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Dependence of productivity in purebred and crossbred bull calves on ethological characteristics in the postnatal period

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Abstract The aim of this study was to determine the relationship between behavioral reactivity and fattening performance in bull calves of different genotypes reared under dry-steppe conditions in western Kazakhstan. The research included four groups of young cattle: purebred Kazakh White-Headed animals and crossbreds obtained from Kazakh White-Headed cows inseminated with Simmental (beef type), Limousin, and Auliekol sires. Observations were conducted from birth to 18 months of age, taking into account changes in body weight, average daily gain, feed intake, and behavioral structure during both the winter and summer periods. It was established that crossbred bull calves exceeded purebreds in birth weight by 2.0–5.1 kg ($p < 0.001$) and by 12.9–40.2 kg at 18 months of age. The Simmental × Kazakh White-Headed genotype resulted in the greatest average daily gain (858 g) and the most efficient feed utilization (7.49 feed units per kilogram of weight gain). Behavioral analysis revealed that crossbred bull calves spent significantly less time on locomotor activity than purebred animals did, which corresponded to reduced nonproductive energy expenditure and increased weight gain. A calm behavior type was identified as a factor enhancing fattening efficiency. Simmental × Kazakh White-Headed crossbreds proved to be the most economically advantageous for beef cattle production under dry-steppe conditions.

Keywords: cattle, genotype, ethological reactivity, body weight, weight gain, feed efficiency, industrial crossbreeding

1. Introduction

The ethological characteristics of farm animals are important factors influencing adaptability, stress resistance, and subsequent productivity. Traditional approaches to evaluating young cattle are primarily based on morphological and fattening indicators, such as body weight, average daily gain, and the feed conversion ratio. However, recent studies have indicated that behavioral responses may serve as early indicators of an animal's resistance to stress and its ability to realize its genetic potential for productivity (King et al., 2006; Hulbert et al., 2011; Hedlund, 2013; Hedlund & Løvlie, 2015; Hanna et al., 2019).

Studies on Aberdeen Angus heifers in the North Kazakhstan region have also demonstrated that adaptive capacity and stress resistance are strongly influenced by the behavioral and physiological traits of the animals (Titanov et al., 2023).

The postnatal period is a key stage in the formation of functional body systems, during which the nervous system develops, digestive and immune functions mature, and basic behavioral patterns are established (Burrow et al., 1997; Voisinet et al., 1997; Fell et al., 1999; Burdick et al., 2011; Kasimanickam et al., 2018; Erdmann et al., 2018; Chen et al., 2021). The level of ethological reactivity at an early age determines the nature of an animal's subsequent behavior in a production environment, its susceptibility to technological stressors, its interaction with personnel, and its ability to adapt to new management conditions (Burrow et al., 2000, Kovács et al., 2014, Kovács et al., 2015). Under intensive production systems, excessive reactivity leads to increased nonproductive energy expenditure and reduced weight gain, whereas a calm behavior is associated with stable food intake, uniform growth, and a high level of adaptability (Llonch et al., 2018; Kelly et al., 2020; Levakhin et al., 1997; Mokhov, 2003). Additional studies also confirm the significant importance of early behavioral responses; in particular, the expression of maternal instinct in beef-direction cows and the ethology of their calves during the first days of life directly affect stress resilience, viability, and subsequent development (Kazhgaliyev et al., 2023). Thus, ethological indicators may be used as additional criteria for evaluating and selecting young cattle for fattening.

Increasing fattening efficiency and realizing the genetic potential of animals are particularly important for beef cattle production in Kazakhstan. In the western regions of the country, the Kazakh White-Headed breed is widespread; it is characterized by its resilience to the extreme conditions of the dry-steppe zone and by acceptable beef qualities (Prakhov, 1975; Nasambaev et al., 2008; Makaev et al., 2015; Kineev et al., 2022). However, its productivity potential and suitability for intensive fattening technologies do not always meet the requirements of modern production. Accelerated improvement of

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growth and adaptive traits cannot be achieved solely through long-term within-breed selection. Therefore, in recent years, industrial crossbreeding of Kazakh White-Headed cows with sires of specialized beef breeds has been actively implemented in dry-steppe zones, enabling the production of offspring with increased viability, improved precocity, and heterosis effects (Asanov et al., 2001; Kayumov & Dubovskova., 2005).

Despite existing research on productivity under crossbreeding, comparative assessments of purebred and crossbred young cattle considering their ethological reactivity remain insufficient. In particular, evidence on how behavioral characteristics are related to feed conversion and growth rates during the postnatal period—the most critical stage in the formation of functional body systems—is lacking. Analyzing the relationship between behavior and productivity will broaden our understanding of the role of genotype in shaping adaptive and growth characteristics and will improve the accuracy of selecting animals with high fattening potential.

The aim of this study was to assess the influence of ethological reactivity on the productivity of young cattle of different genetic origins and to determine whether behavior can be considered a predictor of growth rate and feed efficiency.

2. Materials and Methods

The study was conducted under production conditions at Tokmansai LLP (Aktobe Region, Kazakhstan). Full-aged Kazakh White-Headed cows of at least Class I (3–4 calvings) were used to obtain the experimental young stock. The breeding herd was inseminated with semen from elite record sires of specialized beef breeds: Simmental, Limousin, and Auliekol. All crossbred animals belonged to the first generation (F1) and were obtained as a result of single industrial crossbreeding. Backcrossing was not carried out within the framework of this study.

The within-breed origin of the bulls used (lines, pedigrees) was not considered in this study, which could be a source of genetic variability and influence the viability of the offspring. Moreover, animals with confirmed breed types and stable productivity traits were used, which minimized the effect of this variability on the progeny.

After birth, four groups of bull calves (12 heads each) were formed according to the principle of analogs: Group I - Kazakh White-Headed (purebred); Group II - Simmental × Kazakh White-Headed; Group III - Limousin × Kazakh White-Headed; and Group IV - Auliekol × Kazakh White-Headed.

Until 8 months of age, the calves were kept on suckling together with the cows on natural pastures. After weaning, bull calves were transferred to an open feedlot with year-round group loose housing.

Grouping, according to genotype, was used to account for food intake once a month for two consecutive days. Feed consumption was determined by the difference between the mass of feed offered and the uneaten residues. On the basis of these data, the total intake of feed units, digestible protein, and metabolizable energy per animal for the entire rearing period was calculated.

To evaluate productivity, the animals were weighed at key developmental stages (at birth and at 3, 8, 12, 15, and 18 months). On the basis of the weight results, live weight gain and average daily gain were calculated.

Ethological reactivity was determined using the time-budget method and visual observations in accordance with the methodological guidelines of the All-Union Research Institute of Farm Animal Breeding (1975).

The recording of behavioral responses was carried out by continuous observation with momentary fixation of behavioral acts at equal time intervals. Behavior was recorded over a 24-hour period (1440 minutes) with a 5-minute recording interval, which corresponds to the classical scheme of ethological studies and allows a reliable assessment of the daily activity structure of the animals.

Observations were conducted during different seasons of the year—in the winter (February) and summer (July) periods—which made it possible to consider the influence of environmental conditions on the behavioral responses of the animals. During each season, behavior was recorded for a full 24-hour period following a unified observation protocol.

During the observations, the main elements of behavior were recorded: food intake, drinking, standing and lying positions, locomotor activity, and manifestations of social behavior (aggressive contact and elements of sexual activity). On the basis of the data obtained, the proportion of time spent on each type of activity was calculated.

Observations were carried out by two trained observers who had undergone preliminary training to standardize the recording of behavioral acts. To improve the accuracy and reproducibility of the results, cross-checking of the observations was performed.

To exclude the influence of humans on animal behavior, observations were conducted at a distance that excluded direct contact or the use of shelters. During the ethological observations, the service personnel did not interfere with the behavior of the animals, and all the technological operations were carried out outside the observation period.

Additionally, to assess the level of ethological reactivity, the “novel object test” and the “human approach test” were used, in which reaction latency, locomotor activity, number of contacts, and avoidance responses were recorded.

Clinical physiological parameters (rectal body temperature, respiratory rate, and pulse rate) were recorded in the animals at rest according to generally accepted methods, after which three measurements were averaged.

To determine feed efficiency, actual live weight gain was compared with the consumption of feed units and metabolizable energy throughout the rearing period. On the basis of these data, the feed conversion ratio (FCR), feed conversion efficiency (FCE), energy expenditure, and energy efficiency were calculated, which made it possible to relate behavioral activity to energy costs and fattening performance.

The obtained results were processed using variation statistics with the calculation of means and standard errors. Differences between groups were assessed using Student's t test, and relationships between behavioral and productivity indicators were analyzed using correlation analysis.

Additionally, to eliminate the influence of early postnatal development factors, an analysis of covariance (ANCOVA) was performed. In the model, genotype was considered a fixed factor, whereas birth weight and cow parity were used as covariates. The average daily gain (ADG) was used as the dependent variable. The statistical significance of the factors was evaluated using the Fisher F test at a significance level of $P < 0.05$.

To assess the relationship between the time to the first suckling act (time to first suckle, TFS) and the live weight of bulls at 18 months of age, an individual correlation analysis was carried out using data from all the animals. The calculations included individual TFS values recorded after birth and live weight at 18 months of age. The analysis was performed both for the entire sample and separately within each genotypic group. The strength and direction of the relationship were evaluated using the Pearson correlation coefficient. To characterize the linearity of the relationship, the coefficient of determination (R^2) was calculated. The statistical significance of the relationship was assessed using the P value; differences were considered significant at $P < 0.05$.

The experiments were conducted in accordance with current ethical standards and animal welfare regulations. All procedures were performed in compliance with the GOST 33216-2014 "Guidelines for the keeping and use of farm animals," international guidelines for biomedical research involving animals, the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes, and the principles of humane treatment and euthanasia recommended by the American Veterinary Medical Association (AVMA).

3. Results and Discussion

Compared with the central and northern regions of Kazakhstan, the Aktobe region is characterized by low precipitation and a poorer feed base, which limits the nutritive value of pasture herbage during summer. In the phase of declining pasture quality (mid-summer), calves received additional supplementation with hay and concentrates in paddocks equipped with shade shelters, group feeders, and troughs.

After weaning, the young stock was moved to an open feedlot with year-round group loose housing. In the winter, when the air temperature dropped below −25 °C, the animals had free access to a light-type shelter where roughage and succulents were provided. The diets were balanced for energy and digestible protein and included ground barley–wheat grain, mixed-grass hay, and barley whole-crop silage. Mineral nutrition was ensured by salt licks and chalk.

No differences in overall feed intake were detected between the groups; however, crossbred bull calves were characterized by increased consumption of hay and pasture herbage. During the entire rearing period, crossbreds consumed 1.4–4.1% more feed units than their purebred counterparts did (Table 1).

Table 1 Feed and nutrient intake of bull calves from birth to 18 months of age (per animal), kg.

Indicator	I	II	III	IV
Milk	1103	1161	1124	1157
Mixed-grass hay	1296	1393	1318	1369
Barley whole-crop silage	1979	1979	1979	1979
Pasture herbage	2009	2182	2096	2201
Concentrates	1257	1295	1267	1295
Total feed units	3371.1	3509.0	3417.4	3502.0
Digestible protein	357.4	372.8	362.5	371.8
Metabolizable energy, MJ	33483	34880	33991	34588
Digestible protein per 1 feed unit, g	106.0	106.2	106.1	106.2

Regardless of genotype, concentrates formed the basis of the ratio, accounting for 36.9–37.0% of the total intake. A considerable share of the diet was provided by whole-crop silage (20.3–21.1%) and mixed-grass hay (15.4–15.9%). The proportion of milk in early life was similar across groups and remained at 13.1–13.2%, confirming the comparability of initial feeding conditions. During the pasture period, green herbage contributed 13.1–13.8% of the total ratio, reflecting the use of natural forage resources in the dry-steppe zone of the region.

The use of large-framed beef sires (Simmental, Limousin, Auliekol) in the crossbreeding scheme made it possible to obtain young stock with a pronounced heterosis effect. At birth, statistically significant intergroup differences in live weight and average daily gain were established (Table 2).

Table 2 Live weight dynamics of bull calves, kg (X ± Sx).

Age (period), months	I	II	III	IV
Live weight, kg				
Newborn	24.9 ± 0.63	30.0 ± 0.58	26.9 ± 3.65	27.8 ± 0.58
3	98.7 ± 2.74	107.8 ± 2.84	102.0 ± 3.14	104.3 ± 2.45
8	212.4 ± 4.11	228.1 ± 5.13	221.8 ± 4.28	224.6 ± 3.87
12	309.8 ± 5.38	327.5 ± 6.18	314.8 ± 6.25	318.7 ± 5.74
15	394.2 ± 5.65	421.3 ± 4.87	405.2 ± 6.18	410.8 ± 6.11
18	458.5 ± 8.23	498.7 ± 6.84	471.4 ± 7.48	482.2 ± 5.62
Average daily gain, g				
0–8 months	772 ± 10,82	815 ± 15,32	802 ± 13,77	810 ± 18,17
8–12 months	804 ± 29,6	822 ± 21,16	769 ± 19,42	778 ± 23,74
12–15 months	927 ± 27,43	1031 ± 29,25	993 ± 24,13	1012 ± 30,24
15–18 months	707 ± 30,14	851 ± 28,46	727 ± 16,85	785 ± 21,48
0–18 months	794 ± 17,85	858 ± 19,32	814 ± 17,64	832 ± 14,74

The number of crossbred calves exceeded that of purebred Kazakh White-Headed contemporaries by 2.0–5.1 kg at birth, which corresponds to 8.0–20.5%. These differences were highly significant ($P < 0.001$), and no cases of calving difficulty were observed.

During the pasture period (3–8 months), Simmental crossbreds showed the highest growth rate. Their average live weight at weaning was 228.1 kg, which was 15.7 kg (+7.4%, $P < 0.01$) greater than that of purebred Kazakh White-Headed calves. Limousin and Auliekol crossbreds also outperformed purebreds by 9.4 and 12.2 kg, respectively ($P < 0.05$).

After weaning (8 months), the response of the animals to changes in feeding and housing conditions differed among genotypes. In Kazakh White-Headed and Simmental × Kazakh White-Headed bull calves, the average daily gain increased, whereas Limousin × Kazakh White-Headed and Auliekol × Kazakh White-Headed crossbreds experienced a temporary decline in growth rate. This coincided with the autumn–winter period, when the temperature fluctuated from +11.5 to −20.5 °C and the sanitary conditions on the exercise yards deteriorated. These differences can be explained by genotype-specific adaptation: Simmental crossbreds and purebred Kazakh White-Headed animals exhibited greater resistance to environmental stress.

With age, the influence of genotype intensified. At 12 months, Simmental, Limousin, and Auliekol crossbreds surpassed purebreds by 17.7, 5.0, and 8.9 kg, respectively. By 18 months, these advantages increased to 40.2, 12.9, and 23.7 kg, respectively. Differences between groups were statistically significant ($P < 0.01$). The retained limousin crossbred values were close to those of purebred Kazakh White-Headed animals (the differences did not reach statistical significance; $P > 0.05$), whereas Simmental crossbreds consistently occupied a leading position throughout the study. Auliekol crossbreds held an intermediate position and approached Simmental crossbreds as they grew. Obtaining young stock with high live weight at an early age is possible only when the growth intensity is high, as confirmed by average daily gain data.

In all the genotypes studied, weight gain was relatively high, but growth rates varied depending on the sire breed. The influence of genotype on growth intensity was evident at an early age: crossbred young stock exceeded purebred contemporaries in birth weight by 2.0–5.1 kg (8.0–20.5%, $P < 0.001$). Despite the higher birth weights, no calving complications were recorded, indicating good adaptation of the base breed cows to the use of beef bull semen.

During the pasture rearing period (3–8 months), all the animals demonstrated high growth energy, but the most intensive gains were observed in Simmental × Kazakh White-Headed crossbreds. By weaning, their live weight reached 228.1 kg and surpassed that of purebreds by 15.7 kg or 7.4% ($P < 0.01$). Limousin and Auliekol crossbreds also outperformed Kazakh White-Headed animals by 9.4 and 12.2 kg, respectively ($P < 0.05$), indicating a pronounced heterosis effect when improverbred beef is used under pasture conditions.

During the postweaning period (after 8 months), the response to new feeding and housing conditions was not uniform. In purebreds and Simmental crossbreds, live weight gain continued to increase, whereas Limousin and Auliekol crossbreds showed a temporary decrease in growth rate. This coincided with sharp temperature fluctuations (+11.5 to −20.5 °C) and deteriorating sanitary conditions in the exercise yards. The decline in gain is likely associated with adaptation to new housing conditions. Kazakh White-Headed animals and their Simmental crossbreds proved to be the most resistant to stress factors, confirming the high environmental plasticity of these genotypes.

The maximum growth intensity occurred between 12 and 15 months, when the feeding and housing conditions were optimal. During this period, Simmental crossbreds achieved an average daily gain of 1031 g and exceeded purebreds by 104 g/day, or 11.2% ($P < 0.001$). Limousin and Auliekol crossbreds occupied an intermediate position, approaching Simmental animals while also outperforming purebred contemporaries ($P < 0.05$). Over the entire rearing period (0–18 months), the average daily gains were 858 g in Simmental crossbreds, 832 g in Auliekol crossbreds, 814 g in Limousin crossbreds, and 794 g in purebred Kazakh White-Headed bulls. Thus, the Simmental × Kazakh White-Headed genotype exhibited the greatest growth intensity (P < 0.01), underscoring its potential value for beef production. In many periods, Limousin crossbreds did not significantly differ from purebreds in terms of gain or live weight (P > 0.05), indicating a less pronounced heterosis effect in this cross.

The relative growth rate during the rearing period remained high for all the genotypes (177.3–179.4%), confirming the good realization of productive potential under beef production conditions. However, crossbred animals, particularly those of the Simmental genotype, retained a distinct advantage in terms of growth rate and response to environmental conditions.

To clarify the effect of genotype on productivity while considering individual differences at birth, an analysis of covariance (ANCOVA) was performed, the results of which are presented in Table 3.

Table 3 Results of the analysis of covariance of the effect of genotype on the average daily gain of bull calves.

Source of variation	df	F test statistic	P value
Genotype	3	5,64	0,002
Birth weight	1	24,27	<0,001
Parity	1	1,14	0,293
Error	42	–	–

The results of the covariance analysis revealed that genotype had a statistically significant effect on average daily gain (P = 0.002) even after birth weight and cow parity were accounted for. Birth weight also has a significant effect on productivity (P < 0.001), whereas parity does not reach statistical significance (P > 0.05). These findings indicate that the observed differences between genotypes are primarily due to genetic factors rather than initial physiological differences among the animals.

The behavioral characteristics of young stock directly affect productivity and feed efficiency. According to Voisinet et al. (1997) and Burrow & Dillon (1997), calmer animals spend less energy on excessive locomotor activity, which promotes greater live weight gain at equal feed intake. In contrast, highly active and excitable animals expend a substantial portion of energy on movement and social interactions, thereby reducing the efficiency of nutrient utilization. The results of our winter time-budget observations confirm these patterns (Table 4).

Table 4 Behavioral activity of bulls (1440 min = 100%).

Behavioral element	I	II	III	IV
Winter period				
Feeding, min (%)	332 (23.1%)	362 (25.1%)	320 (22.2%)	346 (24.0%)
Total rest, min (%)	947 (65.8%)	961 (66.7%)	939 (65.2%)	956 (66.3%)
Locomotion, min (%)	156 (10.8%)	113 (7.8%)	175 (12.2%)	133 (9.2%)
Drinking, min (%)	5 (0.3%)	4 (0.3%)	6 (0.4%)	5 (0.3%)
Sexual activity (mounts), events	14	8	10	6
Aggressiveness (fights), events	11	6	7	4
Summer period				
Behavioral element	I	II	III	IV
Feeding, min (%)	363 (25.2%)	380 (26.4%)	352 (24.4%)	369 (25.6%)
Total rest, min (%)	842 (58.5%)	899 (62.4%)	867 (60.2%)	886 (61.5%)
Locomotion, min (%)	227 (15.8%)	150 (10.4%)	210 (14.6%)	179 (12.4%)
Sexual activity (mounts), events	21	11	18	9
Aggressiveness (fights), events	16	7	14	6

The winter time-budget data revealed genotype-dependent differences in ethological reactivity. Purebred Kazakh White-Headed bulls spent 156 minutes per day on locomotor activity (10.8% of the time). They also showed the highest numbers of aggressive (11) and sexual (14) acts. This indicates a more excitable temperament and heightened reactivity to external stimuli.

Crossbred animals displayed a more economical behavioral pattern. In Simmental crossbreds, the locomotion time was 113 minutes (7.8%), and the number of aggressive contacts decreased to six events per day. Auliekol crossbreds also showed relatively low activity: 133 minutes of movement (9.2%). The highest level of locomotor activity among crossbreds was recorded in Limousin crossbreds—175 minutes, or 12.2%, which is indicative of a more active temperament.

Comparisons of time-budget data with performance indicators revealed a direct relationship between locomotor activity and feed efficiency. Animals that spent less time in motion had more favorable feed conversion ratios. In Simmental crossbreds, with minimal locomotor activity (7.8%), the FCR was 7.49 feed units per kilogram of gain, whereas in Kazakh White-Headed animals, with a locomotor activity of 10.8%, the FCR was poorer at 7.77 feed units. These findings confirm that a portion of the energy consumed by more active animals is diverted to movement rather than live weight gain.

In summer, the behavioral structure changed compared with that in winter, reflecting pasture conditions and high food availability. All the animals spent 24.4–26.4% of the day feeding. The longest feeding time was recorded for Simmental × Kazakh White-Headed crossbreds (26.4%), whereas 25.2% and 24.4% of purebred Kazakh White-Headed bulls and Limousin crossbreds, respectively, were fed. The increased feeding time in Simmental crossbreds may be associated with their calmer temperament, which enables the effective use of pasture access.

Genotype was also associated with differences in resting time. In Simmental and Auliekol crossbreds, the rest accounted for 62.4 and 61.5% of the day, respectively, compared with 58.5% in purebreds. Longer rest can be viewed as an indirect indicator of better adaptation and lower reactivity to external stimuli. Limousin crossbreds occupied an intermediate position, remaining 60.2% of the time.

Maximum locomotor activity in summer was observed in purebred Kazakh White-Headed bulls (227 minutes, 15.8%) and Limousin × Kazakh White-Headed crossbreds (210 minutes, 14.6%). The lowest locomotor time was recorded in Simmental crossbreds—150 minutes, or 10.4%. This finding is consistent with the winter data: lower locomotor activity in Simmental × Kazakh White-Headed crossbreds indicates a calm temperament type.

The number of sexual and aggressive episodes also reflected differences in temperament. Purebred bulls exhibited the highest sexual activity (21 events) and aggressiveness (16 events per day). In contrast, Simmental crossbreds showed almost twofold lower values: 11 sexual events and 7 aggressive events per day. Auliekol crossbreds had the lowest aggressiveness (six events) and moderate activity (12.4% of the time in motion), indicating a calm and stable behavioral type.

Behavioral-type differences were consistently expressed in both winter and summer, indicating stable ethological reactivity across genotypes. Bull calves with calmer behavior and lower locomotor activity, which are typical of Simmental × Kazakh White-Headed crossbreds, presented superior feed conversion and the greatest increase in live weight. Conversely, purebred Kazakh White-Headed bulls and Limousin crossbreds spent more time on movement and social behavior, which increased nonproductive energy expenditure and worsened feed efficiency. These findings confirm that temperament is an important factor in energy and productivity costs and that selecting genotypes with calmer reactivity can be considered an effective tool for increasing the profitability of beef cattle production.

Analysis of behavioral and productive characteristics revealed pronounced differences between genotypes. Purebred Kazakh White-Headed bulls were characterized by increased locomotor activity and increased conflict behavior: they spent more time in motion and more often displayed aggressive and sexual behavior. This was accompanied by increased nonproductive energy expenditure and, consequently, a higher FCR (7.77 feed units/kg gain) and the lowest average daily gains (794 g/day). Elevated ethological reactivity negatively affects feed efficiency.

Simmental × Kazakh White-Headed crossbreds presented the opposite extreme: a calm temperament, low conflict behavior, and a relatively low proportion of time spent on movement provided the best feed efficiency (FCR 7.49 feed units/kg—the lowest among genotypes) and the greatest increase in live weight gain (858 g/day). These findings confirm that moderate behavioral reactivity is associated with an energetic economy and high growth potential.

Limousin × Kazakh White-Headed crossbreds showed a rational behavioral pattern: a greater percentage of time spent lying and ruminating with moderate locomotor activity. Their productivity (814 g/day) and feed efficiency were higher than those of purebreds, indicating a balanced response to external factors.

Compared with Simmental crossbreds, Auliekol × Kazakh White-Headed bulls exhibited a calm behavioral profile with low conflict behavior but spent slightly more time moving. This resulted in intermediate FCR (7.71 feed units/kg) and weight gain (832 g/day).

Thus, with increasing ethological reactivity and locomotor activity, feed conversion deteriorates, and the growth rate decreases. Calm and economic behavior promote more efficient energy use and higher productivity.

These results can be explained by the physiological mechanisms of early postnatal development. According to the literature, in the first hours of life, calves experience a “macromolecule absorption window” that ensures the transfer of immunoglobulins from colostrum into the systemic circulation. A delay in the onset of sucking behavior may reduce the efficiency of passive immune transfer, which subsequently affects metabolism and growth rates (Godden et al., 2019; Ontsouka et al., 2016).

Moreover, the early postnatal period is considered a critical stage for the formation of the somatotropic axis and metabolic programming of the organism. During this time, early behavior and nutrition can have long-term effects on the realization of the productive potential of the animals (Cardoso et al., 2021; Chavatte-Palmer et al., 2018; Harvey et al., 2021).

Cattle respond differently to changes in ambient temperature depending on housing conditions, making the analysis of physiological indicators practically important for assessing adaptive responses. The physiological state of the bulls depending on the season is presented in Table 5.

Table 5 Dynamics of Heart Rate, Respiratory Rate, and Body Temperature of Bulls (X±Sx).

Group	Autumn (8 months)	Winter (12 months)	Spring (15 months)	Summer (18 months)
	Heart rate, bpm (beats per minute)			
I	73,9±0,46	76,1±0,51	69,6±0,36	73,6±0,51
II	75,0±0,34	77,5±0,38	71,7±0,34	74,2±0,51
III	75,8±0,54	77,6±0,41	72,0±0,51	74,1±0,32
IV	74,0±0,32	76,2±0,36	69,8±0,41	73,6±0,38
	Respiratory rate, breaths/min			
I	23,1±0,34	18,4±0,38	27,5±0,41	36,6±0,38
II	24,5±0,28	19,3±0,44	28,1±0,28	37,5±0,28
III	23,9±0,38	19,0±0,28	27,8±0,42	37,3±0,46
IV	23,0±0,41	18,2±0,52	27,3±0,34	36,8±0,22
	Body temperature, °C			
I	38,0±0,22	38,1±0,28	38,3±0,18	38,3±0,22
II	38,1±0,23	38,2±0,17	38,5±0,22	38,5±0,17
III	38,1±0,10	38,3±0,22	38,3±0,24	38,6±0,23
IV	38,0±0,16	38,1±0,16	38,3±0,17	38,4±0,10

Regardless of the genotype, all clinical parameters remained within physiological norms, indicating the absence of pronounced stress conditions in the animals.

During the summer period, with increasing ambient temperature, an increase in heart rate was observed, reflecting the activation of thermoregulation mechanisms. During the winter period, a slight increase in heart rate was also noted, which was associated with maintaining the body's thermal balance. Compared with purebred Kazakh White-Headed cattle, crossbred bulls presented higher heart rate values at all age stages.

The respiratory rate proved to be the most sensitive indicator of environmental changes. In summer, with higher air temperatures, an increase in the respiratory rate was observed, facilitating heat dissipation. In the winter, the respiratory rate decreased, reflecting the need for more efficient warming of inhaled air. The lowest respiratory rates were recorded in Kazakh White-Headed bulls and crossbred bulls with Auliekol cattle, while the crossbreeds of the other genotypes presented slightly higher values.

Body temperature was relatively stable. During summer, a slight increase was observed, which was associated with high ambient temperatures (+35 °C) and low air humidity. No significant intergroup differences were found for this parameter.

Thus, environmental conditions significantly influence the physiological parameters of the animals. Changes in heart rate and respiration reflect thermoregulation mechanisms and can be considered indirect indicators of adaptive responses.

The obtained physiological data are consistent with the results of ethological observations, confirming that differences in behavioral activity are accompanied by features of energy expenditure and adaptive reactions of the organism.

FCR and energy conversion values confirm the genotype differences in the ability to utilize feed efficiently (Table 6).

Table 6 Feeding efficiency (FCR and energy conversion).

Group	Total weight gain over 18 months, kg	FCR, feed units/kg gain	FCE, kg gain per 1 feed unit	Energy expenditure per 1 kg gain, MJ/kg	Energy efficiency (kg/MJ)
I	433.6	7.77	0.129	77.2	0.0130
II	468.7	7.49	0.134	74.4	0.0134
III	444.5	7.69	0.130	76.5	0.0131
IV	454.4	7.71	0.130	76.1	0.0131

The combination of gain and feed-unit expenditure was most favorable for the Simmental crossbreds: the FCR was 7.49 feed units/kg gain, which is 3.6% better than that for purebred Kazakh White-Headed bulls (7.77 feed units/kg). The total weight gain over the rearing period was maximal in Simmental crossbreds (468.7 kg), confirming their greater genetic potential for beef productivity. Accordingly, energy expenditure per kilogram of gain was minimal (74.4 MJ vs. 77.2 MJ in the control group), and energy efficiency was the highest.

Limousin and Auliekol crossbreds occupied an intermediate position. Their FCR values were 7.69 and 7.71 feed units/kg, respectively, which were better than those of purebred animals but inferior to those of Simmental crossbreds. Purebred Kazakh White-Headed bulls had the least favorable feed conversion and the lowest total weight gain (433.6 kg).

Thus, crossbred cattle have higher feed and energy efficiency than purebred animals do, with the most economical option being the use of Simmental sires in crossbreeding with Kazakh White-Headed cows.

The within-group assessment of the relationship between locomotor activity and average daily gain (ADG) made it possible to determine the influence of ethological reactivity on the productivity of young bulls depending on their genotype.

The obtained data indicate that the nature of the effect of locomotor activity on growth rates is strongly genotype dependent (Figure 1).

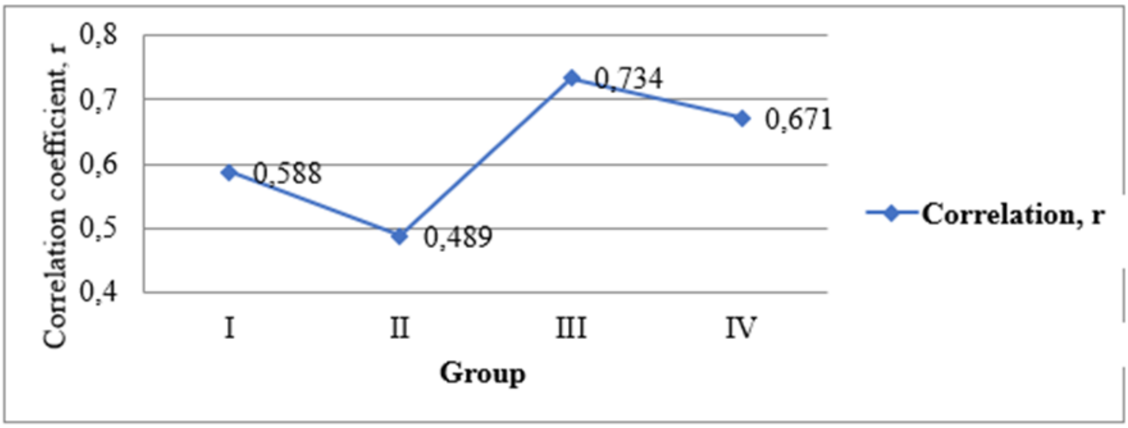

Figure 1 Within-group correlation between locomotor activity and average daily gain.

In purebred Kazakh White-Headed bulls, a weak positive correlation was identified (r = +0.588). These findings suggest that increased locomotor activity does not increase productivity but instead increases nonproductive energy expenditure, which is consistent with the FCR value (7.77 feed units/kg). In other words, more active behavior in this breed is associated with less efficient conversion of dietary energy into growth.

In Simmental × Kazakh White-Headed crossbreds, a moderate correlation was observed (r = +0.489). Productivity in this group is determined primarily by the genetic potential for growth rather than by the level of activity. These findings align with their more favorable FCR values (7.49 feed units/kg), confirming their "economic" behavior and efficient feed utilization.

The highest correlation coefficients were detected for Limousin × Kazakh White-Headed and Auliekol × Kazakh White-Headed crossbreds (r = +0.734 and r = +0.671, respectively). For these genotypes, moderate locomotor activity contributes to improved metabolic processes and positively affects productivity. Thus, part of the energy expended on movement is compensated by a more powerful metabolic response and a high capacity for weight gain.

To clarify the role of early postnatal behavior in productivity formation, an individual analysis of the relationship between time to first suckling and body weight at 18 months of age was conducted (Table 7).

Table 7 Correlation between time to first suckle and body weight at 18 months.

Animal group	r (Pearson)	P value	R^2
I	−0,93	<0,001	0,86
II	−0,95	<0,001	0,90
III	−0,91	<0,001	0,83
IV	−0,92	<0,001	0,85
Overall sample	−0,94	<0,001	0,88

In all the studied groups, there was a statistically significant strong negative correlation between TFS and final body weight (r = −0.91…−0.95; $P < 0.001$). This finding indicates that an increase in the time to first suckling is associated with a decrease in productivity regardless of genotype.

The most pronounced relationship was observed in the Simmental × Kazakh White-headed crossbreds (r = −0.95; R^2 = 0.90), indicating a high consistency between early behavioral reactions and subsequent growth in this genotype. In purebred animals and other crossbreds, the correlation strength was slightly lower but remained high and statistically significant.

Analysis of the overall sample confirmed a clear linear relationship (r = −0.94; $P < 0.001$; R^2 = 0.88), indicating that the time to the first suckling accounts for up to 88% of the variation in body weight at 18 months of age.

4. Conclusions

This study provides a comprehensive assessment of the influence of genotype and ethological reactivity on bull calf productivity during the postnatal period. Compared with purebred contemporaries, crossbred young stock obtained by mating Kazakh White-Headed cows with beef sires (Simmental, Limousin, Auliekol) has clear advantages in terms of fattening performance and feed efficiency. At birth, crossbred calves already had higher live weights (by 2.0–5.1 kg, $P < 0.001$), which reflects a heterosis effect and was not associated with calving complications. As rearing progressed, these differences increased: by 18 months of age, crossbreds surpassed purebreds by 12.9–40.2 kg in live weight, with the greatest advantage observed in the Simmental × Kazakh White-Headed genotype.

The average daily gains over the entire rearing period also depended on the genotype. The highest growth intensity (858 g/day) was recorded for Simmental crossbreds, whereas the lowest gain (794 g/day) was recorded for purebred Kazakh White-Headed bulls. Limousin and Auliekol crossbreds occupied an intermediate position, confirming breed-specific differences in growth rate and heterosis expression.

Data on feed intake and energy efficiency revealed that crossbreds utilize feed more productively. The FCR in Simmental crossbreds was 7.49 feed units/kg gain, which is 3.6% better than that in purebred animals (7.77 feed units/kg). Even with similar feed intake, final weight gain is greater in crossbreds, which is associated with more economical use of energy for maintenance.

A key scientific finding is the confirmation of the influence of ethological reactivity on feed and energy efficiency. Behavioral observations revealed that purebred Kazakh White-Headed bulls were characterized by increased locomotor and social activity, more frequent aggression, and greater sexual behavior. In the winter and summer, they spent 10.8–15.8% of the day in motion, whereas Simmental crossbreds spent only 7.8–10.4%. A direct relationship was identified: animals with higher activity had poorer feed conversion and lower weight gain. In contrast, calm and moderate behavior in crossbreds was associated with a greater proportion of time devoted to rest and feeding and resulted in superior fattening performance.

The obtained physiological data are consistent with the results of the ethological observations and indicate that differences in the behavioral activity of the animals are associated with the specifics of their energy expenditure and adaptive responses.

Correlation analysis confirmed that the effects of locomotor activity on productivity differ among genotypes. In purebreds, a weak positive correlation ($r = +0.588$) indicated that increased activity does not improve gain and is accompanied by nonproductive energy loss. In Simmental × Kazakh White-Headed crossbreds, the correlation was moderate ($r = +0.489$), suggesting that their growth is largely determined by genetic potential. The highest correlations ($r = +0.734$ and $r = +0.671$) were observed in Limousin × Kazakh White-Headed and Auliekol × Kazakh White-Headed crossbreds, reflecting more efficient metabolism at moderate activity levels.

The identified differences may be due to the characteristics of energy metabolism in animals of different genotypes. An increase in the proportion of motor activity is accompanied by an increase in nonproductive energy expenditure, which reduces the share of energy directed toward live weight gain. Moreover, a calmer behavioral type contributes to lower energy costs for maintaining activity and increases feed conversion efficiency.

The observed variability in correlation coefficients between genotypes indicates different degrees of dependence of productive traits on behavioral factors, which may be related to genetically determined features of metabolic regulation.

Analysis of the relationship between the time to the first suckling act and live weight at 18 months demonstrated that the influence of early postnatal behavior on productivity was stable and universal across all the studied genotypes. High values of the coefficient of determination indicate that the time to first suckling is among the key factors determining the realization of genetic growth potential.

Early activation of suckling behavior likely ensures more effective colostrum intake and initiates physiological mechanisms of metabolic programming, which subsequently results in increased growth intensity and better feed efficiency.

Overall, the results demonstrate that ethological reactivity is a significant factor influencing productivity and that its consideration allows the prediction of fattening efficiency. Calmer animals require less energy for avoidance responses and social interactions, which ensures more rational use of feed energy and increases production profitability.

Thus, industrial crossbreeding of Kazakh White-Headed cows with beef sires is an effective strategy for improving the productivity of beef cattle production under dry-steppe conditions in western Kazakhstan. The best overall performance in terms of live weight, FCR, and economic behavior pattern was recorded for Simmental × Kazakh White-Headed bull calves. It was established that a calm temperament is among the key factors determining higher feed and energy efficiency during fattening. Moreover, the observed differences between genotypes cannot be explained solely by the behavioral characteristics of the animals. They are likely the result of a complex interaction of genetic factors (heterosis effect, breed combination features) and physiological mechanisms, including the efficiency of early colostrum absorption and subsequent metabolic programming. Therefore, behavioral indicators should be considered as one element of the overall adaptive–productive system of the organism, shaped by both genotype and environmental conditions.

It should be noted that this study has several limitations. Observations were conducted on 4 groups of 12 animals each, which corresponds to the minimally acceptable sample size for ethological studies but remains relatively small for evaluating fattening performance. For this reason, the obtained results should be regarded as preliminary and interpreted with caution when extrapolated to other farming conditions. To more reliably confirm the identified patterns, further research with larger sample sizes and in different climatic and geographic zones is advised.

It should also be noted that modern studies increasingly employ automated methods for recording animal behavior, including accelerometers, GPS trackers, and feeding behavior monitoring systems. These technologies allow for more detailed and continuous data on motor activity and social interactions. In the present study, a classical visual observation method was used, which, despite being labor intensive, remains informative and widely applied in ethological research. A promising direction for future work is the integration of traditional and digital behavior monitoring methods.

5. Declarations

5.1. Ethical considerations

The experimental procedures complied with current ethical standards and regulatory requirements governing animal welfare. All manipulations were carried out in accordance with GOST 33216-2014 "Guidelines for the Housing and Use of Farm Animals," the international guiding principles for biomedical research involving animals, the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes, and the principles of humane handling and euthanasia recommended by the American Veterinary Medical Association (AVMA).

5.2. Use of artificial intelligence (AI)

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation, analysis, or writing of this manuscript.

5.3. Conflict of interest

The absence of conflicts of interest has been declared by the authors.

5.4. Funding

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