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Article

Population status and adaptive capacity of black-and-white cattle in the Agrocity area, Ulaanbaatar

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Abstract

Sustainable agribusiness development relies on productive and well-adapted livestock populations to ensure food security and support dairy farming systems. This study evaluated the population structure, production performance, genetic diversity, and environmental adaptability of Black-and-White (Holstein-type) cattle in the Agro-City regions of Ulaanbaatar, Mongolia an important hub for intensive dairy production. The area maintains 23,500 cattle, including 5,300 Black-and-White and crossbred cows, accounting for 54.1% of the national population of this breed and supplying approximately 28.1 million liters of milk annually to urban consumers.

Localized Black-and-White cows produced an average of 3,277 ± 220.9 kg of milk per lactation, with mean fat and protein contents of 3.55% and 3.1%. Reproductive indicators included a 267.6 ± 16.5-day lactation length, 395.3 ± 21.1-day calving interval, 84.0% conception rate, 1.2 calvings per year, and 96.4% calf survival, resulting in an overall reproductive efficiency of 80.0%. Genetic analysis showed moderate variability, with an inbreeding coefficient of 0.31 and expected heterozygosity of 0.627. After more than 15 generations since their introduction from Russia, the population demonstrated strong climatic resilience, with an adaptability index of 4.23.

Overall, the localized Black-and-White population represents a well-adapted genetic resource with significant potential to enhance sustainable and intensive dairy production in Mongolia's Agro-City region.

Keywords: Black-and-White cattle, dairy production, adaptability, sustainable livestock development; adaption index

Introduction

Ensuring food security and strengthening rural livelihoods remain national priorities, particularly in countries with highly seasonal agricultural systems. In Mongolia, milk production, one of the country's key strategic food resources, exhibits pronounced seasonality, with about 65% of raw milk produced in summer and only 35% in winter [1]. Consequently, milk processing plants operate at just over half of their installed capacity, and dairy imports continue to fill the supply gap [2]. Addressing this imbalance requires the development of a technologically advanced and economically efficient system to ensure a stable, year-round milk supply.

To promote such development, the Government of Mongolia has designated the Songino-Khairkhan district of Ulaanbaatar as the site of the "Agrocity" Special Economic Zone (SEZ), envisioned as a green development model integrating intensive agriculture, food processing, renewable energy, digital technologies, and innovation through public–private partnerships [3–5]. Evidence-based planning for this initiative necessitates an assessment of existing regional conditions,

including livestock productivity, genetic resources, and adaptive capacity. Evaluating cattle populations under Mongolia's extreme climatic variability requires approaches that go beyond conventional productivity metrics. Adaptation is a multidimensional process encompassing behavioral, physiological, morphological, and genetic responses, which vary among breeds in relation to environmental stressors [6,7]. Although genetic similarity indicators provide insight into population structure, they often fail to capture the full extent of genotype–environment interactions. Integrating phenotypic data allows for a more accurate assessment of adaptive potential and its phenotypic expression under diverse production conditions [8].

Cattle adaptation emerges from complex interactions among genomic, phenotypic, and environmental factors [9]. Recent large-scale genomic analyses [10], have quantified global patterns of cattle genetic diversity and adaptation, emphasizing the importance of aligning breed characteristics with local ecological and technological conditions. Understanding these mechanisms is essential for optimizing productivity and ensuring the long-term sustainability of dairy production systems.

The present study provides a comprehensive evaluation of the population status, productivity, domestication level, and adaptive capacity of dairy cattle in the Agrocity area. It offers the first detailed characterization of Black-and-White cattle populations in this region and quantifies their adaptation to local ecological and production environments.

The findings generate baseline data crucial for the development planning in the Agrocity SEZ and serve as a reference for assessing adaptation and domestication potential in cattle breeds introduced into Mongolia's extreme climatic conditions.

Materials and methods

Study Area and Herd Selection

The study was conducted in the 21st administration unit khoroo of the Songino-Khairkhan district, Ulaanbaatar capital, within the Agrocity Special Economic Zone, and included seven dairy cattle farms. Farms were selected based on herd size, breed composition, herd structure, and production level. In total, 48 households were sampled.

The overall cattle population comprised of 406 Black-and-White and crossbred animals, which were classified into five groups, with 18–30 individuals selected from each group for assessment. Of these, 123 cows and bulls, representing the indigenous Black-and-White breed, were subjected to detailed measurements to evaluate productivity and adaptive capacity.

Data Collection and Measurements

Data were collected from the selected dairy farms through field measurements, evaluations, structured questionnaires, and direct observations. The dataset covered the population status of the total herd and the Black-and-White breed, regional ecological and climatic conditions, milk production and supply patterns, milk quality, milk performance indicators of Black-and-White cattle, reproductive and breeding characteristics, and the breeding performance of bulls using deep-frozen semen.

Primary quantitative and qualitative information was obtained from on-farm measurements, interviews with farm owners, questionnaire surveys, and milk testing reports from processing facilities covering the previous two years. Secondary data were compiled from the Ministry of Food, Agriculture and Light Industry, the National Statistics Office, municipal and district statistical databases, professional associations, research reports, and additional milk quality records from processing plants. Complementary data was also drawn from the Sustainable Livestock Project (2021–2025), FAO reports, statistical publications, and government reports related to milk supply incentive programs.

The adaptive capacity of the indigenous Black-and-White breed was evaluated using 13 indicators grouped into four composite indices. Where applicable, measurements were compared with reference data from the original Russian Black-Mottled population.

The Physiological Adaptation Index included five indicators such as fluctuations in body temperature, respiratory rate, heart rate, and selected blood biochemical and immune parameters, with emphasis placed on the first three.

The Reproductive-Productivity Adaptation Index comprised four indicators, including milk yield variability, calving frequency, growth rate, and calving outcomes. The Genetic–Population Adaptation Index was based on expected heterozygosity and the inbreeding coefficient. The Feed-Environment Adaptation Index included four indicators characterizing feed intake and appetite,

adaptability to changes in feed type, responses to environmental temperature fluctuations, and tolerance to drought and highland conditions.

Statistical Analysis and Data Processing

Data was processed and analyzed using standard statistical methods, including the calculation of means, standard deviations, and coefficients of variation. Each adaptation index was derived from the corresponding measured indicators according to established formulae, and the resulting mean values were evaluated using a 1–5 scoring scale. An integrated adaptation index was subsequently calculated as a weighted average of the individual indices to provide an overall assessment of adaptive capacity.

Results

Herd Population, Distribution, and Breed Composition

Across the 48 surveyed dairy farms in the Agrocity area, a total of 623 dairy and dual-purpose cows were recorded. Black-and-White cattle and their crossbreeds accounted for 65.2% of the herd population. From these herds, 123 animals were selected through a stratified sampling approach for detailed evaluation of productivity and adaptive capacity.

Physiological and Morphological Adaptation

Physiological measurements of mature cows demonstrated stable homeostatic function under local climatic conditions. The mean body temperature of sampled cows was 38.3°C, the average respiratory rate was 21 breaths per minute, and the heart rate averaged 67 beats per minute.

Table 1.

Physiological Parameters of Black-and-White cattle in Mongolia

Parameter	At Birth	12 months	18 months	24 months	Mature Cow
Body Temperature (°C)	39.1	38.4	38.3	38.3	38.3
Respiratory Rate (breaths/min)	34.0	20.0	18.0	18.0	21.0
Heart Rate (beats/min)	81.0	59.0	57.0	54.0	67.0

No major infectious diseases were reported during the study period, classifying the region as low-risk. Observed reproductive disorders, including postpartum retention, ovarian cysts, and jaundice, occurred in 10–15% of cows, while lameness affected ~10% of animals, with veterinary care promptly provided.

Growth measurements indicated consistent and balanced development. The mean birth weight of calves was 30.2 ± 1.6 kg, and animals reached approximately 208–210 kg at 12 months of age, and 410–415 kg at 24 months. Mature cows averaged 509.2 ± 3.8 kg, reflecting steady physiological growth under local management conditions

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Table 2.

Growth Performance of Black-and-White cattle (kg)

Herds location	At Birth	12 months	18 months	24 months	Mature Cow
Paritzan	30 ± 1.3	205 ± 4.5	336.1±1,2	405 ± 4.5	502.5 ± 4.5
Nariin	31 ± 1.2	208 ± 7.5	328.3±5,1	415 ± 3.3	519.1 ± 5.1
Rashant	29 ± 1.0	209 ± 4.5	329,2±2,5	412 ± 3.1	504.3 ± 2.5
Shar Khad	31 ± 1.4	205 ± 4.5	327,5±3,1	414 ± 2.5	513.2 ± 3.1
335	30 ± 0.9	207 ± 4.5	325.4 ± 1.2	413 ± 4.1	508.5 ± 4.5
347	30 ± 1.5	207.6 ± 4.5	326.5 ± 3.3	409 ± 4.2	507.4 ± 3.3
Mean ± SD	30.2 ± 1.6	240.4 ± 4.5	328.2 ± 2.7	411.3 ± 3.6	509.2 ± 3.8
Imported Black-and-White breed	32-37	260-280	340-360	400-440	500-650

Morphometric data showed that the local Black-and-White cattle fell within established breed standards, exhibiting a large skeletal frame, moderate chest capacity, and an elongated body typical of dairy-type conformation.

Table 3.

Morphometric Comparison of Mature Cows: Local vs. Russian Black-and-White cattle

Parameter	Local mature cow	Imported Black-and-White breed	Difference		Analysis
			cm	%	
Withers Height (cm)	129.6 ± 2.73	128 -135	0	0	Within breed standard
Back Height (cm)	130.2 ± 0.65	130-133	-0.8	-0.6	Slightly lower
Body Slant Length (cm)	164.3 ± 4.7	159-170	+3.0	+1.8	Longer than average
Hip Height (cm)	132.3 ± 4.6	131-136	0	0	Within standard
Chest Girth (cm)	185.1 ± 7.2	180-200	0	0	Average
Chest Width (cm)	42.2 ± 2.8	40-47	0	0	Average
Chest Depth (cm)	66.5 ± 2.2	67-70	-1.5	-2.2	Slightly shallow
Pelvis Width (cm)	48 ± 0.39	47-49	0	0	Standard
Shank Girth (cm)	19.6 ± 0.7	18-22	0	0	Standard

Table 4.

Morphometric Ratios of Mature Cows

Ratio	Calculation	Result	Interpretation
Thoracic Index	(Chest Girth / Body Slant Length) × 100	112.66	Balanced body proportions, moderate development
Length Index	(Body Slant Length / Withers Height) × 100	126.77	Elongated body typical of dairy breeds
Chest Index	(Chest Width / Chest Depth) × 100	63.46	Slightly shallow, elongated chest, within normal range for dairy cattle
Pelvic-Chest Index	(Pelvis Width / Chest Width) × 100	113.74	Wider pelvis relative to chest; low dystocia risk, good reproductive capacity
Skeletal Index	(Shank Girth / Withers Height) × 100	15.12	Moderate skeletal development, well-balanced musculature
Rump Index	(Pelvis Width / Chest Width) × 100	113.74	Wide rump, supporting lactation efficiency

Minor deviations from reference values of the original Russian Black-and-White population, such as slightly reduced chest depth, reflected localized environmental adaptation while remaining within acceptable morphological limits for the breed.

Productive and Reproductive Performance

Milk production data collected from farm records and milk testing reports indicated a mean lactation length of 257.6 ± 16.5 days, with a coefficient of variation of 6.4%. The average annual milk yield per cow was 3,277 ± 220.9 kg, with a coefficient of variation of 6.74%.

Table 5.

Milk Production and Composition of Local Black-and-White Cows

Farm group	Annual milk yield per cow		Fat (%) ± SD	Protein (%) ± SD
	(kg) ± SD	CV, %		
Group 1 (n=30)	2358 ± 217.9	9.24	3.15 ± 0.23	3.07± 0.08
Group 2 (n=25)	2807 ± 232.3	8.28	3.34 ± 0.15	2.98 ± 0.03
Group 3 (n=25)	3266 ± 225.9	6.92	3.55 ± 0.17	3.13 ± 0.02
Group 4 (n=25)	3714 ± 208.9	5.62	3.77 ± 0.21	3.18 ± 0.07
Group 5 (n=18)	4240 ± 219.3	5.17	4.03 ± 0.11	3.11 ± 0.06
Total (n=123)	3277 ± 220.9	6.74	3.57 ± 0.17	3.08 ± 0.06
Imported Black-and-White breed	4000-6000		3.6-4.2	3.0-3.4

The milk of the local Black-and-White population had a mean fat content of 3.57 ± 0.17% and a mean protein content of 3.08 ± 0.06%. Variation in milk yield and composition among farms corresponded to differences in feed availability, water supply, and management practices.

Reproductive indicators showed that the interval from insemination to calving averaged 395.3 ± 21.1 days. The calving frequency for the population was 1.2 per year, and calf survival reached 96.4%.

Table 6.

Reproductive Parameters of Local Black-and-White Cows

Herd group	Interval from Insemination to Calving (days)		Lactation Length per Cow (days, μ±δ, CV%)		Annual Calving Frequency	Calf Survival (%)
	μ±δ	(CV,%)	μ±δ	(CV, %)		
Group 1 (n=30)	400.2 ± 21.8	12.06	229.8 ± 2 1.8	12.06	1	94,0
Group 2 (n=25)	397.6 ± 18.4	7.59	244.3 ± 18.4	7.59	1	96,0
Group 3 (n=25)	394.3 ± 16.1	6.07	265.1 ± 16.1	6.07	1	98,0
Group 4 (n=25)	392.4 ± 14.5	4.93	294.2 ± 14.5	4.93	1.5	96,0
Group 5 (n=18)	391.9 ± 8.7	2.85	304.4 ± 8.7	2.85	1.5	100,0
Total (n=123)	**395.3 ± 21.1**	**5.7**	**267.6 ± 16.5**	**6.4**	1.2	96.4

These results suggest a stable reproductive turnover in the surveyed herds despite variations in management capacity and technical support across farms.

Genetic and Population-Level Adaptation

Genetic assessments conducted in six herds using frozen semen from elite sires demonstrated an expected heterozygosity of 0.627 and an inbreeding coefficient of approximately 0.31. The observed heterozygosity deficit was 0.43. The introduction of multiple sire lines increased allelic diversity within the population and contributed to improved genetic adaptability compared with earlier herd assessments.

Table 7.

Mean Breeding Value of Elite Sires Used in Artificial Insemination

Sire Breed / Name		Selection Trait (Breeding Certificate)	Mean Breeding Value (μ±δ)
Holstein	Kapo	Dam Average Productivity	10160 ± 934
		Sire Average Productivity	9058 ± 1127
Holstein	Colonel	Offspring Productivity Index	122.7 ± 12.1

Holstein	Luka	The state of Productivity increasing fertility in offspring	Milk Yield, L	+527.0 ± 22.1
Holstein	Colombus		Milk Fat %	-0.06 ± 0.3
			Milk Fat, kg	+8 ±1.1
Holstein	Nectar		Protein %	-0.13 ± 0.2
			Protein, kg	+12± 1.5
Holstein	Bad		Breeding Value Index	100± 0.1
			Calving	Uncomplicated

Table 8.

Expected Genetic Diversity and Heterozygosity in Offspring

Herds location	Sire Lines Used						New Alleles	AI Cows	Allele Frequency Change (p)	Expected Heterozygosity (He = 2p(1-p))
	Kapo	Colonel	Luka	Colombus	Nectar	Bad				
Paritzan	1	0	0	0	0	1	2	2	0.011	0.0999
Nariin	1	1	1	1	0	1	5	109	0.623	0.611
Rashant	1	1	1	1	1	1	6	35	0.200	0.960
Shar Khad	1	1	1	0	0	1	4	13	0.074	0.995
335	1	1	1	0	0	0	4	15	0.086	0.993
347	0	0	1	0	0	0	1	1	0.006	0.0999
Population Mean							7	175	-	**0.627**

Feed and Environmental Adaptation

Environmental response data indicated that cattle adapted effectively to local production conditions. Animals tolerated a grazing period of 180–200 days and an intensive housing period of 165–185 days, as well as substantial seasonal temperature fluctuations from −40°C to +40°C. Farm observations and interviews from owners confirmed that cattle maintained stable feed intake, good appetite, and flexibility in adapting to variations in forage type and quality.

Overall Adaptation Index

The four composite indices physiological, morphological, production stability, and environmental tolerance, were calculated using the 12 indicators described in the Methods section and integrated using weighted scoring. The overall adaptation score for the Black-and-White cattle population in the Agrocity area was 4.23 on a 1–5 scale. This rating indicates that the population demonstrated an above-average adaptability to the ecological and management conditions of the Agrocity region.

Table 9.

Adaptation Index of Black-and-White Cattle in the Agrocity Region

Adaptation Type	Parameter	Mean Score
Physiological Adaptation	Body Temperature (°C)	5
	Respiratory Rate (breaths/min)	5
	Heart Rate (beats/min)	5
	Skin Surface Temperature (°C)	4,2
	Skin Thickness and Hair Structure	4,8
Morphological Adaptation	Hoof Shape and Hardness	4,4
	Body Conformation Changes	4,3

Production Stability	Milk Yield	3,0
	Milk Fat and Protein Content	4,5
	Reproductive Performance	4,0
	Calf Survival (%)	4,8
Environmental Tolerance	Response to Ambient Temperature Variation	4,4
	Drought and High-Altitude Tolerance	4,2
	Feed Intake Appetite	4.3
	Feed Type Flexibility	4,3
Genetic Adaptation	Inbreeding Coefficient	~ 0.31
	Observed Heterozygosity Deficit (Ho)	~0.43 Ho < He
	Expected Heterozygosity (He)	~ 0.627
Overall Adaptation Index:		**4.23**

Discussion

This study assessed the production orientation, population structure, and adaptive capacity of the Black-and-White cattle population localized in the Agrocity region of Mongolia. The results demonstrate that despite the predominance of beef- and dual-purpose cattle nationally, the Black-and-White breed remains the principal dairy-oriented population, representing more than three-quarters of Mongolia's dairy cattle [14].

In the Agrocity area one of the country's main peri-urban dairy zones established under national development policies (Government of Mongolia, 2024; State Great Khural, 2024) the breed accounts for a substantial proportion of the district's cattle holdings, reflecting its importance for urban milk supply and smallholder livelihoods [1].

The long-term presence of Black-and-White cattle in the region, spanning fifteen generations since their introduction from the Russian Federation, has facilitated gradual adaptation to Mongolia's continental climate, characterized by large temperature fluctuations, limited precipitation, strong winds, and variable feed availability. The observed morphological features—including a large skeletal frame, strong limbs, moderate chest depth, and elongated body reflect phenotypic adjustments that support resilience under mixed grazing and intensive housing systems. These findings are consistent with earlier research indicating that adaptation in dairy cattle is expressed through structural and functional modifications that enhance survival and productivity under environmental stressors [15].

Physiological development patterns further confirm successful acclimatization, as steady weight gain from birth to maturity indicates favorable growth conditions and balanced energy utilization. Although milk yield of the localized population remains lower than that of the original Russian Black-and-White stock, similar adaptation patterns have been documented in dairy populations exposed to harsh climates, where energy is redistributed between maintenance and production to optimize survival [10].

These patterns highlight the adaptive trade-offs that support sustainability in resource-limited environments.

Reproductive indicators in the sampled farms show moderate variability across management systems, reflecting differences in feed availability, water supply, and technical capacity factors known to influence dairy productivity in smallholder and peri-urban systems [10].

Nonetheless, conception rate, calving frequency, lactation duration, and calf survival suggest relatively stable reproductive turnover. The mean calving interval observed in this study exceeds the optimal level for high-efficiency dairy production, yet remains acceptable for semi-intensive systems. The identification of target management improvements—including reduced calving interval and extended lactation—offers a realistic pathway for performance enhancement when supported by improved recordkeeping and reproductive monitoring.

The introduction of frozen semen from elite sires under the Sustainable Livestock Project contributed to measurable improvements in both genetic diversity and production potential. Expected heterozygosity increased to 0.627, indicating moderate genetic variability and reduced risk of inbreeding depression, which is consistent with global findings that structured breeding programs enhance adaptability through genomic diversification [10]. The intensified use of elite sires also increased Holstein genetic influence, consistent with patterns observed in international dairy breeding programs [6].

However, the effectiveness of these interventions has been constrained by the absence of a coordinated breeding strategy, inconsistent recordkeeping, and unregulated crossbreeding practices. These challenges highlight the need for systematic genetic management to ensure the long-

term preservation of adaptive traits and prevent uncontrolled dilution of breed identity.

The composite adaptation index of 4.23 derived from morphological, physiological, productive, reproductive, health, and environmental response parameters—confirms that the localized Black-and-White population has attained a high level of adaptability to the agro-ecological context of central Mongolia. This index aligns with theoretical frameworks that emphasize the combined influence of phenotype–genotype–environment interactions on livestock adaptation [9].

The strong adaptive performance of this population provides evidence that imported dairy breeds, when managed over multiple generations in harsh climates, can achieve stable physiological and genetic integration with local production systems [10].

Overall, the findings underscore the significant role of the localized Black-and-White population in Mongolia's peri-urban dairy sector and highlight the potential for genetic improvement, productivity enhancement, and sustainable herd development through coordinated breeding and management strategies. Furthermore, the study demonstrates the importance of evaluating adaptation using integrated, multifactorial indicators to support evidence-based decision-making in breed conservation and dairy sector development [9].

Conclusion

This study shows that the Black-and-White cattle population has become the dominant and most important dairy-oriented breed in Mongolia, representing the majority of dairy cattle nationally and in the Agrocity region. After fifteen generations, under semi-intensive management, the population has developed strong morphological, physiological, and reproductive adaptation to Mongolia's continental climate and variable feed resources.

Reproductive indicators, including calving interval, conception rate, and calf survival, are able to confirm stable herd turnover despite management variability across farms. The introduction of frozen semen from elite sires between 2022 and 2025 increased genetic diversity and improved key production-related traits, although the long-term effectiveness of these interventions depends on coordinated breeding programs and improved recordkeeping.

The overall adaptation index of 4.23 reflects an above-average resilience and confirms that the localized Black-and-White population is well suited to the agro-ecological and management conditions of the Agrocity area. Continued genetic management, enhanced technical capacity, and expanded adaptation assessments of other imported breeds will support sustainable dairy development and strengthen Mongolia's national cattle genetic resources.

Conflict of Interests

The authors declare no conflict of interests.

Author's contribution

N.B. conducted the research and survey, G.D. designed the concept of this study and analyzed data and validated, G.S. designed the concept of this study. The writing process, including original draft preparation, review, and editing, was performed by G.D. All authors read and approved the final manuscript. G.D and G.S are equally contributing corresponding authors for this article.

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