Chabuz *et al. BMC Veterinary Research* (2025) 21:329
https://doi.org/10.1186/s12917-025-04796-8

BMC Veterinary Research

RESEARCH Open Access

Adaptability of Polish Red cows to extensive conditions

Witold Chabuz[1], Paweł Żółkiewski[1*], Wioletta Sawicka-Zugaj[1], Krzysztof Buczek[2], Marta Staniec[2], Sylwester Kowalik[3], Piotr Rydel[4], Andrzej Lisowski[1] and Karolina Kasprzak-Filipek[1]

Abstract

This study assessed the adaptive capacity of Polish Red cattle, one of the oldest indigenous dual-purpose breeds in Europe, to extensive environmental conditions in north-eastern Poland. Twenty-two pregnant cows (average lactation number: 4.6) were divided into two groups: one maintained in a highly extensive 'bale grazing' system (EXT), and the other under traditional housing for suckler cows (TRAD). The experiment was conducted from the onset of winter through to the end of the subsequent pasture season. Parameters assessed included changes in body weight and body condition score (BCS), calf growth performance, milk yield, and haematological and biochemical blood indices. Statistical analysis was performed using independent-samples t-tests and the Mann–Whitney U test ($p \leq 0.05$, $p \leq 0.01$). Despite challenging environmental conditions in the EXT group, including no shelter and exposure to variable climatic factors, cows maintained body condition and health comparable to the TRAD group. While TRAD group calves showed superior growth (29 kg higher body weight, $p \leq 0.01$), EXT group cows exhibited remarkable resilience by supporting calf survival with minimal weight loss (average 4.4 kg loss, less than 1% of initial body weight). Blood parameters remained within physiological ranges for both groups, confirming the breed's adaptability. These findings provide the first experimental evidence of the adaptability of Polish Red cattle to extensive farming systems, highlighting their potential as a valuable genetic resource for sustainable livestock production under increasing environmental variability. This conclusion has significant implications for the conservation of biodiversity and the development of climate-resilient cattle breeding in Europe.

Keywords Native breed, Vital parameters, Body condition, Suckler cows, Environmental conditions

Background

Farm animals, especially cattle, play a significant role in human life, resulting in numerous benefits, as noted by Henry et al. [1] —mainly in the production of food, natural fertilizers, supply of products for the leather industry,, and the economic income for livestock-related employees. However, animal production can be adversely affected by environmental changes, e.g., through changes in the productivity of pastures or fodder plants. These can result in nutritional stress, which together with the other stressors, i.e., heat stress poses one of the greatest threats to this economic sector [2, 3]. The mechanism that enables survival in a specific environment

*Correspondence:
Paweł Żółkiewski
pawel.zolkiewski@up.lublin.pl
[1]Department of Cattle Breeding and Genetic Resources Conservation, University of Life Sciences in Lublin, Akademicka Str. 13, Lublin 20-950, Poland
[2]Department of Epizootiology and Clinic of Infectious Diseases, University of Life Sciences in Lublin, Głęboka Str. 30, Lublin 20-950, Poland
[3]Department of Animal Physiology, University of Life Sciences in Lublin, Akademicka Str. 12, Lublin 20-950, Poland
[4]Lauks Rumian Farm, Polish Red Cattle Breeders Association, Rumian 55, Rybno 13-220, Poland

and adequate welfare is adaptation. In the animal world, adaptation can be described as an evolutionary process taking place in the conditions of a demanding environment, competition for food, migration in search of pastures, challenge associated with diseases, and social needs, which allows a relatively small group of animals to transform into a separate and distinct unit in a specific geographic and climatic niche [4].

The current decline in biodiversity has made it clear that many species and populations of both animals and plants are unable to adapt rapidly enough to the changes taking place in nature [5]. The subject of adaptation of farm animals has also been raised by the Food and Agriculture Organization (FAO) of the United Nations [6], which has indicated the need to protect genetic resources to preserve a valuable reservoir of genes of animals that can be easily adapted to widespread climate change.

From a scientific and practical perspective, adaptation is a problematic process, because it usually has low heritability, e.g., 0.04–0.08 for the respiration rate and rectal temperature. Furthermore, it can have antagonistic genetic correlations with milk production [7, 8]. Examples of adaptation include anatomical, physiological and behavioural mechanisms that help the animal survive in a given environment [9]. Adaptation can therefore be defined as a generalised response to specific factors (stressors). It can be short-term (phenotypic) and non-genetic or long-term (generational) and genetic.

The most commonly mentioned environmental stressors that determining the comfort of animals include temperature, humidity, wind speed, and solar radiation. These types of stressors magnify the role of sensible heat transfer (through conduction, convection, or radiation) and latent heat transfer (evaporation through sweating and panting) [10]. A short-term response when the neutrality of these factors is exceeded may involve the activation of mechanisms aimed at maintaining homeothermy, i.e., an increased respiration rate, increased internal temperature, reduced pulse, panting, profuse sweating and decreased feed intake [9, 11, 12]. Notably, environmental factors, particularly low precipitation and drought conditions, directly reduce the quantity and quality of feedstuffs and limit animals' access to pastures and water [13]. The resulting nutritional stress may have a negative impact on growth and milk production in cattle and, above all, reproductive parameters, including late maturation, reduced fertility, and increased pregnancy losses [14, 15].

With this in mind, it is believed that animals that are able to maintain their responses within physiological ranges under stressful environmental conditions are adapted to this environment [16]. Local breeds therefore seem adapted to the prevailing environmental conditions in a given area. Researchers have identified many beneficial traits in local farm animals, including longevity, good fertility, resistance to disease, adaptation to difficult living conditions, and especially tolerance to low-quality feed or temporary periodic feed shortages [17–20]. This phenomenon is especially discussed in the case of cattle living in tropical areas, where in numerous regions, cattle must contend with heat, a lack of water, and limited access to feed [21]. Adaptation to unfavourable environmental conditions has also been demonstrated among *Bos indicus* cattle (Borana, Ankole and Yunnan Yellow breeds), which have a greater ability to digest feed fibre in the rumen than *Bos taurus* cattle [22–24]. The aforementioned beneficial functional traits have also been observed among many local cattle breeds across Europe [25–30]. Maintained for decades in small-scale farming systems, often under conditions of recurrent feed shortages and variable environmental challenges, these breeds have retained substantial adaptive capacity, which has enhanced their survival rates [4, 31, 32]. A wide range of genetic tools are now being used to identify these traits and their associated genes, for use in response to ongoing climate change [33–37]. Such traits may play a crusial role in ensuring future global food security [38, 39].

In Poland, four local cattle breeds are covered by the national genetic resources conservation programme: Polish White-Backed, Polish Black-and-White, Polish Red-and-White, and Polish Red cattle [40]. The latter belongs to the red mountain cattle cluster—one of the oldest indigenous European cattle breeds—derived from the short-horned taurine cattle *Bos taurus brachyceros*, which has been maintained in Central Europe for thousands of years [41–43]. Polish Red cattle are characterised by a uniform coat colour ranging from light red to dark brown, with dark pigmentation of the muzzle and hooves. Their horns are short, grey, and tipped with dark colouration. The average withers height of mature cows ranges between 135 and 140 cm. According to 2023 data, the breed's average milk yield is 3,295 kg per lactation, with a fat content of 4.27% and a protein content of 3.43%. The average herd size is composed of nine cows [44] (See Fig. 1).

This breed dominated the cattle population in Poland during the first half of the 20th century. Unfortunately, as a result of the Second World War and subsequent political decisions, its population was reduced dramatically [45]. The current population of Polish Red cows, which are concentrated mainly in southern and northern Poland, is estimated at approximately 5,000 heads [44], of which approximately 4,300 cows on 319 farms are covered by a genetic resources conservation programme [46]. The breeding of this breed is supported by two programmes: the Genetic Improvement of Breeds Programme and the Genetic Resources Conservation Programme. With the support of the programmes, the

Fig. 1 Polish Red cows in experimental farm (source: collections of Department of Cattle Breeding and Genetic Resources Conservation, University of Life Sciences in Lublin)

number of Polish Red cows has increased by approximately 75% over the last decade. The meat direction of use is mainly responsible for this increase.

Polish Red cattle represent a dual-purpose breed providing not only high-quality milk with valuable nutritional and technological properties [47–49], but also excellent-quality beef [50], noted for its tenderness, marbling, and juiciness [45, 51–53]. Furthermore, this breed is distinguished by its high resistance to challenging environmental conditions, good health and resistance to diseases, exceptional fertility and calf viability, longevity, the ability to reduce yield to survive temporary feed deficits, rapid regeneration of lost body condition following nutritional stress [45]. In addition, as indicated by a study by Gurgul et al. [42], genes associated with resistance of the mammary gland to Gram-negative bacteria, Gram-positive bacteria, viruses and unicellular parasites have been identified in individuals of this breed.

So far, research on the Polish Red breed has focused mainly on production traits. Available descriptions of the breed emphasize its robust health and ability to adapt to harsh environmental conditions. However, there is a lack of research that directly substantiates these claims. In view of this, the present study represents the first attempt to experimentally verify these features.

The aim of the study was to evaluate the adaptive capacity and expand understanding of the functional potential of Polish Red cattle to harsh environmental conditions.

Materials and methods

Ethical statement

The study protocol, described below, was reviewed and approved by the Local Ethics Committee on Animal Experimentation of University of Life Sciences in Lublin, Poland (Decision No. 104/2015 of December 8, 2015). All procedures in this study were minimized to reduce any potential pain and stress to the animals, ensuring that their welfare was maintained throughout the experiment. Additionally, all procedures were conducted in accordance with relevant guidelines and regulations to ensure compliance and ethical standards [54] and [55].

Study area and experimental conditions

The study was performed in the Warmia and Masuria region of north-eastern Poland (Fig. 2, LAT: 53.42, LNG: 19.91), located between the Vistula and Niemen

Fig. 2 Location of the experimental farm

river valleys and the Baltic Sea to the north. The region has largely retained its natural character, with highly diverse terrain formed during the last glacial period and abundant lakes. The climate is closely correlated with the geographic location of the region and the combined influence of a continental and maritime climate [56]. The microclimate of the region is characterized by high levels of precipitation, frequent fog, and humid summers, which contribute to a moist and variable environment. These conditions, along with a short growing season, result in limited periods of optimal vegetation growth and influence the composition and availability of natural forage. Winter is typically long, cold, and snowy, with average temperatures often falling below freezing from late November to early March. Snow cover is persistent and thicker than in majority of Polish regions, lasting several weeks or even months. The region also experiences frequent fog and calm, windless conditions due to high humidity from nearby lakes and the moderating but limited influence of the Baltic Sea. The interaction between the region's geographic location, its glacially formed terrain, and the combined effects of continental and maritime climate patterns further emphasizes the environmental variability and challenges posed by the local climate. It is described as the second coldest region of Poland after the mountainous areas [57, 58]. The meteorological conditions prevailing during the experiment are detailed in Table 1. Poor and very poor soils classified as susceptible to drought are predominant in the region [59–61].

Animals and experimental groups

The study was carried out on 22 Polish Red cows with their offspring, kept at a private certified organic family farm, called Lauks Rumian [63]. The study took place from 15 October, i.e., the start of the winter season – to 30 October of successive year, i.e., the end of the pasture season. The animals were kept as beef suckler cows. When the animals had left the pasture, the herd was divided into two experimental groups. The traditional (TRAD) group was kept during the winter period in a fenced outdoor enclosure, with a two three-sided roofed

Table 1 Meteorological data for the region during the study period (Polish Institute of meteorology and water Management) [62]

	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Average atmospheric pressure (hPa)	Average relative humidity (%)	Average wind speed (km/h)	Average amount of precipitation (mm)	Total days that snowed
2017								
October	9.2	19.9	0.4	1013.5	88.6	14.5	113.56	2
November	4.1	10.8	-3,7	1013.6	90,6	12.2	44.69	6
December	1.8	9.5	-4.3	1010.8	90,5	14.6	103.64	11
2018								
January	-0.3	8.8	-10.0	1015.7	88.0	13.0	105.15	13
February	-4.2	4.3	-17.0	1020.9	83.1	9.4	83.10	18
March	-0.4	13.1	-15.6	1009.7	73.4	11.2	10.65	13
April	12.1	27.9	-2.2	1014.2	65.9	12.8	25.90	1
May	17.3	30.3	3.4	1018.7	58.8	10.1	39.12	
June	18.3	31.4	3.3	1014.9	63.3	9.9	91.44	
July	20.4	31.8	9.9	1012.8	70.9	9.7	93.46	
August	20.0	32.3	6.7	1016.8	69.0	8.5	69.09	
September	15.7	29.5	-0.7	1019.5	71.3	9.5	13.71	
October	9.6	22.0	-0.3	1017.9	78.7	11.4	44.46	

Temperature - air temperature at 2 m above the earth's surface; Atmospheric pressure - atmospheric pressure at the weather station level; Humidity - relative humidity at 2 m above the earth's surface; Wind speed - mean wind speed at 10–12 m above the earth's surface over the 10-minute period immediately preceding the observation

Fig. 3 View of the study areas. (source Google Earth)

shelters with bedding to provide protection from adverse weather conditions. In contrast, the extensive (EXT) group was maintained in an 'bale grazing' system on a 49,300 m² plot (Fig. 3). These animals had no access to any constructed shelter; instead, a forest grove provided natural protection from environmental conditions. Straw was delivered daily, serving as both fodder and bedding. Both groups had continuous access to water and were fed ad libitum roughage (see Table 2 for details).

The cows chosen for the experiment were matched for age, lactation number, physiological status, and body condition (Table 3). The average age of the cows expressed as lactation number was 4.6 (4.9–4.3 lactations). Physiological status was expressed as gestation length. At the beginning of the study, the cows were pregnant for 76–81 days, and at the end of the winter season, they were on on the216th day of gestation in the TRAD group, and 213 days in the EXT group).

Table 2 Nutritional value according to the INRA system and the proximate chemical composition of the feedstuffs used in the diets of lactating cows

Feedstuff	Dry matter (%)	Content of nutrients in kg dry matter							
		UFL	PDIN (g/kg)	PDIE (g/kg)	FUC	Crude protein (%)	Crude fat (%)	Crude Fibre (%)	Crude ash (%)
EXT									
Wheat straw	93.85	0.42	38	44	1.60	6.06	2.07	31.2	3.71
Rye straw	93.25	0.42	39	44	1.60	6.19	1.47	37.9	3.30
Cereal blend straw	94.32	0.42	33	44	1.60	5.25	1.93	43.0	3.85
Meadow hay (2nd cut)	93.36	0.70	44	67	1.10	7.00	1.23	29.9	4.08
TRAD									
Meadow hay (1st cut)	92.73	0.77	78	84	1.00	12.62	1.53	28.5	4.47
Haylage from permanent grassland (1st cut)	62.84	0.74	83	84	1.10	13.37	1.73	24.3	6.16
Haylage from permanent grassland (2nd cut)	66.08	0.83	78	87	1.00	12.62	2.37	25.4	5.72

Note: UFL - Forage Unit for lactation; PDIN – Protein Digestible in the Small Intestine from Rumen-Degraded Dietary Protein; PDIE – protein truly digestible in the intestine with energy limiting factor for microbial synthesis in the rumen; FUC - fill unit for cows

Table 3 Age and physiological status of the cows

Parameter	Experimental group				*p*-value	Total	
	EXT		TRAD				
	X	SD	X	SD		X	SD
Number of animals	11		11			22	
Lactation number	4.9	2.4	4.3	2.5	0.554	4.6	2.4
Day of gestation (days) – start of winter season	76.1	31.7	81.5	34.7	0.704	78.8	32.6
Day of gestation (days) – end of winter season	213.1	31.7	218.5	34.7	0.704	215.8	32.6

Note: Experimental group EXT – Diet based on straw and meadow hay; Experimental group TRAD – Diet based on haylage from permanent grassland and meadow hay

The experiment involved the entire herd, which consisted of 22 cows (11 per group). Therefore, a formal sample size calculation was not necessary, as all available animals were included in the study.

Cows were matched for age, lactation number, physiological status, and body condition via the DEFRA [64] and Wildman et al. [65] scoring methodologies. The animals were then divided into two groups of 11 cows each, ensuring that the groups were comparable in terms of these characteristics. Piotr Rydel, as author of the publication, who is also the owner of the animals, was one of the main deciders of group assignment. Randomization was not performed, as the primary goal was to create matched groups to control for potential confounding variables.

Blinding was not performed during the allocation of animals to groups owing to the need for matching on the basis of specific criteria. However, the investigators who conducted the physiological assessments and data analysis were blinded to the group allocations to minimize bias.

Group (EXT) was fed rye straw, cereal blend straw, wheat straw, and floodplains meadow hay, with nutritional value similar to that of straw. The feeds used during the winter period (Table 2) can be classified as extensive due to their high content of crude fibre (29.9–43.0%) and low content of crude protein (5.25–7.00%). Group (TRAD) cattle were fed a typical diet for suckler cows, i.e., haylage and meadow hay. Compared with those in group 1, the feeds in group 2 presented a higher content of crude protein (12.62–13.37%) and a lower content of crude fibre (24.3–28.58%). The feed was supplied *ad libitum*, and the basic nutritional needs of the animals were ensured in accordance with the INRA cattle feeding system (INRAtion 4.07 software). The cattle were given water *ad libitum* from troughs connected to the local water supply system.

Assessment of weight and body condition

To determine changes in the cows' body mass, the animals were weighed using an electronic livestock scale (Tru-Test XR3000, maximum capacity: 2000 kg, readability: ± 0.5 kg). The Tru-Test XR3000 features an auto-calibration system, which ensures consistent accuracy by automatically adjusting for any deviations caused by environmental factors or wear over time. Prior to each weighing session, the scale was inspected and confirmed to be functioning within the manufacturer's specified tolerances. Body Condition Score (BCS) of cows was assessed on a 5-point scale. The BCS assessments were performed by a single evaluator with 20 years of experience in BCS evaluation as part of their scientific work in the Department of Cattle Breeding and Genetic Resources Conservation. This evaluator has extensive expertise in assessing key anatomical traits, including fat cover over the ribs, spine, hips, and tailhead, as well as muscle mass and overall body shape. The scoring adhered to the standardized guidelines outlined by Wildman et al. [65] and DEFRA [64], ensuring consistency and accuracy. All assessments were conducted at the start and end of the winter season (15 October and 1 March, respectively). All cows included in the experiment gave birth to healthy calves, which were weighed twice–at birth and at weaning.

The weights of the calves were used to determine the following:

- daily gains:

$$DG = (WW - BW)/A_W$$

where:

BW = calf weight at birth

WW = calf weight at weaning

$A_{W=}$ calf age at weaning

– 210-day standardized body weight:

$$W_{210} = (WW - BW)/A_W x (210 - A_W) + WW$$

- The milk yield of suckler cows was estimated as the amount of milk used during the 210-day lactation period by calves with an initial birth weight of 35 kg, which consumed 10 kg of milk daily during the first 3 months, and 8–9 kg during the 4–8 months [66]:

$$MYC = WWx1700/A_W$$

Blood collection and analyses

Blood samples were collected from each individual twice—at the beginning and end of the experiment by vena *jugularis externa* venepuncture — using a Vacutainer blood collection system (Becton, Dikinson and Company, USA). Approximately 2 ml of blood was collected into a tube containing EDTA K2, and approximately 9 ml of blood was collected into a tube containing a clotting activator. The samples were then cooled in a water bath to approximately + 4 °C. Hematological analysis was performed via an automatic hematological analyser with species-specific software (Horiba Scil Vet ABC Plus, Horiba Ltd., Japan) to determine the number of erythrocytes (RBCs), leukocytes (WBCs), and thrombocytes (PLTs) as well as the hematocrit (HCT) and hemoglobin (HGB) concentrations. In addition, the following red blood cell parameters were determined: mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin concentration (MCHC), and mean corpuscular volume (MCV).

Samples for biochemical analysis, after 30 min at room temperature to allow clotting, were centrifuged (2000 G x 10 min, + 4 °C), and the serum obtained was analysed for following parameters: bilirubin (BIL), total cholesterol (CHOL), creatinine (CREA), urea, total protein (TP), and minerals such as calcium (Ca), magnesium (Mg) and phosphorus (P). The activities of enzymes, alanine aminotransferase (ALAT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP), were also determined. These parameters were determined via colorimetric methods via a fully automated biochemical analyser (Mindray BS120, China) and AlphaDiagnostics reagent kits (AlphaDiagnostics, Poland).

Statistical methods

Statistical analysis of the data was performed via Statistica 13.0 software. Means and standard deviations were calculated. The significance of the differences in the means was tested via an independent samples t-test at significance levels of $p \leq 0.05$ and $p \leq 0.01$. For hematological and biochemical parameters of the blood, owing to the varied physiological status of the cows (advancement of lactation), the significance of differences was analysed only within experimental groups in a given period, without comparing the parameters obtained at the start and end of the winter season.

To compare the BCS between the two groups, the Mann-Whitney U test was applied due to the non-parametric nature of the data.

Results

The rearing parameters for the calves in the study population are presented in Table 4. Both the EXT and TRAD groups demonstrated comparable calf birth weights and weaning ages, indicating effective standardisation of initial conditions. However, significant differences emerged in subsequent performance parameters, reflecting the influence of differing nutritional strategies on calf growth and maternal productivity. Calves in the TRAD group achieved significantly higher weaning weights, with an average advantage of 29 kg compared to the EXT group ($p \leq 0.01$). This growth benefit was also evident in average daily live weight gains, with TRAD calves gaining approximately 110 g/day more than their EXT counterparts ($p \leq 0.01$). By 210 days of age, the standardised body weight of TRAD calves exceeded that of EXT calves by 24.5 kg ($p \leq 0.01$). Milk yield from suckler cows was a key factor contributing to these differences. TRAD cows produced, on average, 193.6 kg more milk than cows in the EXT group ($p \leq 0.01$), which likely played a critical role in supporting the enhanced growth performance of

Table 4 Rearing parameters of calves

Parameter	Experimental group				*p*-value	Total	
	EXT		TRAD				
	X	SD	X	SD		X	SD
Number of animals	11		11			22	
Birth weight (kg)	32.0	2.5	33.4	3.6	0.320	32.7	3.1
Age at weaning (days)	211.5	21.4	215.7	20.9	0.648	213.6	20.8
Body weight at weaning (kg)	204.5	12.0	233.5	19.8	0.001	219.0	21.8
Daily gains until weaning (kg)	0.82	0.08	0.93	0.08	0.003	0.88	0.10
210-day standardized body weight (kg)	204.4	16.5	228.9	15.3	0.001	216.6	20.0
Mothers' milk yield (kg)	1655.2	157.4	1848.8	139.5	0.006	1752.0	175.9

Experimental group EXT – Diet based on straw and meadow hay; Experimental group TRAD – Diet based on haylage from permanent grassland and meadow hay

Table 5 Changes in the body weight and body condition (BCS) of cows during the winter period

Parameter	Experimental group				*p*-value	Total	
	EXT		TRAD				
	X	SD	X	SD		X	SD
Number of animals	11		11			22	
Body weight of cows (start of winter season) (kg)	531.1	52.8	576.4	61.7	0.079	553.7	60.6
Body weight of cows (end of winter season) (kg)	532.4	57.7	566.4	65.1	0.210	549.4	62.5
Changes in body weight in winter period (kg)	1.27	40.6	-10.0	36.4	0.500	-4.4	38.1
Body condition of cows (start of winter season) (BCS, pts.)	3.5	0.6	3.8	0.5	0.245	3.7	0.5
Body condition of cows (end of winter season) (BCS, pts.)	2.9	0.5	3.2	0.4	0.194	3.1	0.5
Changes in body condition in winter period (BCS, pts.)	-0.6	0.3	-0.6	0.3	0.487	-0.6	0.3

Note: Experimental group EXT – Diet based on straw and meadow hay; Experimental group TRAD – Diet based on haylage from permanent grassland and meadow hay

TRAD calves. Despite the nutritional constraints faced by the EXT group, cows exhibited notable adaptive traits by maintaining lactation sufficient to support calf survival and development, albeit at a reduced growth rate. The ability of EXT calves to survive and grow under such challenging conditions underscores the resilience and functional adaptability of Polish Red cows within low-input, extensive production systems.

The results presented in Table 5 highlight the adaptability of Polish Red cows to harsh environmental conditions and extensive feeding systems. At the beginning of the winter season, no significant differences were observed in body condition scores (BCS) between the EXT and TRAD groups ($p = 0.245$). Similarly, changes in BCS over the course of the experimental period were not statistically significant ($p = 0.487$), with both groups showing an average loss of 0.6 BCS points. Although cows in the TRAD group had slightly higher body weights at both the start and end of the winter season, these differences were not statistically significant. Changes in body weight during the winter period were also not significant ($p = 0.500$), with cows in the EXT group gaining an average of 1.27 kg, while those in the TRAD group lost an average of 10.0 kg. Overall, the mean change in body weight across all cows amounted to a minimal loss of 4.4 kg, representing less than 1% of the initial average body weight (553.7 kg). These findings underscore the resilience and adaptive capacity of Polish Red cows. Despite exposure to more demanding environmental conditions in the EXT group—characterised by the absence of conventional shelter and a reliance on a low-input management system—cows maintained their body condition and successfully reared calves without significant losses in weight or condition. This demonstrates the strong adaptability of the breed to extensive production systems and confirms its suitability for sustainable, low-input farming conditions.

Hematological analysis of the blood of the cows did not reveal significant differences in parameters between the EXT and TRAD groups (Table 6). However, notably, at the beginning of the winter period, the EXT group presented slightly lower values for all hematological parameters than did the TRAD group. Nevertheless, despite these slight differences, the average values for the hematological parameters were generally within the physiological ranges for the species, indicating no apparent health concerns. The biochemical analysis revealed revealed some notable findings. In the TRAD group, total bilirubin level exceeded the normal physiological range at the end of the winter season. Additionally, statistically significant differences ($p \leq 0.05$) were observed between the two groups in terms of cholesterol content and aspartate aminotransferase levels (Table 7). These differences may

Table 6 Results of the hematological analyses of the blood of cows in the two experimental groups at the beginning and end of the winter feeding period

Parameter	Ref. range*	Experimental group				p-value	Total	
		EXT		TRAD				
		X	SD	X	SD		X	SD
Start of winter season								
WBC (10^9)	4.0–12.0	6.71	1.43	7.01	1.38	0.623	6.86	1.38
RBC (10^{12})	5.0–10.0	6.20	0.56	6.41	0.49	0.365	6.31	0.52
HCT (%)	24.0–46.0	28.52	2.19	29.72	3.14	0.311	29.12	2.71
HGB (g/dl)	8.0–15.0	11.04	0.80	11.58	1.04	0.184	11.31	0.95
MCV (fl.)	40.0–60.0	46.08	2.60	46.42	4.55	0.833	46.25	3.62
MCH (pg)	11.0–17.0	17.85	0.80	18.14	1.51	0.592	18.00	1.19
MCHC (g/dl)	30.0–36.0	38.77	0.79	39.14	0.70	0.268	38.95	0.75
PLT (10^9)	100–800	164.91	23.94	174.09	47.95	0.576	169.50	37.28
End of winter season								
WBC (10^9)	4.0–12.0	6.68	1.28	7.75	1.26	0.061	7.22	1.35
RBC (10^{12})	5.0–10.0	5.86	0.55	6.24	0.43	0.087	6.05	0.52
HCT (%)	24.0–46.0	30.98	3.70	32.55	2.69	0.270	31.76	3.25
HGB (g/dl)	8.0–15.0	10.95	1.16	11.62	0.87	0.139	11.28	1.06
MCV (fl.)	40.0–60.0	52.81	2.77	52.32	4.90	0.775	52.56	3.89
MCH (pg)	11.0–17.0	18.71	0.85	18.70	1.53	0.986	18.70	1.21
MCHC (g/dl)	30.0–36.0	35.48	0.77	35.82	0.57	0.259	35.65	0.69
PLT (10^9)	100–800	140.73	37.83	137.18	26.75	0.802	138.95	32.02

Note: Experimental group EXT – Diet based on straw and meadow hay; Experimental group TRAD – Diet based on haylage from permanent grassland and meadow hay

*Reference ranges according to *Merck's Veterinary Manual* [67]

reflect variations in metabolic responses to the differing nutritional strategies employed in the two groups.

Discussion

Compared with *B. indicus*, contemporary *B. taurus* breeds are characterized by lower voluntary feed intake [70, 71], higher feed efficiency on a high-roughage diet [70], and a lower metabolic rate [10]. However, some adaptive traits have been preserved in various populations of *B. taurus*. One example is the typical lowland Jersey breed, which was introduced and acclimatized to the high mountain conditions of Tibet [72, 73], or the Simmental breed, which adapted superbly to the changing climatic conditions of South Africa [74]. The preservation of these special traits is highly important because climate change is expected to result in an increased frequency and duration of drought, which affects grassland and fodder production, as anticipated changes in herbage composition and plant growth may influence the digestibility of fodder for ruminants [75, 76].

The minimal changes in body weight during the winter period observed in the studied population of Polish Red cows indirectly confirm their good utilization of feed with low nutritional value. According to Konopiński [77], from the 18th century to the interbellum period Polish Red cattle were already spread across nearly all Polish regions. The fact that this breed was bred mainly by peasants, whereas the nobility preferred mainly imported breeds (Dutch Black and White or Simmental), says a great deal about its conformation and functional traits. Long-term breeding under these conditions has led to the perpetuation of traits such as resistance to severe climatic conditions, poorer-quality feedstuffs, and even periodic feed shortages during the winter feeding period [78].

Our study revealed that cows had a lower BCS in spring, but this difference was not clearly reflected in their body weight. Changes in BCS are associated with the strategy of the accumulation of lipid tissue by ruminants during periods with a large amount of nutrient-rich feed and its mobilization for energy production in times of shortage [79–81]. This phenomenon is characteristic of indigenous breeds in subtropical environments, where wet seasons are interspersed with long dry periods with low quantity and quality pastures, and the ability to store fat in seasons of high abundance and later use it for maintenance, pregnancy and lactation during adverse seasons is a basic survival strategy. Similar results to those obtained in the present study were reported by Manninen et al. [82], who tested various systems of winter maintenance and feeding of Hereford suckler cows in North Karelia (latitude 62 N). Following 200 days of sparse winter feeding, the authors reported that animals receiving a limited amount of roughage supplemented with oat maintained their initial body weight, and their BCS decreased by only by 0.14. Notably, these animals

Table 7 Results of the biochemical analyses of the blood of cows in two experimental groups at the beginning and end of the winter period

Parameter	Ref. range*	Experimental group				*p*-value	Total	
		EXT		TRAD				
		X	SD	X	SD		X	SD
Start of winter season								
ALAT (U/l)	11–40	27.92	5.69	28.52	2.70	0.755	28.22	4.36
ALP (U/l)	0-500	30.89	6.68	31.97	9.67	0.763	31.43	8.13
AST (U/l)	60–125	61.22	10.34	74.91	13.47	0.015	68.06	13.66
BIL (mg/dl)	0.0–1,6	0.43	0.08	0.66	0.26	0.009	0.54	0.22
Ca (mg/dl)	8.0-11.4	10.53	0.35	10.72	0.16	0.114	10.63	0.28
CHOL (mg/dl)	65–220	113.94	35.55	138.05	29.74	0.099	126.00	34.29
CREA (mg/dl)	0.5–2.2	1.27	0.29	1.10	0.22	0.148	1.18	0.26
Mg (mg/dl)	1.5–2.9	2.22	0.22	2.19	0.17	0.755	2.21	0.19
P (mg/dl)	5.6-8.0	5.20	1.12	5.75	0.85	0.216	5.47	1.01
Urea (mg/dl)	10–25	13.63	4.31	15.29	4.32	0.377	14.46	4.30
TP (g/dl)	6.7–7.5	7.82	0.63	7.69	0.54	0.633	7.75	0.58
End of winter season								
ALAT (U/l)	11–40	21.97	2.66	21.15	3.27	0.522	21.56	2.94
ALP (U/l)	0-500	22.02	4.15	22.08	7.59	0.981	22.05	5.97
AST (U/l)	60–125	44.85	9.66	44.42	8.22	0.913	44.63	8.75
BIL (mg/dl)	0.0–1,6	1.48	0.44	1.98	0.47	0.019	1.73	0.51
Ca (mg/dl)	8.0-11.4	7.58	0.66	8.05	0.48	0.068	7.81	0.61
CHOL (mg/dl)	65–220	92.76	21.23	95.86	22.85	0.745	94.31	21.58
CREA (mg/dl)	0.5–2.2	0.71	0.17	0.74	0.21	0.699	0.73	0.19
Mg (mg/dl)	1.5–2.9	1.54	0.23	1.48	0.17	0.487	1.51	0.20
P (mg/dl)	5.6-8.0	2.34	0.83	2.10	0.65	0.464	2.22	0.74
Urea (mg/dl)	10–25	18.04	6.91	21.90	6.98	0.207	19.97	7.06
TP (g/dl)	6.7–7.5	2.41	1.00	2.82	1.00	0.349	2.62	1.00

Note: Experimental group EXT – Diet based on straw and meadow hay; Experimental group TRAD – Diet based on haylage from permanent grassland and meadow hay

The significance of differences was analysed only within experimental groups in a given period

*Reference ranges according to *Merck's Veterinary Manual* [68] and [69]

compensated for the loss in the subsequent pasture season, while preserving their normal health parameters.

Harsh environmental conditions did not affect the birth weight of calves, which is within the norms for the national population [results of assessment by the Polish Federation of Cattle Breeders and Dairy Farmers [44]; however it significantly affects the cows' milk yield and thus daily weight gains in calves. These findings suggests that during the period of exposure to environmental stressors, Polish Red cows reduce their milk yield while preserving energy reserves necessary for pregnancy and lactation. Highly productive breeds under nutritional stress react with a short-term response, i.e., by activating their own bodies' reserves. The same stressor in some animals may lead to permanent changes in gene expression, allowing them to cope better than those with a short-term response [13, 83]. If the stress factor lasts long enough, with appropriate selection, the physiological responses arising from the expression of beneficial genes and their combinations can become fixed throughout the entire population [4]. Local breeds in particular have this type of adaptation, as described by Mirkena et al. [81]. In his opinion, breeds adapted to moderate temperatures are highly productive but require a more balanced feed ration composed of high-quality ingredients. On the other hand, they lose weight, and deaths may even occur, when they are fed poor-quality grass or straw. In contrast, animals of indigenous breeds continue to grow, produce some milk, and reproduce in difficult conditions.

The average daily weight gains of calves obtained in the present study, amounting to 880 g, was greater than those reported by Litwińczuk et al. [84] (730 g). Notably, the calves in the present study were kept outdoors with their mothers in the pasture, whereas in the study by Litwińczuk et al. [84] the animals were kept indoors without their mothers. Research on the meat production traits of Polish Red cattle, conducted during the 1970s and 1980s by the National Research Institute of Animal Production, revealed some differences when compared with the findings of the present study. Under controlled fattening conditions using homegrown roughage and bruised grain, average daily weight gains in bulls ranged from 1,018 g to 1,123 g when fattened up to 12 months of age. However, when the fattening period was extended to 15 months, the average daily gains (888–998 g) were more closely aligned with those observed in the current study, in which the average daily weight gain of calves was 880 g [85]. The 'bale grazing' system was also employed in studies by Wiśniewski et al. [52, 86]. in the management of both Polish Red and Limousin cattle. Their findings provide valuable comparative data, particularly with regard to growth performance under extensive conditions. In that study, Polish Red calves exhibited an average daily live weight gain from birth to 210 days of age of 900 g, and from birth to 420 days of age of 880–900 g. The standardised body weight at 210 and 420 days was 233.26 kg and 397.13 kg, respectively. These results are in close alignment with those obtained in the present study, reinforcing the evidence for the Polish Red breed's capacity to sustain satisfactory growth under low-input, extensive systems such as bale grazing. Among breeds of the Baltic Red type, Danish Red has the highest daily gain, at 1090 g [87], similar to Norwegian Red (1020–1040 g) [88]. Somewhat lower effects were obtained for Lithuanian Red (970 g) [89].

The blood hematological and biochemical parameters of the animals did not show any major deviations from the physiological range during the winter period. This may indicate adequate physiological adaptation of the Polish Red breed to variable climatic conditions, and thus feeding conditions. On the other hand, when the cows were switched from pasture to winter conditions the average serum levels of CHOL, BIL and AST differed significantly ($p \le 0.05$; $p \le 0.01$) between the EXT and TRAD groups. Nevertheless, the values were within the physiological ranges for this species and even decreased following the winter period. The only parameter that exceeded the reference values was the BIL concentration. The elevated blood parameters observed in the cows tested in spring (March) compared with autumn may be linked to their advanced pregnancy, as cases of an increase in this parameter in cows during this period have been described. Kozitcyna et al. [90] noted a successive increase in the total bilirubin concentration in cows from 6 to 9 months of gestation. The highest bilirubin concentrations, which exceeded the reference values, were noted immediately after parturition by Zhou et al. [91] and persisted for approximately two weeks. This has also been confirmed by Rohn et al. [92].

González et al. [93] and Moreira et al. [94] reported that analysis of glutamate dehydrogenase (GLDH), gamma-glutamyl transferase (GGT) and aspartate aminotransferase (AST) activity and the concentration of BIL are particularly useful in diagnosing subclinical liver damage and dysfunction in the course of fatty liver disease. However, the results of the analyses of parameters whose values changed significantly in such cases (CHOL, AST, and ALAT) did not confirm any clinical symptoms of this type of disease. The increase in the BIL concentration may also have been caused by long-term energy deficiency in the feed rations, leading to anaemia [95]. However, this hypothesis is not confirmed by the haemoglobin and haematocrit values in the populations, which did not change significantly during the period when they were fed poor-quality feed. Nevertheless, the significantly higher bilirubin levels obtained in the groups of animals fed haylage and permanent grassland (group TRAD) may indicate a dietary cause of these differences.

Conclusion

A dominant trend in current livestock production around the world is based on breeding high-producing, international breeds. This direction is particularly pronounced in cattle breeding and has resulted in the considerable marginalization of local breeds. The Polish Red cattle, one of the oldest autochthonous European breeds, have historically been raised under extensive farming systems. Previous research on the breeding and utilization of this breed has highlighted several advantageous traits, including longevity, and the capacity to produce high-quality raw materials. This manuscript specifically investigates the adaptive capacity of the Polish Red cattle breed to extensive husbandry conditions in northern Poland. The findings presented in this paper represent the first such comprehensive research for the Polish Red breed. Based on the results of selected physiological and productive parameters, it was determined that Polish Red cows exhibit good health and body condition even under challenging environmental conditions, highlighting their resilience, high adaptability and suitability for extensive production. The present study supports the conclusion that the Polish Red breed exhibits significant adaptive potential, which could serve as a valuable genetic and functional resource for high-producing breeds in Europe in the future. This is particularly relevant within the context of sustainable agriculture. The findings affirming the value of the Polish Red breed are of considerable importance given the challenges posed by changing environmental conditions. Consequently, further research aimed at elucidating the mechanisms underlying these adaptive processes is both justified and necessary.

Abbreviations

EXT	Extensive (implying the animal husbandry system, as the name of the experimental group)
TRAD	Traditional (implying the animal husbandry system, as the name of the experimental group)
BCS	Body Condition Score
DEFRA	Department for Environment, Food & Rural Affairs (UK Government Ministerial Department)

UFL	Unité Fourragère Lait (Forage Unit for lactation)
PDIN	Protein Digestible in the Small Intestine from Rumen-Degraded Dietary Protein
PDIE	Protein Digestible in the Small Intestine from Rumen-Fermented Organic Matter
DG	Daily Gains
BW	Calf weight at birth
WW	Calf weight at weaning
AW	Calf age at weaning
W< Subscript>210</Subscript>	210-day standardized body weight of calf
MYC	Milk yield of cows (calculated for suckler cows)
RBC	Erythrocytes
WBC	Leukocytes
PLT	Thrombocytes
HCT	Hematocrit
HGB	Hemoglobin
MCH	Mean corpuscular hemoglobin
MCHC	Mean corpuscular hemoglobin concentration
MCV	Mean corpuscular volume
BIL	Bilirubin
CHOL	Total cholesterol
CREA	Creatinine
TP	Total protein
Ca	Calcium
Mg	Magnesium
P	Phosphorus
ALAT	Alanine aminotransferase
AST	Aspartate aminotransferase
ALP	Alkaline phosphatase
GLDH	Glutamate Dehydrogenase
GGT	Gamma-Glutamyl Transferase

Acknowledgements
Not applicable.

Author contributions
Conceptualization, W.C., P.Ż. and P.R.; methodology, W.C., P.Ż., K.B., M.S. and P.R.; software, P.Ż.; validation, W.C., P.Ż. and W.S.-Z.; formal analysis, P.Ż., W.C. and S.K.; investigation, W.C. and P.Ż.; resources, K.B., M.S., S.K., A.L., K.K.-F.; data curation, P.Ż., K.B., M.S., P.R., A.L. and K.K.-F.; writing—original draft preparation, P.Ż., W.S.-Z.; writing—review and editing, W.C. and W.S.-Z.; visualization, P.Ż.; supervision, W.C., W.S.-Z.; project administration, W.C.; funding acquisition, W.C. All authors reviewed the manuscript.

Funding
This research was supported by the "Uses and conservation of farm animal genetic resources under sustainable development" project co-financed by the National Centre for Research and Development in Poland within the framework of the strategic R&D program "Environment, agriculture and forestry" BIOSTRATEG, contract number: BIOSTRATEG2/297267/14/NCBR/2016. Publication co-financed by a statutory activity subsidy from the Polish Ministry of Education and Science for Faculty of Animal Sciences and Bioeconomy University of Life Sciences in Lublin.

Data availability
The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study protocol was reviewed and approved by the Local Ethics Committee on Animal Experimentation of University of Life Sciences in Lublin, Poland (Decision No. 104/2015 of December 8, 2015).

Informed consent
was obtained from the animal's owner. The owner was involved in establishing the research protocol, assigning animals to groups, and was present during all procedures performed on the animals. He is a co-author of the manuscript (Piotr Rydel) and was responsible for conceptualization, methodology, and data curation.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 11 March 2025 / Accepted: 28 April 2025
Published online: 09 May 2025

References

1. Henry B, Charmley E, Eckard R, Gaughan JB, Hegarty R. Livestock production in a changing climate: Adaptation and mitigation research in Australia. In: Crop and Pasture Science. 2012. pp. 191–202.
2. Thornton PK, Gerber PJ. Climate change and the growth of the livestock sector in developing countries. Mitig Adapt Strateg Glob Chang. 2010;15(2):169–84. https://doi.org/10.1007/s11027-009-9210-9.
3. Ghahramani A, Moore AD. Climate change and broadacre livestock production across Southern Australia. 2. Adaptation options via grassland management. Crop Pasture Sci. 2013;64(6):615–30. https://doi.org/10.1071/CP13195.
4. Naskar S, Gowane GR, Chopra A, Paswan C, Prince LLL. Genetic adaptability of livestock to environmental stresses. In: Sejian V, Naqvi SM, Ezeji T, Lakritz J, Lal R, editors. Environmental stress and amelioration in livestock production. Heidelberg: Springer Berlin; 2012. pp. 317–78.
5. Kristensen TN, Ketola T, Kronholm I. Adaptation to environmental stress at different timescales. Ann N Y Acad Sci. 2018;1476(1):5–22. https://doi.org/10.1111/nyas.13974.
6. Food and Agriculture Organization of the United Nations. The second report on the state of the world's animal. Genetic Resources for Food and Agriculture. Rome; 2015.
7. Luo H, Brito LF, Li X, Su G, Dou J, Xu W, et al. Genetic parameters for rectal temperature, respiration rate, and drooling score in Holstein cattle and their relationships with various fertility, production, body conformation, and health traits. J Dairy Sci. 2021;104(4):4390–403. https://doi.org/10.3168/jds.2020-19192.
8. Strandén I, Kantanen J, Russo IRM, Orozco-terWengel P, Bruford MW. Genomic selection strategies for breeding adaptation and production in dairy cattle under climate change. Heredity (Edinb). 2019;123(3):307–17. https://doi.org/10.1038/s41437-019-0207-1.
9. Aleena J, Pragna P, Archana PR, Sejian V, Bagath M, Krishnan G, et al. Significance of metabolic response in livestock for adapting to heat stress challenges. Asian J Anim Sci. 2016;10(4–5):224–34. https://doi.org/10.3923/ajas.2016.224.234.
10. Hansen PJ. Physiological and cellular adaptations of Zebu cattle to thermal stress. Anim Reprod Sci. 2004;82–83:349–60. https://doi.org/10.1016/j.anireprosci.2004.04.011.
11. Rashamol VP, Sejian V, Pragna P, Lees AM, Bagath M, Krishnan G, et al. Prediction models, assessment methodologies and biotechnological tools to quantify heat stress response in ruminant livestock. Int J Biometeorol. 2019;63(9):1265–81. https://doi.org/10.1007/s00484-019-01735-9.
12. Rashamol VP, Sejian V, Bagath M, Krishnan G, Archana PR, Bhatta R. Physiological adaptability of livestock to heat stress: an updated review. J Anim Behav Biometeorol. 2018;6(3):62–71. https://doi.org/10.26667/2318-1265jabb.v6n2p62-71.
13. Chaidanya KANP, Sejian VSS. Adaptation of livestock to environmental challenges. J Vet Sci Med Diagn. 2015;04(03):1–7. https://doi.org/10.4172/2325-9590.1000162.
14. Qureshi MS. Stress impedes reproductive physiology of dairy animals under Subtripical conditions - A review. J Anim Plant Sci. 2012;22(2 Suppl):75–8.
15. Soren NM. Nutritional manipulations to optimize productivity during environmental stresses in livestock. In: Environmental Stress and Amelioration in Livestock Production. 2012. pp. 181–218.
16. Maurya VP, Sejian V, Gupta M, Dangi SS, Kushwaha A, Singh G, et al. Adaptive mechanisms of livestock to changing climate. In: Sejian V, Gaughan J, Baumgard L, Prasad C, editors. Climate change impact on livestock: adaptation and mitigation. New Delhi, India: Springer; 2015. pp. 123–38.

17. Gandini G, Maltecca C, Pizzi F, Bagnato A, Rizzi R. Comparing local and commercial breeds on functional traits and profitability: the case of Reggiana dairy cattle. J Dairy Sci. 2007;90(4):2004–11. https://doi.org/10.3168/jds.2006-204.
18. Naves M, Alexandre G, Mahieu M, Gourdine J-L, Mandonnet N, Mandonnet Les N. Les races animales locales: bases du développement innovant et durable de L'élevage aux Antilles. Innov Agron. 2011;16:193–205. https://doi.org/10.17180/awhs-nv51i.
19. Dovc P. Local breeds and their potential for progress in animal breeding. Stočarstvo. 2007;61(6):463–6.
20. Rossetti C, Perucatti A, Mottola F, Incarnato D, Genualdo V. Genetic investigation for the characterization of three Indigenous pig breeds of Southern Italy: advantages and prospects. Anim Sci Pap Rep. 2021;39(2):141–50.
21. Porto-Neto LR, Reverter A, Prayaga KC, Chan EKF, Johnston DJ, Hawken RJ, et al. The genetic architecture of Climatic adaptation of tropical cattle. PLoS ONE. 2014;9(11):e113284. https://doi.org/10.1371/journal.pone.0113284.
22. Megersa B, Markemann A, Angassa A, Ogutu JO, Piepho HP, Valle Zárate A. Livestock diversification: an adaptive strategy to climate and rangeland ecosystem changes in Southern Ethiopia. Hum Ecol. 2014;42(4):509–20. https://doi.org/10.1007/s10745-014-9668-2.
23. Kugonza DR, Nabasirye M, Mpairwe D, Hanotte O, Okeyo AM. Productivity and morphology of Ankole cattle in three livestock production systems in Uganda. Anim Genet Resour Génétiques Anim Genéticos Anim. 2011;48:13–22. https://doi.org/10.1017/s2078633611000038.
24. Xi D, Wanapat M, Deng W, He T, Yang Z, Mao H. Comparison of gayal (Bos frontalis) and Yunnan yellow cattle (Bos taurus): In vitro dry matter digestibility and gas production for a range of forages. Asian-Australasian J Anim Sci. 2007;20(8):1208–14. https://doi.org/10.5713/ajas.2007.1208.
25. Román-Trufero A, Martínez A, Ferreira LMM, García-Prieto V, Rosa-García R, Osoro K, et al. Foraging behaviour and performance of steers from two local breeds (Asturian Valley and Asturian mountain) grazing in Cantabrian (N Spain) summer pastures. Span J Agric Res. 2019;17(1):e0601. https://doi.org/10.5424/sjar/2019171-13541.
26. Cozzi G, Brscic M, Contiero B, Gottardo F. Growth, slaughter performance and feeding behaviour of young bulls belonging to three native cattle breeds Raised in the alps. Livest Sci. 2009;125(2–3):308–13. https://doi.org/10.1016/j.livsci.2009.03.011.
27. Stronen AV, Pertoldi C, Iacolina L, Kadarmideen HN, Kristensen TN. Genomic analyses suggest adaptive differentiation of Northern European native cattle breeds. Evol Appl. 2019;12(6):1096–113. https://doi.org/10.1111/eva.12783.
28. Gaughran A, Stout J. Biodiversity audit at Áras an Uachtaráin - Final report. Dublin; 2020.
29. Weldenegodguad M, Popov R, Pokharel K, Ammosov I, Ming Y, Ivanova Z, et al. Whole-genome sequencing of three native cattle breeds originating from the northernmost cattle farming regions. Front Genet. 2019;9:728. https://doi.org/10.3389/fgene.2018.00728.
30. Flori L, Moazami-Goudarzi K, Alary V, Araba A, Boujenane I, Boushaba N, et al. A genomic map of climate adaptation in mediterranean cattle breeds. Mol Ecol. 2019;28(5):1009–29. https://doi.org/10.1111/mec.15004.
31. Solomon T, Hussen E. Benefits of farm animals genetic adaptation: A review. Eur J Exp Biol. 2018;8(4):22. https://doi.org/10.21767/2248-9215.100063.
32. Hiemstra SJ, De Haas Y, Mäki-Tanila A, Gandini G. Local cattle breeds in Europe: development of policies and strategies for self-sustaining breeds. Wageningen Academic, The Netherland;; 2010.
33. Passamonti MM, Somenzi E, Barbato M, Chillemi G, Colli L, Joost S, et al. The quest for genes involved in adaptation to climate change in ruminant livestock. Animals. 2021;11(10):2833. https://doi.org/10.3390/ani11102833.
34. Strandén I, Kantanen J, Lidauer MH, Mehtiö T, Negussie E. Animal board invited review: Genomic-based improvement of cattle in response to climate change. Animal. 2022;16(12):100673. https://doi.org/10.1016/j.animal.2022.100673.
35. Colombi D, Perini F, Bettini S, Mastrangelo S, Abeni F, Conte G, et al. Genomic responses to Climatic challenges in beef cattle: A review. Anim Genet. 2024;55:854–70. https://doi.org/10.1111/age.13474.
36. Kantanen J, Løvendahl P, Strandberg E, Eythorsdottir E, Li MH, Kettunen-Praebel A, et al. Utilization of farm animal genetic resources in a changing agroecological environment in the nordic countries. Front Genet. 2015;6:52. https://doi.org/10.3389/fgene.2015.00052.
37. Boettcher PJ, Hoffmann I, Baumung R, Drucker AG, McManus C, Berg P, et al. Genetic resources and genomics for adaptation of livestock to climate change. Front Genet. 2014;5:461. https://doi.org/10.3389/fgene.2014.00461.
38. Rothschild MF, Plastow GS. Applications of genomics to improve livestock in the developing world. Livest Sci. 2014;166(1):76–83. https://doi.org/10.1016/j.livsci.2014.03.020.
39. Mapiye O, Chikwanha OC, Makombe G, Dzama K, Mapiye C. Livelihood, food and nutrition security in Southern Africa: what role do Indigenous cattle genetic resources play? Diversity. 2020;12(2):74. https://doi.org/10.3390/d12020074.
40. Szarek J, Adamczyk K, Felenczak A. Polish red cattle breeding: past and present. Anim Genet Resour Inf. 2004;35:21–35. https://doi.org/10.1017/s1014233900001784.
41. Czaja H, Trela J. Jak Powstała Populacja Bydła Polskiego Czerwonego. Prace Nad Zachowaniem Rzadkich Ras Zwierząt Gospodarskich. Balice; 1994. pp. 56–7.
42. Gurgul A, Jasielczuk I, Semik-Gurgul E, Szmatoła T, Majewska A, Sosin-Bzducha E, et al. Diversifying selection signatures among divergently selected subpopulations of Polish red cattle. J Appl Genet. 2019;60(1):87–95. https://doi.org/10.1007/s13353-019-00484-0.
43. Janák V, Novák K, Kyselý R. Late history of cattle breeds in central Europe in light of genetic and archaeogenetic Sources—Overview, thoughts, and perspectives. Animals. 2024;14(4):645. https://doi.org/10.3390/ani14040645.
44. Polish Federation of Cattle Breeders and Dairy Farmers. Cattle Assesment and Breeding, Data for 2023 (in polish). 2024.
45. Adamczyk K, Felenczak A, Jamrozy J, Bulla J. Conservation of Polish red cattle. Slovak J Anim Sci. 2008;41(2):72–6.
46. National Research Institute of Animal Production. 2024. Accessed 10 Mar 2025. http://bydlo.bioroznorodnosc.izoo.krakow.pl/liczebnosc
47. Brodziak A, Król J, Barłowska J, Litwińczuk Z, Teter A, Kędzierska-Matysek M. Differences in bioactive protein and vitamin status of milk obtained from Polish local breeds of cows. Ann Anim Sci. 2020;20(1):287–98. https://doi.org/10.2478/aoas-2019-0069.
48. Teter A, Kędzierska-Matysek M, Barłowska J, Król J, Brodziak A. Nutritional value and coagulation properties of milk from local cow breeds, including the selected macro- and micronutrients and trace elements. Mljekarstvo. 2020;70(3):210–20. https://doi.org/10.15567/mljekarstvo.2020.0307.
49. Litwińczuk Z, Barłowska J, Chabuz W, Brodziak A. Nutritional value and technological suitability of milk from cows of three Polish breeds included in the genetic resources conservation programme. Ann Anim Sci. 2012;12(3):423–32. https://doi.org/10.2478/v10220-012-0036-0.
50. Litwińczuk Z, Chabuz W, Domaradzki P, Jankowski P. Slaughter value of young Polish Black-and-White, White-Backed, Polish Holstein-Friesian and limousin bulls under Semi-Intensive fattening. Ann Anim Sci. 2012;12(2):159–68. https://doi.org/10.2478/v10220-012-0013-7.
51. Gajos E, Dymnicki E. Beef production based on a suckling system as an alternative to milk production at the example of Polish red cattle. Anim Sci Pap Rep. 2012;30(4):353–61.
52. Wiśniewski K, Świątek M, Król J, Kuczyńska B. The nutritional value of beef from Polish red and limousin cattle breeds maintained by an extensive production system. Arch Anim Breed. 2024;67(2):259–69. https://doi.org/10.5194/aab-67-259-2024.
53. Wiśniewski K, Kuczyńska B. Current opportunities and challenges in the implementation and recognition of Polish red breed cattle beef production. Acta Agric Scand Anim Sci. 2022;71(1–4):12–20. https://doi.org/10.1080/09064702.2022.2116100.
54. European Parliament and Council. Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes (Text with EEA relevance). Off J Eur Union. 2010;276(L 276).
55. Act on the. Protection of Animals Used for Scientific or Educational Purposes. 2015.
56. Gwiazdzinska-Goraj M, Goraj S. The Contribution of the Natural Environment to Sustainable Development on the Example of Rural Areas in the Region of Warmia and Mazury. In: Rural Development 2013. 2013. pp. 266–71.
57. Tylmann W, Głowacka P, Szczerba A. Tracking climate signals in varved lake sediments: research strategy and key sites for comprehensive process studies in the masurian Lakeland. Limnol Rev. 2017;17(3). https://doi.org/10.1515/limre-2017-0015.
58. Hesse C, Krysanova V, Stefanova A, Bielecka M, Domnin DA. Assessment of climate change impacts on water quantity and quality of the multi-river vistula lagoon catchment. Hydrol Sci J. 2015. https://doi.org/10.1080/02626667.2014.967247.

59. Institute of Soil Science and Plant Cultivation– State Research Institute. Agricultural Drought Monitoring System. 2020. https://susza.iung.pulawy.pl/mapa-kategorii/. Accessed 10 Mar 2025.
60. Kuchar L, Szwejkowski Z, Rychcik B, Dragańska E. Regional climate changes in north-eastern Poland and their impact on maize crops. Acta Sci Pol Form Circumiectus. 2021;20(1):3–18.
61. Puchlik M, Piekutin J, Dyczewska K. Analysis of the impact of climate change on surface water quality in north-eastern Poland. Energies. 2022;15(1). https://doi.org/10.3390/en15010164.
62. Tutiempo Network SL. Climate Data - tutiempo.net. 2023. https://en.tutiempo.net/climate/ws-122700.html. Accessed 10 Mar 2025.
63. Rydel P. Lauks Rumian Wolny Chów Zwierząt, Rumian, Poland, Accessed 10 Mar 2025, source: https://www.lauksrumian.pl/
64. DEFRA. Condition scoring of beef suckler cows and heifers. 2001.
65. Wildman EE, Jones GM, Wagner PE, Boman RL, Troutt HF, Lesch TN. A dairy cow body condition scoring system and its relationship to selected production characteristics. J Dairy Sci. 1982;65(3):495–501. https://doi.org/10.3168/jds.S0022-0302(82)82223-6.
66. Przysucha T, Balcerak M, Gołebiewski M, Kunowska-Slósarz M, Slósarz J, Wnęk K. Comparison of recording results of purebred and crossbred limousine cattle in Poland. Ann Warsaw Univ Life Sci - SGGW - Anim Sci. 2018;57(1):67–75. https://doi.org/10.22630/aas.2018.57.1.6.
67. Fielder SE. Hematology Reference Ranges - MSD Manual Professional Edition. MSD Manual - Professional Version. 2022. https://www.msdvetmanual.com/special-subjects/reference-guides/hematology-reference-ranges. Accessed 10 Mar 2025.
68. Fielder SE. Serum Biochemical Analysis Reference Ranges - MSD Manual Professional Edition. MSD Manual - Professional Version. 2022. https://www.msdvetmanual.com/special-subjects/reference-guides/serum-biochemical-analysis-reference-ranges. Accessed 10 Mar 2025.
69. Jackson PGG, Cockcroft PD. Appendix 3: laboratory reference values: biochemistry. Clinical examination of farm animals. Oxford, UK.: Blackwell Science Ltd; 2007. pp. 303–5.
70. Frisch JE, Vercoe JE. Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilization in *Bos taurus* and *Bos indicus* crossbred cattle. Anim Sci. 1977;25(3):343–58. https://doi.org/10.1017/S0003356100016755.
71. Ledger HP, Rogerson A, Freeman GH. Further studies on the voluntary food intake of *Bos indicus, Bos Taurus* and crossbred cattle. Anim Sci. 1970;12(3):425–31. https://doi.org/10.1017/S000335610002897X.
72. Kong Z, Li B, Zhou C, He Q, Zheng Y, Tan Z. Comparative analysis of metabolic differences of Jersey cattle in different High-Altitude areas. Front Vet Sci. 2021;8. https://doi.org/10.3389/fvets.2021.713913.
73. Liu Z, Yan F, Mi H, Lv X, Wang K, Li B, et al. N-Carbamoylglutamate supplementation on the digestibility, rumen fermentation, milk quality, antioxidant parameters, and metabolites of Jersey cattle in High-Altitude areas. Front Vet Sci. 2022;9. https://doi.org/10.3389/fvets.2022.848912.
74. Averdunk G, Krogmeier D. Minor and dual-purpose bos taurus breeds. In: McSweeney PLH, McNamara JP, editors. Encyclopedia of dairy sciences. Third edit. Academic; 2021. pp. 116–22.
75. Perring MP, Cullen BR, Johnson IR, Hovenden MJ. Modelled effects of rising CO2 concentration and climate change on native perennial grass and sown grass-legume pastures. Clim Res. 2010;42(1):65–78. https://doi.org/10.3354/cr00863.
76. Gauly M, Bollwein H, Breves G, Brügemann K, Dänicke S, Daş G, et al. Future consequences and challenges for dairy cow production systems arising from climate change in central Europe - A review. Animal. 2013;7(5):843–59. https://doi.org/10.1017/S1751731112002352.
77. Konopiński T. Cattle breeding. Poznań: Instytut Naukowo-Wydawniczy Ruchu Ludowego „Polska; 1949.
78. Żukowski K. Polish red cattle: A scheme for their conservation. Anim Genet Resour Inf. 1990;7:71–6. https://doi.org/10.1017/s1014233900003035.
79. Negussie E, Rottmann OJ, Pirchner F, Rege JEO. Patterns of growth and partitioning of fat depots in tropical fat-tailed Menz and Horro sheep breeds. Meat Sci. 2003;64(4):491–8. https://doi.org/10.1016/S0309-1740(02)00227-9.
80. Ermias E, Yami A, Rege JEO. Fat deposition in tropical sheep as adaptive attribute to periodic feed fluctuation. J Anim Breed Genet. 2002;119(4):235–46. https://doi.org/10.1046/j.1439-0388.2002.00344.x.
81. Mirkena T, Duguma G, Haile A, Tibbo M, Okeyo AM, Wurzinger M, et al. Genetics of adaptation in domestic farm animals: A review. Livest Sci. 2010;132(1–3):1–12. https://doi.org/10.1016/j.livsci.2010.05.003.
82. Manninen M, Sankari S, Jauhiainen L, Kivinen T, Anttila P, Soveri T. Effects of outdoor winter housing and feeding level on performance and blood metabolites of suckler cows fed whole-crop barley silage. Livest Sci. 2008;115(2–3):179–94. https://doi.org/10.1016/j.livsci.2007.07.014.
83. Gaughan JB, Sejian V, Mader TL, Dunshea FR. Adaptation strategies: ruminants. Anim Front. 2019;9(1):47–53. https://doi.org/10.1093/af/vfy029.
84. Litwińczuk Z, Florek M, Domaradzki P, Żółkiewski P. Physicochemical properties of meat from young bulls of 3 native breeds: Polish red, White-Backed, and Polish Black-And-White, as well as of simmental and Polish Holstein-Friesian breeds. Food Sci Technol Qual. 2014;21(5):53–62. https://doi.org/10.15193/ZNTJ/2014/96/053-062.
85. Choroszy Z, Choroszy B. The possibility of using Polish red cattle for beef production, Możliwości Wykorzystania Bydła Rasy Polskiej Czerwonej do Produkcji Mięsa Wołowego. Wiadomości Zootech. 2005;R(2):73–8.
86. Wiśniewski K, Kuczyńska B, Comparative Studies of Reproductive and Meat Performance of The Local Breed of Polish Red Cattle against the Background of The Limousine Breed Of Polish And French Heritage. Folia Pomeranae Univ Technol Stetin Agric Aliment Piscaria Zootech. 2023;369(68):93–105. https://doi.org/10.21005/AAPZ2023.68.4.10.
87. Albertí P, Panea B, Sañudo C, Olleta JL, Ripoll G, Ertbjerg P, et al. Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. Livest Sci. 2008;114(1):19–30. https://doi.org/10.1016/j.livsci.2007.04.010.
88. Randby ÅT, Nørgaard P, Weisbjerg MR. Effect of increasing plant maturity in timothy-dominated grass silage on the performance of growing/finishing Norwegian red bulls. Grass Forage Sci. 2010;65(3):273–86. https://doi.org/10.1111/j.1365-2494.2010.00745.x
89. Baltušnikienė A, Jukna V. Impact of genotype on cattle growth, beef chemical composition and cholesterol level. Vet Ir Zootech Kaunas Liet Vet Akad. 2011;54(76):14–9.
90. Kozitcyna AI, Karpenko LY, Bakhta AA, Balykina AB, Enukashvili AI. Pregnant Cows and Heifers Blood Profile Comparison. In: Advances in Engineering Research, International scientific and practical conference Agro-SMART - Smart solutions for agriculture (Agro-SMART 2018). Tyumen, Russia; 2018. pp. 391–6.
91. Zhou Z, Loor JJ, Piccioli-Cappelli F, Librandi F, Lobley GE, Trevisi E. Circulating amino acids in blood plasma during the peripartal period in dairy cows with different liver functionality index. J Dairy Sci. 2016;99(3):2257–67. https://doi.org/10.3168/jds.2015-9805.
92. Rohn M, Tenhagen BA, Hofmann W. Survival of dairy cows after surgery to correct abomasal displacement: 1. Clinical and laboratory parameters and overall survival. J Vet Med Ser Physiol Pathol Clin Med. 2004;51(6):294–9. https://doi.org/10.1111/j.1439-0442.2004.00649.x.
93. González FD, Muiño R, Pereira V, Campos R, Benedito JL. Relationship among blood indicators of lipomobilization and hepatic function during early lactation in high-yielding dairy cows. J Vet Sci. 2011;12(3):251–5. https://doi.org/10.4142/jvs.2011.12.3.251.
94. Moreira CN, Souza SN, Barini AC, Araújo EG, Fioravanti MCS. Serum γ-glutamyltransferase activity as an indicator of chronic liver injury in cattle with no clinical signs. Arq Bras Med Vet E Zootec. 2012;64(6):1403–10. https://doi.org/10.1590/S0102-09352012000600001.
95. Fürll M. Stoffwechselkontrollen und Stoffwechselüberwachung Bei Rindern. Nutztierpraxis Actuell. 2004;9:8–17.

Publisher's note