

## Beyond genetics: epigenetics!

How RUMIGEN explored why cattle with similar genetic level can perform differently

### EXECUTIVE SUMMARY

RUMIGEN explored whether epigenetics can help explain why cattle with similar genetic level perform differently. By developing and testing the EpiChip, the project showed that DNA methylation can reflect environmental effects and is linked to traits such as production, fertility and udder health. Epigenetics will not replace genomics, but it can add useful information for more resilient and balanced breeding.

### THE ISSUE

Modern animal breeding already uses genetic information very effectively. Genomic selection helps breeders predict which animals are more likely to pass on desirable traits, such as milk production, fertility, health, longevity or robustness. But genetics does not explain everything.

Animals with similar genetic potential can perform differently depending on their environment, management, nutrition, health status, heat exposure and early-life conditions. This is especially important for complex traits such as fertility, disease resistance, heat resilience and overall robustness. This is where epigenetics becomes relevant.

Epigenetics refers to biological mechanisms that influence how genes are switched on or off, without changing the DNA code itself. One of the most studied epigenetic mechanisms is DNA methylation. A simple way to explain it is this: DNA is like the instruction book, while methylation is one of the systems that helps decide which instructions are used more or less strongly in a given situation.

For livestock breeding, the central question is practical: can this extra layer of biological information help explain performance, resilience and adaptation?



## RUMIGEN contribution to solutions:

RUMIGEN approached epigenetics from several angles.

First, the project helped move epigenetics closer to practical use by developing and testing the **RUMIGEN EpiChip**. Until now, measuring DNA methylation across the genome has often been expensive and difficult to apply to large animal populations. The EpiChip was designed to make methylation profiling more standardised, high-throughput and cost-effective enough for breeding-related research. This is important because epigenetics only becomes useful for breeding if it can be measured in enough animals and linked to reliable performance records.

RUMIGEN then used this tool to study blood<sup>[1]</sup> DNA methylation in dairy cows. One study compared Jersey cows in Denmark and South Africa that shared a similar genetic background through common Danish sires. Genetically, the animals did not show a clear country separation. However, their blood methylation profiles showed a mild but visible separation between the two countries. This suggests that the environment can leave measurable marks on the animal's biological regulation, even when the genetic background is similar. This is a key message: the epigenome may help capture part of the animal's response to its living conditions.

In a second study, RUMIGEN analysed blood methylation data from a large group of Holstein cows across French farms. The cows had genomic data, methylation data and performance records for many traits. The analysis identified methylation marks associated with several traits and showed that epigenetic information could explain part of the variation in performance. This included traits related to milk production, fertility, udder health and body characteristics.

This does not mean that methylation alone can predict performance. But it does suggest that epigenetic information can help reduce the unexplained part of performance differences between animals.

RUMIGEN also studied the sperm epigenome of Holstein bulls. This was important because there is scientific interest in whether epigenetic marks in sperm can influence offspring performance. In the RUMIGEN dataset, the effect of the sire's sperm epigenome on daughter performance was very limited. The sperm epigenetic effects explained less than 0.4 percent of the variation in the daughter traits studied. However, it is still important to study the sperm epigenome. Indeed, RUMIGEN has shown that it represents a valuable source of male fertility biomarkers, that could be used to predict if an artificial insemination bull is subfertile. This is crucial since the birth of a calf and the production of milk both rely on successful artificial insemination. Finally, RUMIGEN studied the genetic control of DNA methylation in bull sperm. This showed that part of sperm methylation is itself influenced by the animal's genetic background. This matters because it helps distinguish between methylation patterns shaped by DNA and those that may be more strongly shaped by environment or life history.

*[1] Blood was used because it is a tissue that can be collected routinely at farms without altering the regular practices.*

## Applications and potential impact:

For breeding organisations, the main value of RUMIGEN's epigenetic work is that it adds a new layer of information to understand complex traits. Traits such as fertility, health, resilience and adaptation are influenced by many factors. Epigenetic information may help explain some of the variation that is not captured by genetics alone.

For farmers and advisors, the long-term potential is more indirect but still meaningful. As epigenetic approaches continue to improve, they could help identify animals that are better adapted to certain environments or management systems. They may also provide additional insights into how early-life conditions, heat stress, health challenges or nutrition influence later performance supporting more informed management and breeding decisions.

For researchers and breeding companies, the EpiChip is one of the most concrete outputs. It creates a practical route for measuring methylation in larger cattle populations. This could support future studies on resilience, fertility, health, heat stress adaptation, and precision livestock management.

For policymakers, the message is that climate adaptation in livestock should not only be seen through infrastructure or management. Breeding and biology also matter. Epigenetics can help reveal how animals respond to their environment and how management conditions may influence performance and welfare.

The work also supports a more balanced view of innovation. Epigenetics should not be oversold as a solution by itself. Its value lies in combination with genomic information, good phenotyping, environmental data and responsible breeding goals.

## Conclusions:

RUMIGEN shows that epigenetics can help explain part of the biological link between genes, environment and animal performance. The project provides evidence that DNA methylation patterns can reflect environmental conditions and can be associated with traits that matter for dairy cattle performance.

The most promising result is not that epigenetics will replace genetics. The real value is that epigenetics can complement existing breeding tools by helping researchers and breeding organisations better understand complex traits and environmental responses.

The next step is to test the potential of epigenetics on different traits, different breeds and wider populations, and continue developing practical, affordable and reliable tools such as the EpiChip, and to combine epigenetic information with genomic, performance and environmental data. In this way, epigenetics can support more balanced breeding programmes that aim not only for productivity, but also for fertility, health, resilience, welfare and better adaptation to future conditions.