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Relative variability of breeding values of bulls from different countries of origin

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The study was aimed to determine the relative variability of breeding values of Holstein bulls from different countries of origin (USA, Canada, Germany, and the Netherlands) used in Ukraine, as well as the level of agreement between foreign evaluations and national re-evaluations. The data from 220 imported bulls whose semen was used for herd reproduction in 2020–2021 were analyzed. Domestic evaluations were expressed as estimated breeding values (EBV), calculated using a national methodology, whereas foreign evaluations were generally obtained using BLUP-based models. The analysis included milk yield, fat and protein content and yield, number of daughters and herds, and reliability. Foreign evaluations were based on substantially larger datasets, which resulted in higher reliability (94–97%) compared with 86–93% in Ukraine. The average breeding values for milk yield and fat and protein yields in the USA and Canada exceeded the Ukrainian estimates (by 250–350 kg for milk yield, up to 45 kg for fat, and up to 28 kg for protein), while the actual performance of daughters was similar. In contrast to the EBV estimates, the breeding value for milk production for German sires evaluated in Germany was mostly negative. Correlations between Ukrainian and foreign evaluations were moderate for Canadian bulls ($r = 41–55\%$; $P < 0.001$), weak for American bulls ($r \approx 20\%$; $P < 0.05$), and insignificant for German bulls. Significant relationships were observed only for quantitative traits (milk yield), whereas no statistically significant correlations were found for fat and protein percentages. North American selection indices exceeded Ukrainian ones by 1.5–2.0 times, while the German index had negative values. The breeding value of imported bulls varies depending on the country of origin and the evaluation methodology. The highest agreement between Ukrainian and foreign results was observed for Canadian sires, moderate agreement for American sires, and no agreement for German sires. Foreign evaluations should be used only as a preliminary reference, whereas final selection requires mandatory national re-evaluation considering local conditions.

Keywords: bull evaluation; Holstein breed; reliability; selection index; correlation; milk production.

Introduction

In the past, the evaluation of animals' breeding values has ranged from simple performance-based indices and ranking systems to more advanced statistical approaches. Over the past decades, numerous methodologies for assessing breeding value have been developed and implemented worldwide, taking into account genetic, management, and environmental factors (Štrbac et al., 2023). Currently, selection indices are essential tools in dairy production, as they integrate information on multiple traits into a single value that can be used to rank animals and support optimal breeding decisions (Cole et al., 2021). Most countries have developed their own selection indices in accordance with their specific production and economic conditions (Miglior et al., 2005). The main differences among selection indices across countries lie in the relative emphasis placed on specific traits (Miglior et al., 2005; Cole et al., 2018).

In international breeding practice, an important tool for comparing the breeding values of sires is the evaluation provided by the International Bull Evaluation Service (Interbull), which ensures comparability of results across countries on a standardized basis. However, even when standardized methodologies are applied, the results may be influenced by genetic correlations between countries, differences in the structure and volume of available data, as well as heterosis effects (Schaeffer, 1985, 1994). In particular, studies have shown that French bulls that were full brothers of American bulls received different breeding value estimates for milk yield and protein content depending on the country of evaluation. This disparity raises concerns about the absolute comparability of international results (Schaeffer, 1994).

The globalization of the market for genetic material, particularly bovine semen, has made its trade an integral component of breeding programs in modern animal production. With the growing demand for new selection traits and high-performance characteristics in sires, countries are actively exchanging genetic material to improve their herds (Chao, 2026). In 2023, the global trade in cattle semen reached a value of $572 million, representing a 0.64% increase compared with 2022. Over the past five years, the market has grown at an average annual rate of 5.28%, indicating steady expansion. According to the 2025 analytical report by Grand View Research, the leading exporters in 2023 were the United States ($293 million), Canada ($110 million), and the Netherlands ($32.2 million), while the main importers included China ($99.3 million), the United States ($39.4 million), and the United Kingdom ($33.8 million).

In the Holstein population, genetic improvement through sire selection is of decisive importance compared with that of females (Powell et al., 1997). The import of semen from countries with highly developed dairy industries remains one of the most effective tools for enhancing economically important traits in Holstein cattle in developing countries, including Ukraine. According to the Catalogue of Bulls of Dairy and Dual-Purpose Breeds for Herd Reproduction in 2025, semen imports into Ukraine from the United States, Canada, and several European nations (most notably Germany, the Netherlands, and France) have been steadily increasing. Approximately 65–70% of all imported semen originates from American and Canadian sires (Zhukorskyi et al., 2025a).

In this context, a comparative evaluation of the breeding value of bulls from different countries is critical, as only objective data allow for the informed selection of genetic material. For example, studies conducted in Iran have shown that the progeny of French bulls exhibited the highest Lifetime Net Income (LNI) index under warmer climatic conditions, whereas daughters of German sires demonstrated the highest average performance in colder climatic zones (Nazari et al., 2022). These findings highlight the importance of considering both the environmental conditions of the importing country and the origin of the sires when designing breeding programs. Powell et al. (1997) demonstrated that average U.S.-based breeding value estima-

tes for American bulls remained virtually unchanged over a six-month evaluation period. By contrast, estimates for bulls from France, Germany, Italy, and the Netherlands showed increases of approximately 14 kg in milk yield and 0.4 kg in milk fat and protein yields during the same period.

In addition, breeding programs across different continents exhibit considerable variation in pedigree completeness, the proportion of foreign-origin sires, and generation intervals, all of which affect the comparability of estimated breeding values. For example, among Holstein bulls, the proportion of sires with foreign parentage averaged 43%, with substantial variation across regions, while pedigree completeness in proven bulls reached an average of 98%. While such high completeness facilitates international evaluation, it does not entirely eliminate regional differences (VanRaden et al., 2024).

The effective use of sires from other countries in national breeding programs requires the adaptation of their estimated breeding values to the local context. Differences in trait definitions, evaluation models, data structures, and production environments may lead to substantial discrepancies in breeding value estimates and the ranking of animals (Schaeffer, 1994, 1996). Genetic correlations for traits such as productivity or longevity may deviate considerably from unity, particularly under differing management conditions (Forabosco et al., 2009; Philipsson et al., 2009). Even when correlations are high, the ranking of bulls can differ substantially across national, subglobal, and global evaluation scales (Powell et al., 2002). Furthermore, it has been demonstrated that the application of GMACE (Genomic Multi-trait Across Country Evaluation) improves the accuracy of evaluations; however, this approach also requires careful integration into the national evaluation system (VanRaden et al., 2010).

Therefore, when applying various methods aimed at improving selection accuracy, it is essential to account for local conditions and implement appropriate adjustments. In general, international standards established in the 2022 *Code of Practice* of the Interbull Centre stipulate country-specific interpretation of international evaluations as a standard approach to ensure their accuracy and relevance to national conditions.

The diversity and inconsistency of results reported by various researchers necessitate further comparative studies of breeding value estimates for bulls from different countries when used within the specific conditions of Ukraine. This requirement forms the primary objective of the present study.

Materials and methods

The study was conducted based on the results of national evaluations expressed as estimated breeding values (EBV) calculated according to the national methodology (Maiboroda et al., 2019) and international evaluations obtained using BLUP-based models. The analysis included Holstein sires used in 2020–2021 for reproduction in breeding herds, as listed in the respective bull catalogs (Polupan et al., 2020, 2021). The research database comprised breeding value data for 220 Holstein sires, evaluated (or re-evaluated) based on progeny performance in Ukraine. These evaluations were conducted in 2024 using the national EBV method with a reliability threshold of 70% or higher (Pryima et al., 2025). By country of origin, American-bred sires (132 bulls) represented the largest proportion of the sample. The analysis also included 63 bulls born in Canada, 21 in Germany, and 4 in the Netherlands. The data on milk production of cows from active Holstein populations abroad were obtained from the 2024 yearly survey on milk recording systems in cows, sheep, and goats published by the International Committee for Animal Recording, while corresponding data for Ukraine were sourced from the official publication of the State Register of Breeding Entities in Animal Husbandry (Zhukorskyi et al., 2025b).

For each sire, data were recorded on the number of daughters and herds, the reliability of progeny-based evaluations, and the daughters' average milk yield, fat and protein content, and yields, as well as the sires' estimated breeding values for these traits. All 220 sires had been evaluated abroad prior to obtaining their progeny-based evaluations in Ukraine. In addition to the national data, the dataset also included the evaluation results of these sires from their respective countries of origin as of 2024. Relative variability and other statistical parameters were calculated using standard methods of mathematical statistics, processed using the Statistica 12.0 software package (Petrovska et al., 2022).

Results

As of February 26, 2025, the electronic database of dairy and dual-purpose bulls included 3,042 sires evaluated in recorded herds in Ukraine between 1991 and 2024. These evaluations were conducted using the Estimated Breeding Value (EBV) method, with a reliability threshold exceeding 50%. For the 220 sires specifically selected for this study, performance records from an average of 267 daughters were analyzed, with these daughters distributed across an average of 16.6 breeding herds. This data structure ensured a high level of reliability for the national evaluation, reaching 87.5% (Table 1). The average breeding value of the analyzed sires for the composite selection index and individual milk production traits was shifted in a positive direction relative to the theoretically expected zero value. This shift can be attributed to the comparatively lower breeding values of sires born in Ukraine, which serve as the reference base. At the same time, deviations for qualitative traits (milk fat and protein content) were minimal, whereas those for quantitative traits were more pronounced.

Table 1

Comparative characteristics of breeding values and daughter performance of foreign-bred bulls based on evaluations in Ukraine and in the countries of their origin

Trait			Evaluation in Ukraine		Evaluation abroad	
			n	mean ± SE	n	mean ± SE
Number of	daughters		220	267 ± 27	220	2867 ± 516
	herds		220	16.6 ± 1.1	220	560.2 ± 69.4
Reliability, %			220	87.5 ± 0.6	220	96.8 ± 0.2
Breeding value for	milk yield, kg		220	312 ± 54	220	503 ± 48
	milk fat	%	220	0.0005 ± 0.0036	220	0.06 ± 0.02
		kg	220	11.4 ± 2.0	220	26.2 ± 1.9
	milk protein	%	209	0.002 ± 0.002	220	0.04 ± 0.01
		kg	209	10.2 ± 1.8	220	20.5 ± 1.6
	selection index (SI)		220	405 ± 53	220	534 ± 45
Average 305-day adjusted performance of daughters	milk yield, kg		220	11568 ± 117	177	11843 ± 49
	milk fat	%	220	3.76 ± 0.01	177	3.98 ± 0.01
		kg	220	434.1 ± 4.4	177	470.8 ± 2.4
	milk protein	%	209	3.28 ± 0.01	177	3.22 ± 0.01
		kg	209	377.5 ± 4.3	177	381.5 ± 1.7

Bull catalogs for dairy breeds in many countries provide information on average daughter performance adjusted to mature equivalent (ME) and systematic environmental effects (e.g., herd, year and season), alongside breeding values for individual traits and composite selection indices. According to the evaluation results of the studied sires in Ukrainian breeding herds, the adjusted 305-day milk yield of

daughters reached a high level, averaging over 11,500 kg (Table 1). This adjusted daughter performance exceeded the average productivity of cows in the active Holstein population in 2024 by 1,397 kg of milk, 44 kg of milk fat, and 39 kg of milk protein.

The evaluation of breeding values of the studied sires in their countries of origin revealed a markedly higher reliability (by 9.3%). This is primarily due to a 10.7-fold greater number of daughters included in the analysis, distributed across 33.7 times more herds. The higher reliability of foreign evaluations is driven by significantly larger reference populations of Holstein cows in the countries of origin, as well as the earlier initiation of sire use. In terms of average breeding values, a greater positive deviation was observed, which can be logically explained by the import of genetic material predominantly from improving sires. The advantage of foreign over national evaluations amounted to 191 kg for milk yield, 14.8 kg for milk fat yield, and 10.3 kg for milk protein yield. The average adjusted daughter performance in the countries of origin exceeded that observed in Ukraine by 275 kg (or 2.4%) for milk yield, 36.7 kg (8.5%) for milk fat yield, and 4.0 kg (1.1%) for milk protein yield. These results indicate a relatively high level of genetic potential realization regarding the average adjusted productivity of Holstein cattle in Ukraine.

To assess the effectiveness of using foreign-bred sires, there is particular interest in potential differences in the expression of breeding values among bulls from different countries of origin. The largest group evaluated in Ukraine consisted of US-bred bulls. A comparison of national and foreign evaluations for these 132 bulls demonstrated a higher (by 10.9%) reliability for the latter, which was due to a 19-fold greater number of daughters included in the analysis, distributed across 43 times more herds (Table 2).

Evaluations for milk, fat, and protein yields in the US database were substantially higher (on average by 342.3, 17.2, and 13.0 kg, respectively) than the results of their re-evaluation in Ukraine. This may reflect a reduced expression of the genetic potential of imported sires within the genotype-by-environment interaction. Consequently, the selection index (SI) was significantly higher ($P < 0.01$) under the US evaluation (by 228.0 ± 76.2). Meanwhile, the average adjusted performance of first-lactation cows remained at a similar level in both populations. In daughters evaluated abroad, milk yield was even slightly lower (by 46 kg) than in recorded herds in Ukraine. However, due to the higher milk fat content in animals evaluated in the United States, the fat yield of daughters in Ukrainian herds was lower by 21.9 kg (4.8%). The average milk protein yield of first-lactation cows differed only slightly between the groups. The similarity in actual daughter performance, despite differences in breeding value estimates, highlights and confirms the necessity of mandatory re-evaluation for imported sires.

Table 2

Comparative analysis of breeding value evaluations and daughter performance of US-bred bulls in Ukraine and in the countries of their origin

Trait			Evaluation in Ukraine		Evaluation in the USA	
			n	mean ± SE	n	mean ± SE
Number of:	daughters		132	184 ± 14	132	3522 ± 772
	herds		132	13.4 ± 0.8	132	576.9 ± 90.8
Reliability, %			132	86.3 ± 0.7	132	97.2 ± 0.2
Breeding value for:	milk yield, kg		132	287.2 ± 64.1	132	629.5 ± 48.2
	milk fat	%	132	0.001 ± 0.005	132	0.034 ± 0.019
		kg	132	10.5 ± 2.4	132	27.7 ± 2.1
	milk protein	%	126	0.004 ± 0.002	132	0.026 ± 0.008
		kg	126	10.0 ± 2.1	132	23.0 ± 1.4
	selection index (SI)		132	429 ± 67	132	657 ± 37
Average 305-day adjusted performance of daughters:	milk yield, kg		132	11680 ± 127	126	11634 ± 44
	milk fat	%	132	3.76 ± 0.01	126	3.95 ± 0.02
		kg	132	438.6 ± 4.7	126	460.5 ± 2.3
	milk protein	%	126	3.28 ± 0.01	126	3.21 ± 0.01
		kg	126	382.4 ± 4.7	126	373.6 ± 1.6

A comparison of the Ukrainian and Canadian evaluations of sire breeding values (Table 3), similar to the US assessment, revealed substantial differences in the scale of the datasets used. In Canada, evaluations were based on more than 1,500 daughters across over 500 herds, resulting in a reliability of approximately 97%. By contrast, in Ukraine, this parameter was below 90%, based on an average of about 200 daughters per sire. Such a large volume of data significantly increased the reliability of foreign evaluations compared with those conducted nationally. However, the re-evaluation of Canadian-born sires in Ukraine showed a 2.2% higher reliability compared with those born in the United States. This improvement was due to a greater average number of daughters (by 52) and herds (by 3.4) involved in the national assessment of the Canadian group.

According to the Canadian evaluation, the breeding value of the 63 bulls for milk yield exceeded the Ukrainian estimates by an average of nearly 254 kg (Table 3). A similar trend was observed for milk fat yield (an advantage of approximately 26 kg) and milk protein yield (over 20 kg). At the same time, the Canadian evaluation indicated an increase in milk fat content of more than 0.1%, whereas the difference in protein content remained negligible. Notably, the selection index based on sire evaluations in Canada's recorded herds was more than twice as high as the average values obtained in Ukraine (Table 3). These findings further underscore the importance of mandatory re-evaluation for imported sires prior to their widespread use within the national breeding population.

Based on the adjusted average milk yield in Ukraine, the daughters of Canadian-bred sires demonstrated a high level of genetic potential realization for productivity, yielding only 2.0% (246 kg) less than their half-sisters lactating in Canada. Due to the significantly lower milk fat content in daughters lactating in Ukraine (by 0.3 ± 0.02%, $t_d = 13.04$, $P < 0.001$), their milk fat yield was substantially lower than that of their Canadian half sisters (by 45.3 ± 9.9 kg, or 10.0%, $t_d = 4.59$, $P < 0.001$). In terms of milk protein content, daughters of Canadian sires in recorded herds in Ukraine did not differ significantly from their half sisters in Canadian herds. This resulted in an insignificant advantage for the latter in milk protein yield (by 5.8 ± 9.2 kg, or 1.5%, $t_d = 0.63$, $P > 0.1$).

The evaluation of breeding value of 21 German-bred bulls in Ukraine (Table 4) was based on a substantially larger number of daughters compared with those born in the United States and Canada (by 725 and 673 cows, respectively). Furthermore, the national evaluation involved an average of 340 more animals than their corresponding evaluations in German herds. This discrepancy can be attributed to the relatively high proportion of imported live bulls, whereas genetic imports from Canada and the United States consisted almost exclusively of semen. However, evaluations in Germany were conducted across a much larger number of herds (averaging 111.1 more than in Ukraine). As a result, both Ukrainian and German evaluations achieved a similarly high level of reliability, reaching approximately 94%.

The comparison of breeding value estimates revealed substantial differences. In particular, the Ukrainian re-evaluation for milk yield, milk fat, protein yields, and the composite selection index showed a noticeable positive shift, whereas the German evaluation, on the contrary, yielded negative values. This discrepancy can be attributed to the importation of young bulls prior to their progeny-based evaluations in Germany (i.e. they were initially evaluated based on pedigree

data). Regarding the average breeding values for quantitative milk production traits, German-bred bulls exhibited the largest discrepancies between evaluations in their country of origin and their re-evaluation in Ukraine, surpassing the differences observed for US and Canadian sires. By contrast, for milk fat and protein content, the differences between evaluations were less pronounced and remained close to the theoretically expected near-zero values.

The average adjusted performance of daughters of German sires was the lowest among the three studied countries of origin, amounting to nearly 9,400 kg. The German breeding value database does not provide information on average adjusted daughter performance, which precludes a direct comparison with the results of their use in Ukraine. However, according to ICAR data, the average productivity of Holstein cows in Germany in recent years has not exceeded 10,000 kg, which is consistent with the average performance of daughters of German sires observed in Ukrainian herds. Due to the limited number of Dutch-bred sires included in the analysis, their average breeding values were not analyzed as a separate group. Instead, their data were incorporated only into the calculation of the overall variability between Ukrainian and foreign evaluations across the entire dataset.

For the effective utilization of foreign-bred sires in Ukraine, the primary focus should be shifted from comparing average breeding values to assessing the degree of rank stability and correlation between foreign evaluations and their corresponding re-evaluations under domestic conditions in recorded herds. Correlation analysis encompassing all studied bulls from four countries of origin revealed a low and mostly insignificant level of association between breeding value estimates in the countries of origin and their re-evaluation in recorded herds in Ukraine (Table 5).

Table 3
Comparative analysis of breeding value evaluations and daughter performance of Canadian-bred bulls in Ukraine and in the countries of their origin

Trait			Evaluation in Ukraine		Evaluation in Canada	
			n	mean ± SE	n	mean ± SE
Number of:	daughters		63	236 ± 39	63	1777 ± 661
	herds		63	16.8 ± 1.4	63	533.4 ± 118.4
Reliability, %			63	88.5 ± 0.9	63	96.8 ± 0.3
Breeding value for	milk yield, kg		63	291.0 ± 118.7	63	544.6 ± 130.2
	milk fat	%	63	-0.010 ± 0.006	63	0.132 ± 0.037
		kg	63	9.8 ± 4.5	63	36.1 ± 3.8
	milk protein	%	58	-0.001 ± 0.003	63	0.080 ± 0.019
		kg	58	7.7 ± 3.9	63	27.9 ± 3.2
	selection index (SI)		63	332 ± 110	63	733 ± 72
Average 305-day adjusted performance of daughters	milk yield, kg		63	12111 ± 231	51	12357 ± 99
	milk fat	%	63	3.72 ± 0.01	51	4.02 ± 0.02
		kg	63	451.0 ± 8.8	51	496.3 ± 4.6
	milk protein	%	58	3.30 ± 0.01	51	3.25 ± 0.01
		kg	58	395.4 ± 8.6	51	401.2 ± 3.3

Table 4
Comparative analysis of breeding value evaluations and daughter performance of German-bred bulls in Ukraine and in the countries of their origin

Trait			Evaluation in Ukraine		Evaluation in Germany	
			n	Mean ± SE	n	Mean ± SE
Number of:	daughters		21	909 ± 196	21	569 ± 296
	herds		21	38.3 ± 7.7	21	149.4 ± 38.3
Reliability, %			21	93.9 ± 1.6	21	94.1 ± 0.7
Breeding value for	milk yield, kg		21	672.8 ± 135.4	21	-427.2 ± 143.8
	milk fat	%	21	-0.003 ± 0.008	21	0.09 ± 0.05
		kg	21	25.3 ± 5.1	21	-9.9 ± 4.6
	milk protein	%	21	-0.003 ± 0.006	21	-0.03 ± 0.03
		kg	21	21.2 ± 4.6	21	-17.8 ± 4.4
	selection index (SI)		21	584 ± 139	21	-825 ± 155
Average 305-day adjusted performance of daughters	milk yield, kg		21	9390 ± 342	NA*	NA*
	milk fat	%	21	3.72 ± 0.02	NA*	NA*
		kg	21	349.0 ± 12.3	NA*	NA*
	milk protein	%	21	3.17 ± 0.02	NA*	NA*
		kg	21	298.6 ± 12.0	NA*	NA*

Note. * NA (not available); no information on average productivity of daughters in Germany.

Table 5
Correlation between breeding value estimates of sires evaluated in Ukraine and in the countries of their origin (USA, Canada and Germany)

Correlated trait			Correlations between breeding value evaluations in Ukraine and abroad							
			all bulls		including by country of origin					
					USA		Canada		Germany	
			r ± SE %	P	r ± SE %	P	r ± SE %	P	r ± SE %	P
Number of sires			220		132		63		21	
Breeding value for:	milk yield, kg		23.3 ± 6.6	<0.001	19.7 ± 8.6	0.024	55.1 ± 10.7	<0.001	-4.2 ± 22.9	0.856
	milk fat	%	-2.4 ± 6.8	0.727	-1.0 ± 8.8	0.908	4.5 ± 12.8	0.724	8.1 ± 22.9	0.729
		kg	-13.6 ± 6.7	0.044	-15.7 ± 8.7	0.072	1.9 ± 12.8	0.884	-7.2 ± 22.9	0.755
	milk protein	%	11.7 ± 6.9	0.091	11.5 ± 8.9	0.201	21.6 ± 13.0	0.103	-3.2 ± 22.9	0.890
		kg	11.4 ± 6.9	0.100	9.4 ± 8.9	0.295	41.5 ± 12.2	<0.001	13.2 ± 22.7	0.569
	selection index (SI)		-0.9 ± 6.8	0.890	-12.7 ± 8.7	0.145	33.0 ± 12.1	0.009	-2.9 ± 22.9	0.902

A significant, albeit modest, positive relationship was observed for breeding values for milk yield. Positive and close to statistical significance correlation coefficients were also found for milk protein content and protein yield. By contrast, a low negative correlation was observed between breeding values for milk fat content and fat yield, with the latter reaching statistical significance. Thus, the low level of

correlation between evaluations indicates that when using foreign-bred sires, breeding value estimates from the country of origin should be considered preliminary. Mandatory re-evaluation under domestic conditions is essential to mitigate bias in progeny performance results arising from the genotype-by-environment interaction.

Of particular interest is the variation in the degree of consistency between national and foreign breeding value evaluations across different countries of origin. It was established that the highest concordance between foreign and national evaluations occurred among Canadian-bred sires (Table 5). For all milk production traits, positive correlations were detected; specifically, for milk and protein yields, these reached a moderate level (55.1% and 41.5%, respectively) with high statistical significance ($P < 0.001$). By contrast, for milk fat content and fat yield, the relationship between evaluations was virtually nonexistent.

Within the largest group – US-origin bulls, the relationship for milk fat content and yield was also low and insignificant, but notably in a negative direction (Table 5). A low, positive, yet insignificant correlation was observed in US sires for milk protein content and protein yield. For milk yield, this relationship was the most pronounced (nearly 20%) and statistically significant at the first level of significance.

For German-bred bulls, the relative consistency of breeding values was the lowest, inconsistent in direction, and statistically insignificant across all traits (Table 5). For the composite selection index (SI), no significant correlation was found either across the entire dataset or specifically for bulls of US and German breeding. This can be attributed to both the inconsistent relationships between national and foreign breeding value estimates for individual traits and the fundamental differences in the structure of selection indices across countries. Among the studied countries, the selection indices of Canada and Ukraine appear to be the most similar in their component structure. This likely explains the noticeable positive and statistically significant correlation between Canadian and Ukrainian selection indices, which exceeded 30% (Table 5).

In summary, the highest level of concordance between Ukrainian and foreign breeding value evaluations was observed for Canadian sires, followed by a substantially lower level for American sires, and virtually no agreement for German sires. Furthermore, the direction of correlations was consistent only for milk yield, whereas for qualitative traits (fat and protein content), such a consistency was absent in all three cases.

Discussion

The comparative analysis of breeding values (EBV) between Ukrainian national evaluations and foreign data for imported Holstein bulls demonstrates pronounced heterogeneity in the direction and strength of relationships depending on the country of origin.

These findings are consistent with international studies that, despite reporting generally high correlations between international (MACE / Interbull) and national evaluations, emphasize their variability across different countries and traits. For instance, a study of 821 bulls from the United States, Canada, Italy, France, the Netherlands, and Australia reported strong associations ($r \approx 0.9$) between international and domestic evaluations for production traits. However, notable discrepancies observed in Italy have been attributed to modifications in national evaluation models (Nicolazzi et al., 2011). Our results for Canada and the United States partially support these observations. By contrast, for German-bred bulls, the correlation between Ukrainian re-evaluations and foreign data was close to zero and statistically insignificant. Similar trends were reported by Keßler et al. (2025), who noted that German breeding programs place significant emphasis on functional and health-related traits (RZG index used in Germany). This shift in selection priorities reduces direct comparability with national systems that remain primarily focused on milk yield.

Our previous research (Polupan et al., 2022), which analyzed bulls evaluated or re-evaluated between 2003 and 2013, revealed a low level of consistency ($r = -0.1\%$ to 3.6%) between Ukrainian and foreign breeding value estimates. These findings are corroborated by the present study on the current Holstein population, where correlations between foreign and Ukrainian evaluations remained low and inconsistent in direction ($r = -15.7\%$ to 55.1%).

Analysis of Interbull data indicates that transformation to "global" or "subglobal" scales has a minimal effect on bull rankings relative to national scales, provided that international genetic correlations are very high (Powell et al., 2002). However, the proportion of shared "top-100" bulls depends substantially on the strength of genetic correlations between specific countries. This provides a theoretical explanation for our findings: Canada showed the highest level of agreement, whereas Germany exhibited the lowest.

For other traits, including conformation (body type) scores, international genetic correlations fluctuate much more widely (averaging ~0.68–0.80, with some falling to very low levels). This is accompanied by instability in ranking when evaluations are transferred between countries (Battagin et al., 2012). These observations align with our findings regarding the lack of correlation for milk fat and protein content, highlighting the impact of differences in trait definitions, recording systems, and other factors.

Data structure also emerged as a critical factor. In our samples, foreign evaluations were based on significantly larger datasets, which ensured higher reliability and, consequently, higher average breeding values for milk yield and fat and protein yields. Powell et al. (1997) have consistently noted this role of data scale in their international reviews.

Modern approaches to integrating genomic evaluations (GMACE) ensure a high accuracy in international assessments; however, they require national calibration. Without such a calibration, systematic biases can occur when transferring results between countries (VanRaden et al., 2010). Our findings, specifically the weak or nonexistent correlations for certain traits, indicate the necessity of such adaptation before the large-scale implementation of imported sires within the national breeding system in Ukraine.

Differences in breeding value estimates across countries, as a manifestation of the genotype-by-environment interaction, can be attributed to regional variations in temperature, humidity, management practices, housing technologies, feeding systems, evaluation methodologies, and genetic backgrounds (Powell et al., 2002). Consequently, selection decisions regarding the use of foreign-bred sires should primarily rely on progeny-based evaluations (or re-evaluations) conducted in the country of intended use. Foreign evaluations, while valuable, should serve only as supplementary or preliminary information. In this context, it is noteworthy that the *Code of Ethics* was adopted in Canada in 2013 concerning the publication of genetic information in the dairy industry, primarily aimed at domestic producers (Van Doormaal et al., 2015). This code stipulates that the promotion and marketing of genetic material (including bulls, cows, embryos, and semen) must rely on genetic evaluations expressed on the Canadian scale, which is the most relevant for domestic production conditions. This requirement applies to official milk recording data, breeding value estimates, and genomic predictions. Genetic evaluations from other countries may only be included as supporting data. Furthermore, for progeny-tested sires lacking domestic performance data in Canada, the use of official MACE (or GMACE) evaluations is mandatory. Thus, given the identified differences in foreign selection indices and the noticeable discrepancies in EBV estimates, a two-tier strategy may be recommended: preliminary screening based on international indices (considering relevant parameters), followed by mandatory re-evaluation adjusted to local economic weights, feeding systems, and climatic conditions (Interbull, 2022). The requirements of the *Instruction on the Selection of Breeding Bulls of Dairy and Dual-Purpose Breeds* (Pabat et al., 2006) regarding the necessity of appropriate re-evaluation of imported bulls and semen under Ukrainian conditions are therefore fully justified.

Overall, the results of this study confirm that for a sustainable, long-term genetic improvement strategy, Ukraine should further develop its national evaluation system. This system should be integrated with international methodologies while adapting them to the local context to accurately reflect the expression of genetic merit under the influence of genotype-by-environment interaction. Future research

should incorporate larger sample sizes for each import source and employ advanced approaches, such as genomic evaluation (GEBV), to enhance the accuracy of international comparisons.

Conclusion

Substantial discrepancies exist between Ukrainian and foreign breeding value evaluations of Holstein bulls, driven by the country of origin, the scale of the databases used, and the principles underlying the construction of selection indices. The highest level of concordance was observed for Canadian sires, where correlations for milk yield and milk protein yield were moderate and statistically significant. For American bulls, only weak correlations were identified, while for German bulls, agreement was virtually absent. The values of foreign selection indices differ significantly from Ukrainian ones, which can be explained by larger sample sizes and the number of daughters used in calculations, as well as by differences in trait weighting within the index structure. Therefore, the breeding value of bulls determined abroad should be considered preliminary only for the Ukrainian breeding system, as they do not account for local environmental conditions and genetic background.

Further research should focus on expanding the sample of sires from various countries, integrating genomic evaluation methods (specifically GMACE), and examining the relationships between breeding values and daughter longevity and reproductive performance. These efforts will contribute to the development of adapted national selection indices tailored to Ukrainian conditions.

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