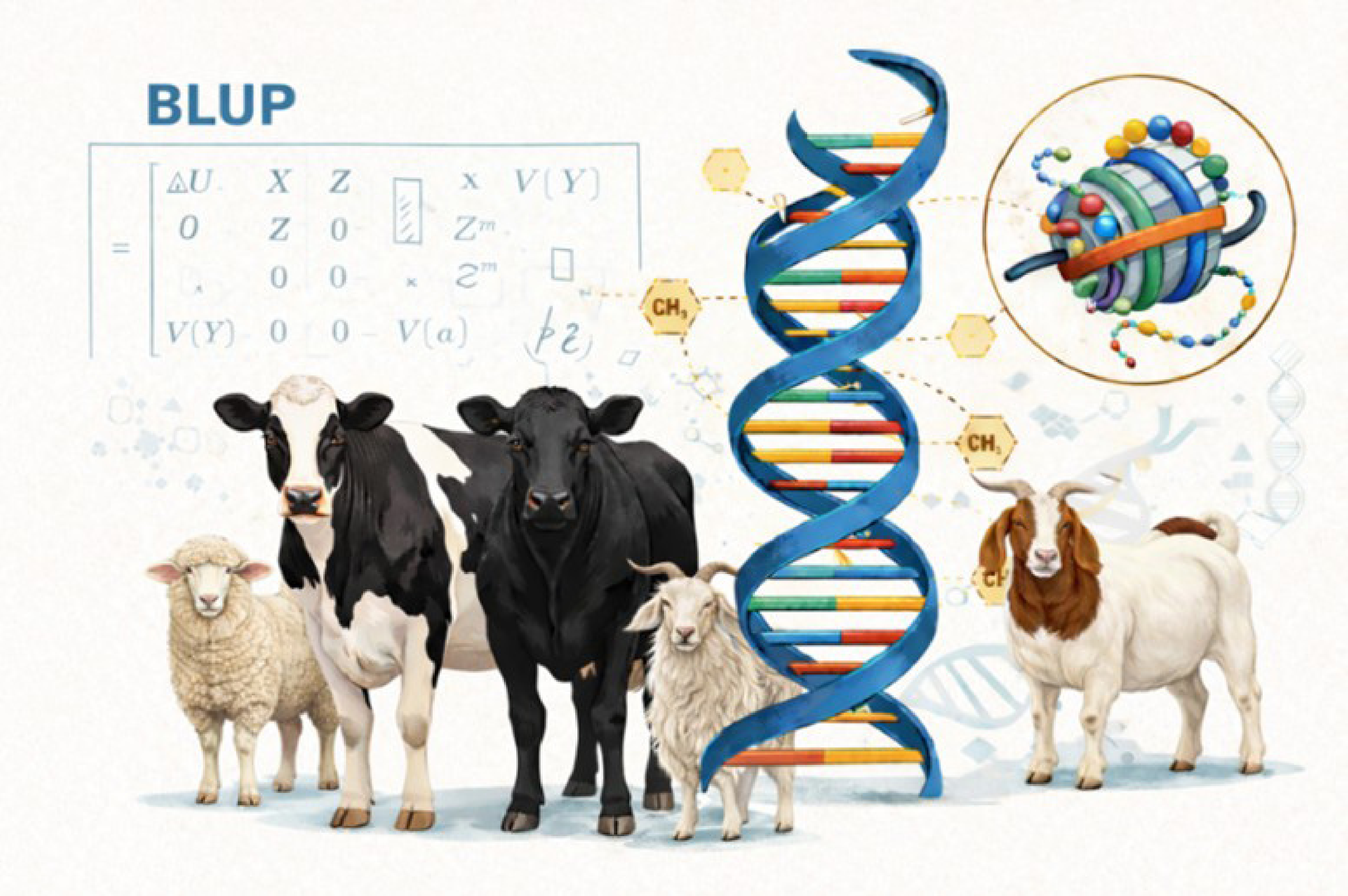


A balanced view on epigenetics in livestock

By Dr Japie van der Westhuizen

Epigenetics has become a buzzword in animal science, but it is often misunderstood. While the mechanisms are complex, the practical message is simple: Epigenetics influences how genes are expressed – not simply which genes animals carry.

For breeders, this distinction is crucial. What is important and will be shown is that the traditional and genomic BLUP systems already handle most (if not all) epigenetic effects exceptionally well, maintaining genetic accuracy. This is the case, even when environmental conditions distort an animal's phenotype (performance, reproduction or any other trait and expression).

What is epigenetics?

Epigenetics describes any changes in how genes are 'switched on or off' without changing the DNA sequence (the coding in the genome for genetic potential) itself.

These switches respond, to varying degrees, to environmental factors such as:

- Maternal nutrition.
- Stress.
- Environmental high temperature (and other climatic stressors).
- Disease exposure.
- Intake of toxins and mycotoxins.
- Mineral deficiencies.
- Colostrum transfer.
- Pasture quality.

Epigenetic changes are therefore particularly active **during pregnancy** (foetal programming) when organs, wool follicles, muscle fibres, and the immune system are formed. It is a critically important and often overlooked aspect in the management of pregnant females and its influence on the future performance of their offspring and even that of their grand progeny where the foetuses were female.

Why epigenetics matters

Epigenetics helps explain why two animals with similar genetics might perform differently when raised under different maternal or environmental conditions. Examples supported by research include:

Beef cattle

Gestational nutrition affects muscle fibre formation, immunity, fertility and carcass traits. Creep-feeding and/or early-life supplementation changes muscle methylation and improves weaning weight and marbling. Studies show that maternal stressors leave epigenetic marks in the foetus that later influence growth, immunity and resilience, this is linked to prenatal stressors, including thermal (heat) and undernutrition.

Dairy cattle

Heat stress in late gestation permanently reduces a daughter's milk yield and immunity. Studies show that dietary components such as methionine, lysine, choline, folate, and other micronutrients influence DNA methylation patterns that affect mammary gland gene expression and milk yield. Maternal nutrition during gestation and lactation can permanently alter epigenetic marks in offspring affecting milk production and composition later in life.

Optimising nutrients that serve as **methyl donors** (e.g., methionine) has been associated with changes in offspring gene expression favouring better immunity and metabolic efficiency – a beneficial epigenetic effect relevant to breeding outcomes. Nutrient-driven epigenetic modulation can modulate the expression of beneficial pathways related to immune function and health resilience in dairy cows.

Wool sheep

Mid-gestation nutrition affects lifetime wool follicle density. Late gestation nutrition through early post-natal life influences the expression of keratin and keratin-associated protein genes, with measurable effects on fibre diameter, staple strength and fleece growth. Heat stress or feed restriction during pregnancy induces epigenetic changes that reduce lamb birthweight, wool growth, and resilience.

Epigenetic regulation of immune-related genes contributes to variation in parasite resistance (e.g., *Haemonchus contortus*), helping explain why resilience can respond rapidly to management and selection beyond DNA sequencing alone.

Mohair and cashmere goats

DNA methylation regulates secondary hair follicle cycling, affecting fibre quality which is especially influenced during mid-gestation. Maternal under- and imbalanced nutrition can permanently reduce follicle density.

Cashmere growth is tightly linked to day length; melatonin signalling induces epigenetic regulation of follicle cycling genes. Nutrition during late gestation and early post-natal life modifies epigenetic regulation of keratin and keratin-associated protein (KAP) genes in skin, affecting fibre diameter, medullation, and staple characteristics in Angora goats. Nutritional or thermal stress during pregnancy leaves persistent epigenetic marks in foetal skin and endocrine tissues, leading to lower fibre yield, coarser fibres and reduced resilience later in life.

Meat sheep and goats

Maternal under-nutrition affects rumen development and growth, while epigenetic signatures support climate adaptation. The effects are similar to that in beef cattle.

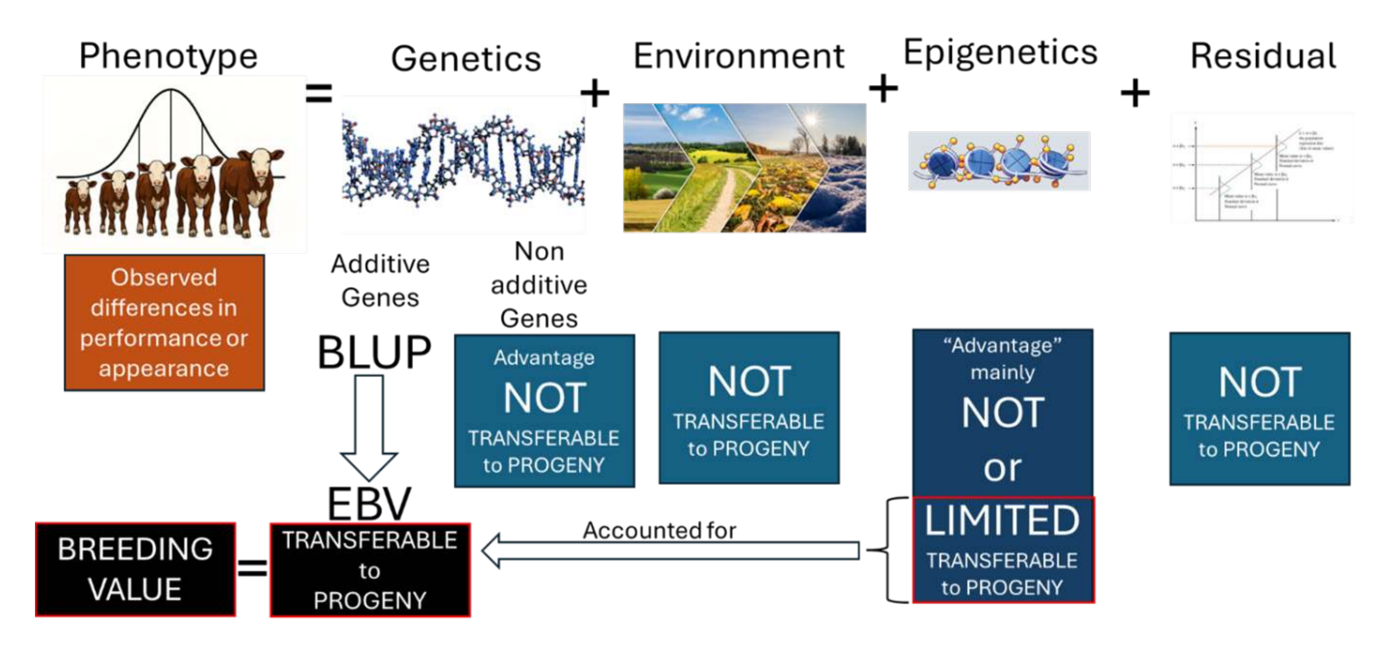
Key insights

Epigenetics, rather than DNA that breeders base their selection on, affects performance. Epigenetic effects may in certain cases alter performance, sometimes dramatically. However, they are mostly not heritable beyond one or two generations and are driven largely by environment, not genetics.

These facts are critical and beg the question: "Does this threaten genetic selection and distort BLUP breeding values?"

It is a common misunderstanding that epigenetics undermines breeding values. This is far from the truth because in reality the structure of BLUP is specifically designed to separate environmental effects ('noise'), including epigenetics, from true genetic merit. Even at a time when epigenetics might be on many sceptics' the lips, it is the unsung strength of BLUP methodology. BLUP compares animals within their contemporary groups and across relatives to separate true genetic merit from short-term, non-heritable influences, allowing accurate breeding values to be estimated even when performance is affected by environmental conditions (*Figure 1*).

Figure 1: Animal performance in beef cattle, dairy cattle, sheep and goats influenced by genetics, and environmental and epigenetic effects.



Contemporary group effects

The key to comparing the performance of animals remain their like-for-like performance against that of their peers, irrespective of the methodology used in the predictions. Animal performance is based on the genes that are expressed in that specific environment. It is therefore no surprise that BLUP estimated breeding values (EBVs) are, and have always been, based on how animals perform relative to their contemporaries – same farm, same season, same management group (e.g. camp, supplement, feeding regime, etc.).

This is powerful because:

- If gestational nutrition was poor, this will be the case for all the calves/lambs/kids in the same group, and they will be equally affected. BLUP treats this as an environmental effect, not as genetics.
- If heat stress at lambing leads to depressed growth, the entire group shifts equally, but rankings within the group remain accurate.
- If a drought year reduces milk production, BLUP will subtract the group effect automatically. Similarly, the ranking within the group is what matters.

IMPORTANT CONCEPT:

Epigenetics mostly acts **at group level**, and BLUP absorbs this effect cleanly.

Environmental noise

Even when epigenetic differences occur **within** a contemporary group (different responses from individual animals), BLUP treats them like any other environmental deviation. They do not distort breeding values unless they are repeated consistently across relatives. This means it only occurs within related animals (or genetic 'lines'). Any 'once-off' effect is absorbed as residual variance (non-explained variance in performance).

> **IMPORTANT CONCEPT:**
> BLUP focusses on **repeatable family patterns**, not temporary environmental variation.

An accurate picture

BLUP tracks relatives and therefore gives a much more accurate picture of true genetic differences among animals based on genetic variation and which are transferable across generations. Even if a calf or lamb underperforms, it may be due to epigenetic suppression (masking of its genes due to methylation):

- BLUP compares it to **parents, half-siblings, progeny, and extended relatives**.

This needs to be well-understood as BLUP not only makes use of the relative performance of individuals, but also takes every related family member's performance in their respective contemporary groups into account.

- The system recognises when poor or good performance is a one-time environmental result or only linked to one animal in the family and therefore not a genetic weakness or strength.

> **IMPORTANT CONCEPT:**
> A single weak calf from a good cow does not destroy the cow's breeding value, nor does a single outstanding calf suddenly make a poor cow a top breeder. The **family signal** remains intact because all relationships are considered and accounted for in BLUP breeding values.

Beyond the fold with gBLUP

Genomic BLUP or gBLUP refers to BLUP breeding values that are enhanced by the inclusion of genomic information (genetic code) in the predictions. gBLUP:

- Measures true genetic relationships among all genotyped animals directly.
- Increases accuracy of predicting the true genetic merit in young, not yet recorded animals.
- Therefore captures genetic potential masked by environmental noise even better.
- Reduces bias from unequal management or variable maternal conditions.
- Detects additive genetic merit (the breeding value) even when epigenetics might suppress or emphasise the phenotype (physical expression of the trait).

This makes gBLUP particularly powerful in herds with inconsistent management, drought stress, or varied nutritional conditions.

From noise to fair genetic values

Epigenetics may mask genetic potential, but BLUP uncovers the genetic ranking by comparing animals fairly within their (environment and treatment) groups. Breeders worldwide, across dairy, beef, mutton, wool, and mohair trust BLUP-based breeding values.

Given that the simple rules are followed, namely recording pedigrees and objective recordings of performance within properly defined contemporary groups, BLUP:

- Adjusts for environmental effects causing performance differences.
- Adjusts for management interventions or adaptations.
- Adjusts for epigenetic differences that might cause performance differences.
- Tracks genetic merit through family connections.
- Finds the underlying genetic signal.
- Ranks animals accurately for selection.

IMPORTANT CONCEPT:

BLUP doesn't need to know **why** performance differs. It only needs to know **when** and **where** animals differ. This simplicity is its power.

Practical take-home messages for breeders

- *Epigenetics is real* and might be important to a variable degree, especially in gestation, immune response, wool and mohair follicle development, early growth, and heat stress adaptation.
- *Manage pregnant females carefully.* Nutrition and stress avoidance pay off across the lifetime of offspring when breeding females are looked after, especially prior to and during pregnancy.
- *BLUP already protects your breeding programme from epigenetic distortions.* You can therefore select with confidence if you follow the rules of diligent recording and correctly defined contemporary groups.
- *gBLUP strengthens accuracy even further.* Strategic genotyping pays off and assists even better in accurate genetic predictions, especially in harsh climates, variable management conditions, or small contemporary groups.
- *Epigenetics explains biology but … BLUP preserves genetics.*

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