine, leucine, lysine, methionine, threonine, phenylalanine, tryptophan and valine, cannot be synthesized in the body of an adult from other amino acids and enter into the body only with food. These amino acids are called irreplaceable ones. For children, also histidine and cystine are considered as irreplaceable ones (WHO, 2002; FAO, 2013). The amino acid structure of milk is affected by a large number of various external and internal factors (Mazhitova et al., 2015; Mazhitova and Kulmyrzaev, 2016).

One of the most important characteristics of consumer properties of a food product is an indicator of biological value. Biological value is the indicator of the quality of food protein, which reflects the degree of compliance of its amino acid structure with the body's need for amino acids for protein synthesis. Different methods are used to assess the biological value of food products, one of which is the comparison of the composition of the irreplaceable amino acids of the product's protein with the corresponding amino acid composition of the so-called ideal protein. Such method is called the method of amino acid score (Schaafsma, 2000). Dealing with this, the study of the amino acids structure and the determination of the full value of milk protein at cows of different genotypes with the use of modern methods of analysis is important and has practical significance for cattle breeding.

The purpose of the work was to study the amino acid composition, nutritional, energy and biological value of crossbred cows' milk compared to pure-breed analogues under different keeping technologies.

Materials and Methods

The research was conducted at the "Mikhailivskoye" JLtd PP, in the village Mykhailivka (49° 11′52″ n.l., 28° 43′29″e.l.) in Vinnitsa district of Vinnitsa region with thoroughbred cows of Ukrainian Black-Spotted (UBS) strain and first-generation breeds obtained as a result of crossbreeding with Brown Swiss breed and at "Azorel" Ltd in the village Mukhivka (48° 57′01″ n.l., 28° 47′09″ e.l.) in the Nemyriv district of Vinnitsa region with the cows of Ukrainian Red-Spotted (URS) dairy strain and first-generation breeds obtained when crossing the URS dairy strain with the Montbeliarde strain. At the "Mikhailivskoye" JLtd a tie-up-stall housing system in winter and free-stall housing at the play-feeding grounds in the spring-autumn periods is used. At "Azorel" Ltd, the free-stall housing is used with the use of a deep, prolonged-unchangeable litter. In both farms there were formed two groups of pure-breeding and domestic cows-analogues with a number of 10 heads in each.

In both farms, the same type of annual feeding of cows with full-fodder mixed fodders is used. The feeding level is quite high: animals consume 21.4-21.8 kg of dry fodder per day, the energy value of the consumed fodder is 211-220 MJ, the energy concentration in 1 kg of dry fodder is 10.3-10.4 MJ.

The amino acid composition of proteins in milk of cows of the investigated breeds was determined in the period of the increasing of milk yield (on the 60-70th day of lactation) at the State Scientific-Research Control Institute of Veterinary Medicinal Products and Feed Additives (Lviv, Ukraine) by the method of capillary electrophoresis using the system of capillary electrophoresis "Kapel-105/105M" (Ukraine).

Amino acid score (AAS, %) of milk protein was calculated according to the percentage of each essential amino acid (EAA) in the milk protein relatively to its content in the "ideal" protein (the standard is considered a chicken egg, soya or women's milk protein) (Schaafsma, 2000).

The biological value of the milk protein was determined using the Protein Digestibility Corrected Amino Acid Score (PDCAAS), which was recommended for the evaluation of protein quality by the Joint FAO/WHO Expert Council (WHO, 2002; FAO, 2013). The biological value of the proteins was estimated by the utility coefficient (U).

Under the analysis of the utility coefficient of each of the EAA of cows' milk, the formula (1) was used:

$$a_1, \% = \frac{AA_{min}}{AA_i \text{ EAAs of milk protein}} \quad (1)$$

where: a_1 – utility coefficient of each EAA;

AA_{min} – the minimum of chemical score of amino acids;

AA_i EAA – the amino acid score of each EAA of milk protein.

On the basis of the obtained data, the coefficient of the total utility of EAA of milk proteins (U) has been calculated:

$$U = \frac{\sum(\text{content}_i EAA \cdot AA_i EAA \cdot {}_{ai} EAA)}{\sum \text{content} EAA, \text{ mg/g of milk protein}} \quad (2)$$

where: $_i$EAA – each EAA (mg/g of protein);

AA_i EAA – amino acid score of each amino acid;

$_{ai}$ EAA – utility coefficient of each EAA.

Results and Discussion

According to Table 1, we see that in both cases, crossbred heifers predominate the pure-breed analogues in terms of the content of the mass fraction of fat, protein and lactose. Thus, the cross of UBS and Brown Swiss cows exceeded the pure-blood analogues by fat per 0.08%, protein per 0.15% and lactose per 0.02%.

In the milk of the investigated crossbreed's cows, the ratio of fat to the protein is within the 1.20:1 range at an optimal ratio of 1.2-1.1:1, the protein to fat ratio in the milk under study is 0.832:1 at an optimal ratio of 1:1. Regarding pure-blooded UBS cows, in their milk the ratio of fat to protein was slightly higher – 1.23:1, and protein to fat, on the contrary – lower, 0.810:1.

The crossbreeds of URS cows with Montbeliarde cows significantly prevailed the pure-blooded analogues in terms of the content of fat per 0.16% and protein per 0.22%, and somewhat per 0.01% in the content of lactose. Also, in their milk, there was observed an advantage over the ratio of protein to fat and the ratio of fat to protein was higher in pure-blooded cows.

Today, following the recommendation of FAO/WHO, when determining the biological value of proteins, it has been accepted to compare the amino acid composition of the studied proteins and their content in the "ideal" protein. In this case, it is important that the protein of interest should contain not only a sufficient amount of EAA, but the ratio between individual irreplaceable amino acids is as close as possible to the ratio in the proteins of the human body. AAS of milk protein, calculated according to the percentage ratio of each of EAA in the milk protein in relation to its content in the "ideal" protein, is presented in Tables 2 and 3. It is known that the violation of the balance of the amino acid composition of food proteins causes the violation of the protein exchange, it deals both with the processes of synthesis, and catabolism in the human body. Insufficient amount of one or another amino acid limits the use of other amino acids for the synthesis of protein, and the excess leads to the violation of the dynamic amino acid equilibrium towards anabolism, to the formation and accumulation of toxic exchange products. At AAS analysis of milk proteins, in addition to the definition of surplus AA scores, the presence of limiting amino acids, which were below 100%, was also evaluated.

AAS, in terms of the EAA percentage of the milk protein of UBS cows with respect to their number on the FAO/WHO adequacy scale for an adult, amounted to 141.7%, and in the crossbreed with Brown Swiss breed – 146.0% (Table 2). The AAS sum of the EAA of URS cows was 141.8%, and in the crossbreed of URS with Montbeliarde – 142.4% (Table 3).

For the milk protein of UBS breed cows, the first limiting amino acids ($PDCAAS_{min\ 1}$) were methionine + cystine, which score was 94.8% of value on the scale of adequacy in

Table 1. The content and ratio of nutrients in milk of primary cows at the average per lactation

Indicators	UBS	UBS x Brown Swiss	URS	URS x Montbeliarde
	n = 10	n = 10	n = 10	n = 10
Mass fraction of fat, %	3.74±0.03	3.82±0.09	3.73±0.05	3.89±0.06
Mass fraction of protein, %	3.03±0.02	3.18±0.03	3.16±0.04	3.38±0.03
Mass fraction of lactose, %	4.54±0.09	4.56±0.07	4.60±0.05	4.61±0.05
Correlations				
fat : protein	1.23:1	1.20:1	1.18:1	1.15:1
protein : fat	0.810:1	0.832:1	0.868:1	0.869:1

Table 2. AAS amino acids protein in milk of cows of different genotypes with respect to the "ideal" protein

Irreplaceable amino acids, EAA	EAA content in the "ideal" protein, mg/g*	The content in milk of cows of different genotypes			
		UBS		UBS x Brown Swiss	
		n = 10		n = 10	
		EAA, mg/g	AAS, %	EAA, mg/g	AAS, %
Lysine	55	65.8	119.6	67.3	122.3
Methionine + cystine	35	33.2	94.8	37.1	106.0
Threonine	40	45.0	112.6	45.4	113.5
Valine	50	48.6	97.2	52.8	105.6
Leucine	70	98.7	141.0	98.3	140.4
Isoleucine	40	48.5	121.2	49.2	123.0
Phenylalanine + tyrosine	60	94.3	157.1	97.5	162.5

Note: * – FAO/WHO Scale of EAA Adequacy with Respect to Human Needs

the "ideal" protein (Table 2). The second limiting amino acid ($PDCAAS_{min\ 2}$) was valine, which score was 94.8%. In the protein of crossbred cows with Brown Swiss breed amino acids in which the score was less than 100% was not detected, that is, the content of each EAA meets the requirements of human needs in the reference protein. Phenylalanine + tyrosine (162.5%) and lysine (122.3%) were the most superfluous.

As for the protein content of URS breed cows, limiting amino acids ($PDCAAS_{min\ 1}$) were methionine + cystine – 96.5% of the content in the "ideal" protein (Table 3). AAS of each of the EAA of the crossbred cows with the Montbeliarde breed was higher than 100%, the most excess was: phenylalanine + tyrosine (162.5%) and leucine (140.4%).

The results of the utility coefficient calculation for each EAA of milk protein of cows of different breeds are given in Table 4. According to the data of the table it is evident that at cows of all breeds the value of the total utility coefficient indicates a high level of balance of the amino acid composition. That is, the content of EAA protein, which is used for constructive needs of the human body, is high enough. The largest value of the total utility coefficient is established at the crossbreeds of the URS breed with the Montbeliarde breed – 108.06%, and the UBS crossbreeds with the Brown Swiss breed – 104.94%, whereas at the UBS and URS cows these values were somewhat lower and amounted to 93.63 and 96.26% respectively.

For normal life proteins, lipids, carbohydrates, macro- and trace elements, vitamins, edible fibers and other substances should come from food into the human body every day according to the formula of balanced nutrition which takes into account the norms of consumption of nutrients and energy by different groups of population depending on kind of their activity, age and gender, as well as by children and the elderly (Stoll et al., 1998; WHO, 2002; FAO, 2013).

Human food is characterized by a nutritional, biological and energy value. On the ground of above-mentioned, we have calculated the energy and nutritional value of milk of cows of different breeds (Table 5). The results of the research indicate a slightly higher nutritional value of protein, fat and lactose in the milk of crossbred cows, rather than pure-blooded analogues.

Table 3. AAS amino acids protein in milk of cows of different genotypes with respect to the "ideal" protein

Irreplaceable amino acids, EAA	EAA content in the "ideal" protein, mg/g*	The content in milk of cows of different genotypes			
		URS		URS x Montbeliarde	
		n = 10		n = 10	
		EAA, mg/g	AAS, %	EAA, mg/g	AAS, %
Lysine	55	58.1	105.6	63.4	115.2
Methionine + cystine	35	33.8	96.5	38.8	110.8
Threonine	40	40.6	101.4	44.0	110.0
Valine	50	52.9	105.8	57.7	115.4
Leucine	70	92.2	131.7	95.3	136.1
Isoleucine	40	42.8	107.0	43.5	108.7
Phenylalanine + tyrosine	60	90.4	150.6	93.8	156.3

Note: * – FAO/WHO Scale of EAA Adequacy with Respect to Human Needs

Table 4. Utility coefficients of milk protein of cows of different genotypes

Irreplaceable amino acids, EAA	Milk of cows of different genotypes			
	UBS	UBS x Brown Swiss	URS	URS x Montbeliarde
	n = 10	n = 10	n = 10	n = 10
Lysine	0.79	0.86	0.90	0.94
Methionine + cystine	1.00	0.99	1.00	0.98
Threonine	0.84	0.93	0.95	0.98
Valine	0.97	1.00	0.91	0.94
Leucine	0.67	0.75	0.73	0.79
Isoleucine	0.72	0.85	0.90	1.00
Phenylalanine + tyrosine	0.60	0.64	0.64	0.69
∑U	93.63	104.94	96.26	108.06

Table 5. Nutritional and energy value of milk of cows of different genotypes, in 100 g of product

Indicator	Daily human need	Breed			
		UBS	UBS x Brown Swiss	URS	URS x Montbeliarde
		n = 10	n = 10	n = 10	n = 10
Nutritional value of milk					
Protein, part of the total protein need, g	80	3.78	3.85	4.05	4.22
Protein, part of the need in animal protein, g	30	10.10	10.27	10.80	11.26
Fat, part of the general need for fat, g	60	6.23	6.36	6.21	6.48
Fat, part of the need in animal fat, g	25	14.96	15.28	14.92	15.56
Lactose, part of the general need in carbohydrates, g	400	1.13	1.14	1.15	1.16
Lactose, part of the need in mono- and disaccharides, g	75	6.07	6.08	6.13	6.15
Energy value of milk					
- kcal	3000	65.91	66.82	66.88	69.06
- kJ	12540	275.95	279.76	280.01	289.14

Proteins are vitally necessary products that serve as a material for cells' construction. The role of proteins in the body takes a large place due to the fact that they are the material which is necessary for the synthesis of hemoglobin, most hormones and enzymes (Moshel et al., 2006).

It was established that 100 g of milk protein, of the crossbred UBS and Brown Swiss cows provides for a person 3.85% of his/her daily need and 10.26% of the need of animal protein, and crossbred URS with Montbeliarde cows provide 4.22% and 11, 26% respectively. At the same time, this indicator for pure-bred cows was at UBS cows – 3.78 and 10.10%, while at URS cows it was 4.05 and 10.80%.

Milk of crossbred cows of UBS and Brown Swiss breeds in a quantity of 100 g provides daily human need in fat at 6.36% and 15.28% of fats of animal origin, which is 0.13% and 0.32% higher than that of pure-bred analogues. 100 g of milk of crossbred URS and Montbeliarde cows contained milk fat with the highest energy, and hence the nutritional value, and constituted 6.48% of the total daily requirement and 15.56 of the animal fat need. These values are 0.27% and 0.64% higher than that of pure-bred URS cows.

Lactose as a carbohydrate is contained only in milk. This saccharide has no small share in the functioning of the body (Bos et al., 2003). Only getting into the oral cavity it affects the saliva consistency – gives it a characteristic viscosity. In addition, it promotes more active absorption of vitamin B group, ascorbic acid and calcium, and getting into the intestine it stimulates multiplication of bifidobacteria and lactobacilli which are important for proper body function (Chuang et al., 2005; FAO, 2013).

Nutritional value of lactose in milk of crossbred cows is somewhat predominant the pure-breeding analogues: per 0.01% in both cases; as for the mono- and disaccharide hybrids of UBS with Brown Swiss breed predominated the purebred UBS cows by 0.01% and hybrids of URS cows with Montbeliarde ones predominated URS analogues per 0.02%.

Food calorie or energy value of food products is the amount of energy that is produced during the oxidation of fats, proteins and carbohydrates that are in food and spent for the physiological functions of the body. Milk is a significant source of energy that comes thanks to its fats, proteins and carbohydrates (Stoll et al., 1998; Chuang et al., 2005; Li et al., 2007).

Thus, 100 g of milk of UBS and Brown Swiss cow hybrids provides human's body up to 2.23% of the daily energy needs, which is 0.04% more than at purebred UBS counterparts. The highest energy value was at the crossbred cows of URS and Montbeliarde breed – 2.30% of the daily human need for energy that is 0.08% higher than the URS analogues.

Conclusions

It has been established that in the milk of crossbred cows per lactation, the mass fraction of fat and protein in the average essentially prevailed the pure-breed analogues.

The milk protein of crossbred cows had a higher biological value compared to purebred animals. For the milk protein of UBS breed cows, the first limiting amino acids ($PDCAAS_{min\ 1}$) were methionine + cystine, which score was 94.8% of value on the scale of adequacy in the "ideal" protein. The second limiting amino acid ($PDCAAS_{min\ 2}$) was valine, which score was 94.8%. As for the protein content of URS breed cows, limiting amino acids ($PDCAAS_{min\ 1}$) were methionine + cystine – 96.5% of the content of the "ideal" protein. In both cases, the milk protein of the crossbred cows did not contain amino acids shorter than 100%.

The highest total value of the utility coefficient has been set in hybrids of URS with Montbeliarde breed – 108.06% and UBS with Brown Swiss hybrids – 104.94%, while the UBS and URS purebred cows had these values slightly lower – 93.63 and 96.26% respectively.

Milk of crossbred cows had a great deal of nutritional and energy value compared to pure-blooded counterparts.

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