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Short communications

Increased phenotypic diversity in the Icelandic goat breed following population expansion

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INTRODUCTION

The settlement of Iceland is dated to the period 870-930 CE, with ongoing debate on the chronology and process of settlement (Smith 1995, Vésteinsson & McGovern 2012). The Icelandic goat (*Capra hircus*) is believed to have been brought to Iceland during this period, with no evidence of later importation to the country (Adalsteinsson 1981). Since recording began, with the 1703 census of domestic animals, the population size has mostly been below one thousand but peaked at 2983 animals in 1930. The population twice declined to under 100 animals, in 1885 and 1962. After the 1962 bottleneck, concerns arose that the breed might go extinct, which led to subsidies starting in 1965 (Baldursdottir et al. 2012). After this, the population has grown and consisted of 1928 animals in 114 herds in 2024 (Ministry of food, agriculture and fisheries 2025).

In the mid-20th century Iceland was divided into isolation zones for the purpose of controlling the spread of sheep and goat diseases, which led to fragmentation and limited gene flow within the goat population (Thorbjarnarson et al. 2025, Baldursdottir et al. 2012). Fragmentation can increase inbreeding and reduce adaptability (Frankham et al. 2017, Pinto et al. 2024). The effects of inbreeding on the fitness of the Icelandic goat was estimated in 1994, revealing insignificant effects on fertility, litter size, and number of kids born alive (Stefán Aðalsteinsson et al. 1994). Analysis in 2006 showed the population to be highly fragmented, with a 10.5% population-wide average level of inbreeding, a 3% annual rate of inbreeding, and an effective population size of 5.1 animals (Baldursdottir et al. 2012). This led to increased subsidies, more emphasis on registration, and collection of semen to increase gene-flow between isolation zones. A more recent analysis of the population showed decreased inbreeding and increased genetic diversity (Thorbjarnarson et al. 2025).

One of the distinguishing features of Icelandic domestic populations is the lack of standardization in physical appearance, leading to mixed polled and horned phenotypes in cattle, sheep, and goats, and a multitude of colors and patterns in horses, sheep, cattle, goats, and dogs (Adalsteinsson 1981). Although the genetics of coat color and pattern in goats is not as well characterized as in many other domestic species, it is assumed the same loci play a major part (Cieslak et al. 2011, Eizirik & Trindade 2021). A crossbreeding experiment, which included the Icelandic goat, suggested that variation in colors and patterns might be explained by nine *Agouti* (*A*) alleles, two *Brown* (*B*) alleles, and two *Spotting* (*S*) alleles. Also, that the white/tan color is caused by a dominant *Agouti* allele (A^{Wt}), similar to that in sheep (Norris & Whan 2008) while

remaining *Agouti* alleles, such as "black mask" (A^{bm}) and "badger face" (A^{b}), are codominant (Adalsteinsson et al. 1994). Presence or absence of horns can be attributed to the action of two alleles, the dominant *P* (polled) and the recessive *p* (horned). Animals with scurs are heterozygous for the polled allele, and the inheritance is more complex and cannot be explained by a single locus (Simon et al. 2022, Zhang et al. 2024). Here we describe diversity in coat color and pattern in the Icelandic goat and show that following a population expansion and reduced inbreeding, coat color variation not previously recorded has emerged. Based on our analysis, we suggest that a more widespread and consistent recording by farmers is needed to safeguard the rarest coat colors, as some of the observed changes in coat color are more likely explained by inconsistent registration rather than actual changes in allele frequencies.

MATERIAL AND METHODS

Phenotypic analysis

Frequency of color/patterns and of the polled phenotype within the Icelandic goat was gathered from the herdbook 'HEIÐRÚN' (https://torg.bondi.is/ 31/10/2025) and compared to older data, preserved on paper at the Farmers Association. The Shannon diversity index (H'), calculated as $H' = -\Sigma\ p_i \times \ln(p_i)$ where p_i is the proportion of individuals in the i-th phenotype category, was used to quantify changes in frequency of color/patterns over time (Scherer et al. 2013, Scherer & Pallmann 2024, DeJong 1975). Data were in all cases for goats alive at the end of the year. Color/patterns were previously grouped into eight categories in the herdbook: white/tan, solid gray, badger face, and five groups of piebalds (black, gray, tan, brown, and red), but the emergence of brown piebald necessitated an expansion of the coat color scheme.

RESULTS AND DISCUSSION

Phenotypic diversity

Since the 1962 bottleneck, the Icelandic goat population has grown from 87 animals to 1928 animals in 2024 (Figure 1). For the current analysis, color/pattern information was available for 2581 goats and information about the horned/polled phenotype for 952 goats. The three most common colors/patterns in 2008 were black piebald, white/tan, and gray piebald, in that order (Figure 2A). In 2023 the three most common colors/patterns were black piebald, white/tan, and solid gray. The increase in solid gray, from 0.3% in 2008 to over 15% in 2023, is interesting. Especially as that color has never been verified in the Icelandic goat (Jóhanna Bergmann Þorvaldsdóttir, personal communication, November 2025). This is most likely explained by an incorrect recording of the gray piebald as solid gray, which would fit well with the decrease seen in the frequency of gray piebald in the same period (Figure 2A). Grouping the data according to years reveals

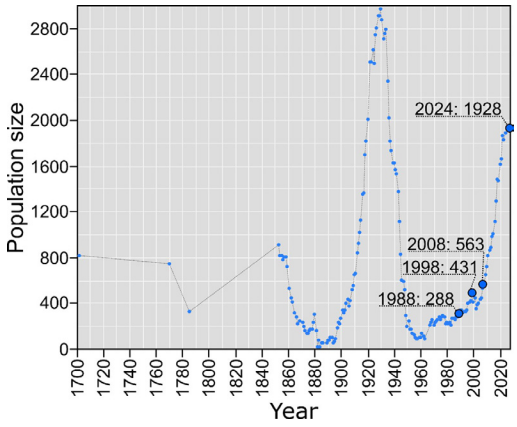

Figure 1. Changes in the Icelandic goat population from 1703 to 2024. Since recording began in 1703, the population size has fluctuated, with at least two severe bottlenecks. For a more detailed population analysis see Thorbjarnarson *et al*. (2025). The four timepoints analyzed are indicated with blue circles. The data are from a national census and the database 'HEIÐRÚN'.

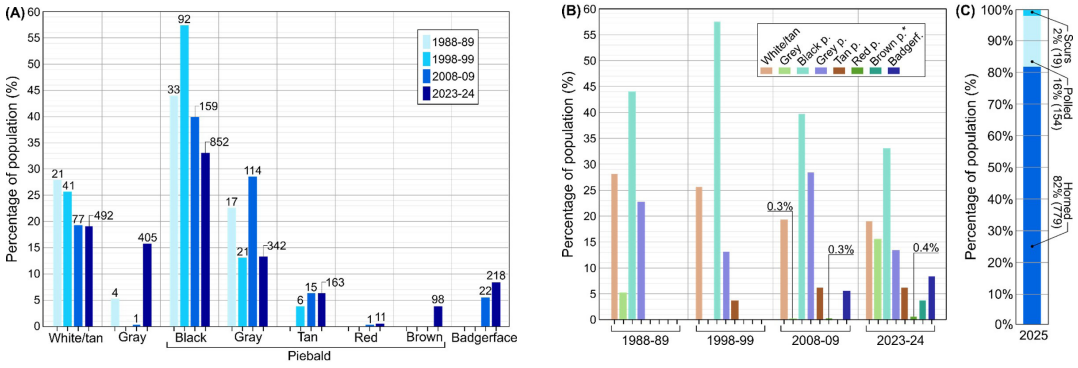

Figure 2. Phenotypic variation in the Icelandic goat. (**A**) Comparison of coat color/pattern variation in the Icelandic goat at four timepoints, with number of animals above columns. (**B**) Percentage of coat colors/patterns grouped by years. The data for the first three years previously reported in Baldursdóttir *et al.* (2012). (**C**) Percentage of goats that are horned, polled, and with scurs in 2025 (total number of animals in parentheses).

how the frequency of colors/patterns is getting more even over time (2B), with a Shannon Index (H') for the four periods being 1.21, 1.06, 1.40, and 1.77, respectively. Only a slight overlap was seen for the 95% CI for the first two timepoints.

In 1999 there were only three polled goats in Iceland (0.6%), all located on the Sólheimar farm (Southern Iceland). The goats were rescued from culling by the farmer at the Háafell farm (Western Iceland), but, to achieve this, the goats had to be vaccinated for paratuberculosis, and the new owner had to accept a ten-year prohibition of sale of goats (Jóhanna Bergmann Þorvaldsdóttir, personal communication, November 2025). In the winter 2008-2009 the total number of polled goats was 39 (6.9%), all at Háafell farm (Baldursdottir et al. 2012). In the 2024 census,779 goats (82%) were horned, 154 (16%) polled, and 19 (2%) had scurs (Figure 2C). The number of polled goats has increased considerably, as well as the badger face color pattern with tan that most often accompanies the polled phenotype, and they are now found on several farms.

Despite low estimates of genetic diversity (Thorbjarnarson et al. 2025, Baldursdottir et al. 2012), the Icelandic goat harbors considerable variation in phenotypes. This includes solid white/tan, four types of piebalds (black, gray, brown, and red), badger face, as well as white and black face stripes (Figure 3). The solid brown color, once found in the population, seems to have been lost at least two decades ago.

The results presented here show that the Icelandic goat breed harbors considerable phenotypic diversity, and we can still expect new phenotypes to appear in the breed, as evidenced by the emergence of brown piebald. This is not entirely surprising for recessive phenotypes that go undetected in populations when in low frequencies. Our analysis also underscores that more accuracy is needed for registration of phenotypes. Increased awareness of the importance of detailed records might prevent this misregistration from continuing.

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Figure 3. Examples of coat color and patterns observed in the Icelandic goat. **(A)** A herd in Möðrudalur (Northeast Iceland), showing white and black piebald goats. **(B)** A solid white doe and kid. **(C)** A black piebald doe. **(D)** Brown piebald buck. **(E)** Gray piebald doe with black piebald kid. **(F)** Red piebald kid. **(G)** Solid white kid. **(H)** Black piebald kid with white markings on legs and head. **(I)** Tan badger face polled kid. **(J)** Tan badger face doe with black and white stripes. **(K)** Solid white buck, badger face kid and black piebald doe. **(L)** Solid white doe and kid. **(M)** Solid white buck with four scurs. **(N)** Tan badger face polled doe. Photos by Birna Kristín Baldursdóttir and Jóhanna Bergmann Þorvaldsdóttir.

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