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AGE 306

INTRODUCTION TO ANIMAL BREEDING

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Course code: AGE 306

Course title: Introduction to Animal Breeding

Course credit load: 2 Units

Series 1: Basic Concepts of Animal Breeding

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Introduction

Animal breeding is the applied science concerned with improving the genetic merit of livestock populations for traits of economic importance. It draws on the principles of genetics, statistics, and reproductive biology to design programmes that increase animal productivity, efficiency, and adaptability over successive generations. The practice of animal breeding is as old as domestication itself, but the scientific foundation that underpins modern breeding has developed rapidly over the past century.

This Series introduces you to the foundational concepts of animal breeding. We begin by defining the discipline and tracing its historical development, then examine the key concepts of genotype, phenotype, heritability, and variation that underpin all breeding decisions. We proceed to the goals of breeding programmes, including the definition of breeding objectives and the calculation of genetic gain. The Series concludes by surveying the breeding priorities for cattle, small ruminants, pigs, and poultry in the Nigerian context.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- SLO 1.1 define animal breeding and describe its scope and importance in livestock production (Linked to Part 1.1),
- SLO 1.2 outline the historical development of animal breeding from traditional selection to modern genomics (Linked to Part 1.1),
- SLO 1.3 distinguish between genotype, phenotype, and environmental effects on livestock performance (Linked to Part 1.2),
- SLO 1.4 define heritability and explain its significance in breeding decisions (Linked to Part 1.2),
- SLO 1.5 describe the sources of genetic and phenotypic variation in livestock populations (Linked to Part 1.2),

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- SLO 1.6 explain how breeding objectives and economic traits are defined in livestock programmes (Linked to Part 1.3),
- SLO 1.7 describe the breeding cycle and the role of selection within it (Linked to Part 1.3),
- SLO 1.8 explain genetic gain and the factors that influence its rate (Linked to Part 1.3),
- SLO 1.9 describe the breeding priorities for cattle, small ruminants, pigs, and poultry in Nigeria (Linked to Part 1.4), and
- SLO 1.10 evaluate the contribution of animal breeding to food security and agricultural development in Nigeria (Linked to Part 1.1, Part 1.4).

1.1 Definition, Scope, and Importance of Animal Breeding

1.1.1 Definition and scope of animal breeding

Animal breeding is the science and practice of changing the genetic composition of livestock populations through controlled mating, selection, and other reproductive interventions to improve economically important traits over successive generations. It is distinguished from animal husbandry in that it focuses specifically on the genetic component of animal performance rather than the environmental management of individual animals. The scope of animal breeding encompasses **population genetics** (the study of gene frequencies and how they change), **quantitative genetics** (the analysis of continuously varying traits such as milk yield and growth rate), and **reproductive technology** (methods such as AI and embryo transfer that multiply the use of superior genetics).

Modern animal breeding also incorporates molecular genetics and genomics, which allow direct measurement of an animal's DNA to predict its genetic merit for production traits without waiting for offspring performance. This development has dramatically accelerated genetic improvement in dairy cattle, pigs, and poultry worldwide. In Nigeria, the application of these tools remains limited, but the foundational principles of selection, mating systems, and performance recording that underpin advanced breeding are directly applicable to smallholder and commercial livestock systems at any scale.

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Fill in the blank: The branch of breeding science that analyses continuously varying traits such as milk yield is called _____ genetics.

1.1.2 Historical development of animal breeding

The history of animal breeding begins with the domestication of livestock approximately 10,000 years ago, when early farmers began selecting the most tractable, productive, and reproductively prolific animals for continued breeding. This empirical selection, based entirely on observable traits without any understanding of heredity, gradually shaped the domesticated breeds we recognise today. The work of Robert Bakewell in 18th-century England, who systematically improved Longhorn cattle and Leicester sheep through rigorous selection and inbreeding, is considered the first scientifically deliberate livestock improvement programme.

Gregor Mendel's discovery of the laws of inheritance in 1866 laid the genetic foundation for modern breeding. The early 20th century saw the development of **quantitative genetics** by Ronald Fisher, Sewall Wright, and J.B.S. Haldane, who showed that the inheritance of continuously varying traits could be explained by many genes each with small effects. The introduction of **artificial insemination (AI)** in the mid-20th century allowed a single superior sire to produce hundreds of thousands of offspring, transforming dairy cattle improvement globally. The sequencing of livestock genomes in the early 21st century and the development of **genomic selection** have further revolutionised the speed and accuracy of genetic evaluation.

Fill in the blank: The first scientifically deliberate livestock improvement programme was conducted by _____ Bakewell in 18th-century England.

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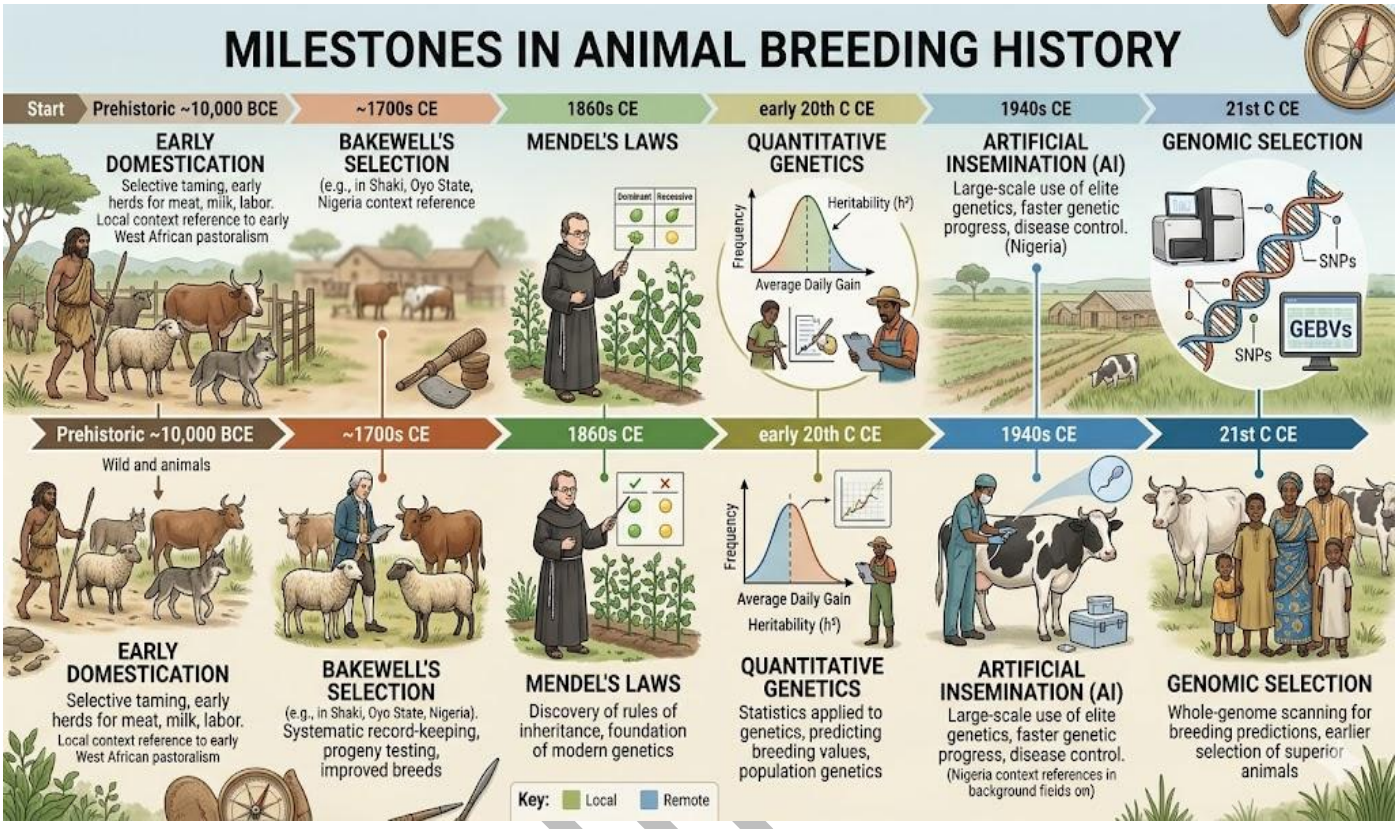

Figure 1.1: Key milestones in the history of animal breeding

1.1.3 Importance of animal breeding in livestock production

Animal breeding contributes to livestock production by permanently and cumulatively improving the genetic potential of animals for economically important traits. Unlike management improvements, which must be paid for repeatedly each generation, genetic gains achieved through selection are retained and accumulate over time without additional cost. In the dairy industry, genetic improvement through AI programmes has been responsible for a doubling of milk yield per cow over the past 50 years in developed countries, reducing the cost of production per litre and improving farm profitability.

In Nigeria, animal breeding is important for improving the productivity of indigenous livestock breeds that are well adapted to tropical conditions but produce at low levels. By selecting the best-performing animals within local breeds and, where appropriate, introducing exotic genetics through crossbreeding, producers can increase milk yields, growth rates, feed conversion

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efficiency, and reproductive performance. These improvements directly contribute to household food security, income generation, and the national agricultural development agenda.

Fill in the blank: Unlike management improvements, genetic gains from selection are _____ and accumulate over time without additional cost.

Pilot questions 1.1

1. Define animal breeding and distinguish it from animal husbandry.
2. Name the three main branches of science that constitute the scope of animal breeding.
3. Describe the contribution of Robert Bakewell to the development of animal breeding.
4. Explain how artificial insemination transformed genetic improvement in the 20th century.
5. State three ways in which animal breeding contributes to livestock production in Nigeria.

1.2 Key Concepts in Animal Breeding

1.2.1 Genotype, phenotype, and the environment

The **genotype** of an animal is the complete set of genes it carries, inherited from its parents. The **phenotype** is the observable or measurable expression of those genes, such as body weight, milk yield, coat colour, or litter size. The relationship between genotype and phenotype is not one-to-one: the same genotype can produce different phenotypes depending on the environment in which the animal is raised. The basic model is: **Phenotype = Genotype + Environment + Genotype x Environment interaction**. This model reminds breeders that the performance they observe is a product of both genetic and non-genetic influences.

The environment includes all non-genetic factors that influence performance: feeding level and diet quality, housing, climate, disease pressure, management, and the age and parity of the

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animal. Because breeders aim to change only the genetic component of performance, they must correct for environmental effects when comparing animals for selection purposes. Failure to account for environmental differences leads to incorrect ranking of animals and poor selection decisions. This is the reason why performance recording and statistical adjustment for environmental effects are prerequisites for any credible breeding programme.

Fill in the blank: The observable expression of an animal's genes, influenced by the environment, is called its _____.

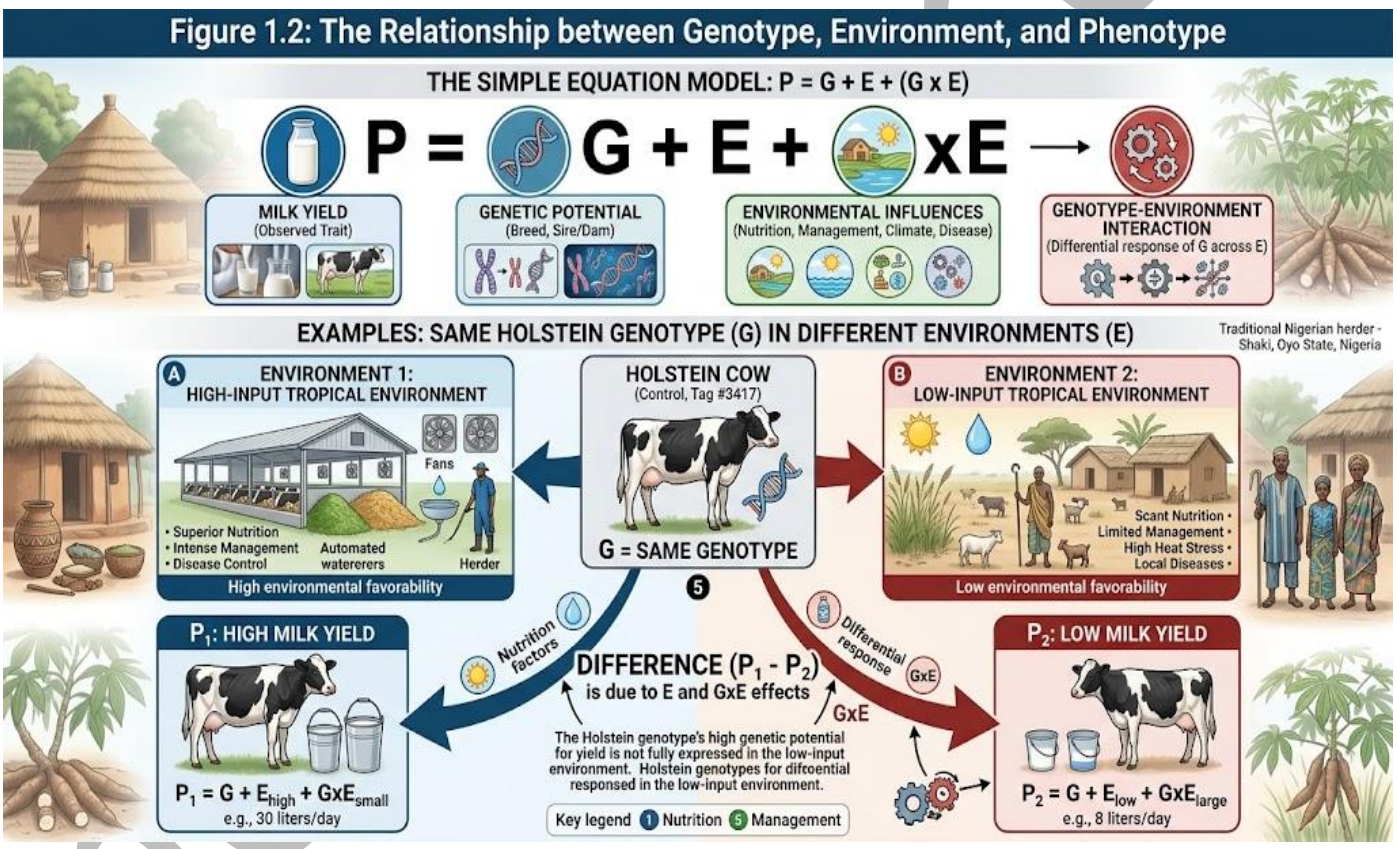

Figure 1.2: The relationship between genotype, environment, and phenotype

1.2.2 Heritability and its significance

Heritability (h2) is the proportion of the total phenotypic variation in a trait that is due to additive genetic differences among individuals. It ranges from 0 (none of the variation is genetic) to 1 (all variation is genetic). A trait with high heritability, such as carcass fat percentage (h2 = 0.40 to 0.60), responds rapidly to individual selection because the phenotype is a good predictor

of the underlying genetic value. A trait with low heritability, such as litter size in pigs ($h^2 = 0.10$ to 0.15) or conception rate ($h^2 = 0.01$ to 0.05), responds slowly to individual selection because much of the phenotypic variation is due to environment rather than genetics.

Heritability is important in breeding because it determines the most effective selection strategy for a given trait. For low-heritability traits, family selection or progeny testing is more effective than individual selection, because averaging the performance of many relatives provides a more accurate estimate of an individual's genetic value than its own record alone. Heritability also enables the prediction of response to selection: the expected response per generation equals the heritability multiplied by the selection differential applied. Understanding heritability therefore allows breeders to set realistic expectations for genetic improvement.

Fill in the blank: Heritability is the proportion of phenotypic variation that is due to _____ genetic differences among individuals.

1.2.3 Genetic and phenotypic variation in livestock

Variation is the raw material on which selection acts: without differences among individuals, there is nothing to select. **Phenotypic variation** is the total variation observed in a measured trait and is composed of **genetic variation** (differences due to genes) and **environmental variation** (differences due to non-genetic factors). Genetic variation is further partitioned into **additive genetic variance** (due to the average effects of individual alleles, which is inherited and responded to by selection), **dominance variance** (due to interactions between alleles at the same locus), and **epistatic variance** (due to interactions between alleles at different loci). Only additive genetic variance is directly exploited by mass selection.

The sources of genetic variation in livestock include spontaneous mutation (new alleles arising in the DNA), recombination during meiosis (new combinations of existing alleles), and migration of animals between populations. In practical breeding, maintaining adequate genetic diversity within a population is important to avoid inbreeding depression and to retain the flexibility to

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respond to future selection pressures. The breeding value of an individual is its expected genetic contribution to offspring performance, estimated from its own phenotype and that of its relatives.

Fill in the blank: The component of genetic variation that is directly exploited by mass selection is called _____ genetic variance.

Component	Definition	Response to Selection
Additive genetic variance (VA)	Effects of individual alleles summed across loci	Directly transmitted to offspring; main driver of genetic gain
Dominance variance (VD)	Interaction between alleles at the same locus	Not predictably inherited; limited response to selection
Epistatic variance (VI)	Interaction between alleles at different loci	Complex inheritance; contributes to trait variation but less exploitable
Permanent environmental variance (VEp)	Long-term non-genetic influences (e.g., early nutrition, disease history)	Not heritable; affects lifetime performance but not genetic progress
Temporary environmental variance (VEt)	Short-term factors (e.g., weather, feed fluctuations)	Random, non-heritable; adds noise to trait measurement

Box 1.1: Components of phenotypic variation in livestock traits

Pilot questions 1.2

1. Distinguish between genotype and phenotype, and write the basic model that relates them.
2. Explain why performance recording and correction for environmental effects are essential in breeding programmes.
3. Define heritability and explain what a heritability of 0.40 means for a trait.
4. Why is individual selection less effective for traits with low heritability?
5. Name the three components of genetic variation and state which one responds directly to selection.

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1.3 Goals and Criteria of Animal Breeding

1.3.1 Breeding objectives and economic traits

A **breeding objective** is a precise definition of the traits to be improved and the direction of desired change (increase or decrease), weighted by their relative economic importance. Breeding objectives are derived from the production system and market context: a dairy breeding objective might include increasing milk fat and protein yield while maintaining body condition and reproductive efficiency. An **economic trait** is any trait that affects the profitability of the livestock enterprise, either by increasing revenue (such as milk yield, growth rate, or litter size) or by reducing costs (such as feed conversion efficiency, disease resistance, or longevity).

The relative economic value of each trait in the breeding objective is expressed as the change in profit per unit improvement in the trait, holding all other traits constant. These economic weights are combined into an aggregate breeding value or selection index, which ranks animals according to their total economic merit rather than performance on a single trait. In Nigeria, breeding objectives for local cattle might prioritise trypanotolerance and heat tolerance alongside growth rate, reflecting the specific production constraints of the tropical environment.

Fill in the blank: The combination of breeding objective traits weighted by their economic importance and used to rank animals is called a selection _____.

1.3.2 Selection and the breeding cycle

Selection is the process of choosing which animals in a population will be used as parents for the next generation. Animals with superior genetic merit for the traits in the breeding objective are preferentially selected for breeding, increasing the frequency of favourable alleles in the offspring population. The **selection differential (S)** is the difference between the average performance of selected parents and the average performance of the population from which they were chosen. A larger selection differential results in greater genetic improvement per generation.

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The breeding cycle encompasses the sequence of events from the selection of parents, through mating and the production of offspring, to the assessment of offspring performance and the selection of the next generation of parents. The length of the generation interval, defined as the average age of parents when their offspring are born, directly affects the annual rate of genetic gain: shorter generation intervals allow more selection cycles per year and thus faster improvement. In poultry, generation intervals of about one year enable very rapid genetic progress; in cattle, generation intervals of four to six years slow the rate of improvement considerably.

Fill in the blank: The difference between the average performance of selected parents and the population average is called the selection _____.

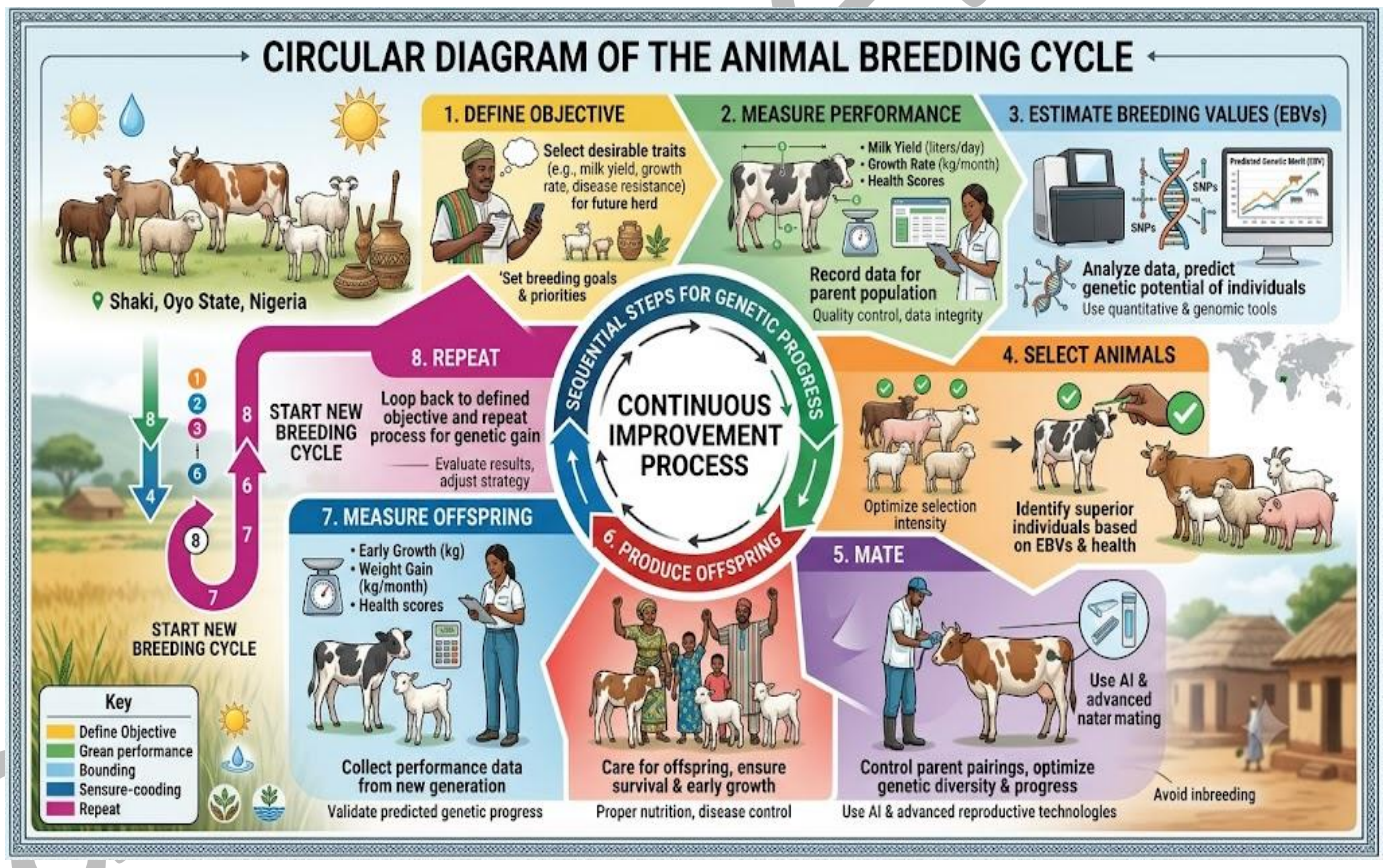

Figure 1.3: The animal breeding cycle

1.3.3 Genetic gain and factors affecting it

Genetic gain (**DG**) per year is the standard measure of the effectiveness of a breeding programme. It is calculated using the breeder's equation:

DG per year = (h2 x S) / L

where **h2** is heritability, **S** is the selection differential, and **L** is the generation interval in years. This equation shows that genetic gain is increased by selecting for traits with high heritability, applying intense selection (large S by selecting few but superior parents), and shortening the generation interval. In practice, these factors interact: selecting more intensely often means keeping fewer replacement females, which can shorten the generation interval but may also reduce genetic diversity.

Accuracy of selection, which is the correlation between the true breeding value and the estimated breeding value used for selection, is an additional factor not explicit in the simplified equation above. High accuracy is achieved by using large amounts of performance data on the candidate and its relatives. Genomic selection achieves high accuracy at young ages by using DNA information, which is why it has enabled a dramatic reduction in generation intervals in dairy cattle from six to about two years, more than tripling the annual rate of genetic gain.

Fill in the blank: In the breeder's equation, L represents the _____ interval.

Factor	Definition	Effect on Genetic Gain	Improvement Strategy
Heritability (h2)	Proportion of phenotypic variance due to additive genetic variance	Higher heritability → greater response to selection	Improve trait measurement accuracy; reduce environmental noise
Selection Differential (S)	Difference between mean of selected parents and population mean	Larger differential → greater genetic gain	Apply intense selection; choose top-performing individuals

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Generation Interval (L)	Average age of parents when offspring are born	Shorter interval → faster genetic progress per year	Use early selection, reproductive technologies (AI, embryo transfer)
Accuracy of Selection (r)	Correlation between true breeding value and estimated breeding value	Higher accuracy → more reliable genetic gain	Use genomic selection, better performance recording, advanced statistical models

Table 1.1: Factors affecting the rate of genetic gain in livestock breeding programmes

Pilot questions 1.3

6. Define a breeding objective and explain why economic weights are assigned to traits.
7. What is a selection index and why is it preferred over selecting on a single trait?
8. Define the selection differential and explain how it is increased in practice.
9. Write the breeder's equation for genetic gain per year and explain each term.
10. Explain how genomic selection has increased the annual rate of genetic gain in dairy cattle.

1.4 Overview of Livestock Species and Their Breeding Priorities

1.4.1 Cattle breeding priorities in Nigeria

Nigerian cattle production serves both beef and dairy markets, and breeding priorities differ between these two systems. For beef production, the primary breeding objectives are growth rate (daily gain from weaning to market weight), feed conversion efficiency, and carcass quality (dressing percentage and lean:fat ratio). Equally important are adaptation traits: trypanotolerance in the humid Middle Belt and south, heat tolerance throughout the country, and tick and disease resistance, all of which affect the cost of production and survivability under extensive management.

For dairy production, the primary breeding objective is milk yield (litres per lactation), with secondary emphasis on milk composition (fat and protein percentage), udder health (low somatic

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cell count), fertility (short calving interval), and longevity. The practical strategy for most Nigerian dairy producers is to use Friesian or Friesian-Bunaji crossbreds in peri-urban intensive systems, selecting within this crossbred population for milk yield while maintaining the heat tolerance of the local Bunaji component. Performance recording of milk yields by dairy cooperatives and government multiplication centres is the essential first step toward organised genetic improvement in Nigerian cattle.

Fill in the blank: For Nigerian dairy cattle, the primary breeding objective trait is _____ yield per lactation.

1.4.2 Small ruminant and pig breeding priorities

For sheep and goats, breeding priorities in Nigeria centre on growth rate (live weight at weaning and at market age), prolificacy (litter size and kidding or lambing interval), and adaptation to local environments. The Red Sokoto goat has additional breeding priorities around skin quality, as its hide commands high international leather market prices. Crossbreeding of local WAD sheep and goats with more productive exotic breeds such as Saanen (dairy goats) or Dorper (meat sheep) has been explored, but maintaining trypanotolerance and heat tolerance in the offspring is essential for humid zone production.

For pigs, the main breeding priorities are litter size (number born alive), pre-weaning survival, post-weaning growth rate, feed conversion ratio, and carcass lean percentage. Commercial pig production in Nigeria relies primarily on exotic Large White and Landrace breeds and their crosses, which have been genetically improved over many generations for these traits. The challenge is maintaining adequate performance in the hot, humid Nigerian climate, which significantly reduces voluntary feed intake and growth rates in breeds selected under temperate conditions. Heat-tolerance traits are therefore increasingly included in Nigerian pig breeding objectives.

Fill in the blank: In pig breeding, the efficiency of converting feed into body weight is measured by the feed _____ ratio.

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Species	Primary Production Traits	Adaptation Traits	Main Breeding Strategy
Beef cattle	Growth rate, carcass quality, feed efficiency	Heat tolerance, tick resistance, disease resilience	Crossbreeding indigenous × exotic breeds; selection within local breeds
Dairy cattle	Milk yield, fat and protein content, lactation length	Adaptation to tropical climate, disease resistance	Crossbreeding (Friesian × local breeds); upgrading programs
Sheep and goats	Meat yield, milk (goats), prolificacy	Tolerance to parasites, drought resilience	Selection within indigenous breeds; community-based breeding programs
Pigs	Growth rate, litter size, feed conversion efficiency	Adaptation to local feed resources, disease resistance	Crossbreeding with exotic breeds; nucleus herd selection

Table 1.2: Breeding priorities for major livestock species in Nigeria

1.4.3 Poultry breeding priorities and commercial application

Commercial poultry breeding in Nigeria and globally is dominated by a small number of multinational breeding companies that operate sophisticated closed nucleus flocks with populations of hundreds of thousands of birds. Breeding objectives for broilers focus on growth rate (body weight at 42 days), feed conversion ratio, breast meat yield, and livability. For layers, objectives centre on egg number per hen housed, egg weight, shell quality, feed efficiency, and viability. The generation interval in poultry is approximately one year, enabling rapid genetic progress.

Because commercial poultry genetics are supplied as day-old chicks or hatching eggs from parent stock, most Nigerian poultry farmers do not conduct their own genetic improvement but instead purchase improved stock from hatcheries. The breeding work is done entirely at the nucleus and multiplier levels of the pyramid breeding structure. Understanding the principles behind this system, however, helps producers choose appropriate strains for their conditions,

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interpret strain performance data, and appreciate the genetic basis of the performance differences between commercial lines and local ecotypes.

Fill in the blank: In commercial broiler breeding, one of the primary objectives is increasing _____ meat yield.

Pilot questions 1.4

1. State the primary breeding objectives for beef cattle production in Nigeria.
2. Why is trypanotolerance an important breeding trait for cattle in the Nigerian Middle Belt?
3. Describe the breeding priorities for pigs in Nigeria and explain why heat tolerance is increasingly included.
4. Explain the pyramid breeding structure used in commercial poultry production.
5. Why do most Nigerian poultry farmers not conduct their own genetic improvement programmes?

Series Summary

This Series has introduced you to the foundational concepts of animal breeding. We began by defining animal breeding, tracing its historical development from Bakewell's empirical selection through Mendel's laws, quantitative genetics, the AI revolution, and modern genomic selection, and explaining its importance for livestock productivity in Nigeria. We then examined the key concepts of genotype, phenotype, heritability, and genetic and phenotypic variation, establishing the genetic framework within which all breeding decisions are made.

We proceeded to explore breeding objectives, the selection differential, the breeding cycle, and the factors that determine the rate of genetic gain. The breeder's equation, which relates genetic gain to heritability, selection intensity, and generation interval, was presented as the central tool for planning and evaluating breeding programmes. The Series concluded with a survey of breeding priorities for cattle, small ruminants, pigs, and poultry in Nigeria, illustrating how the

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principles introduced in this Series are applied in each species context. Together, these concepts provide the foundation for all subsequent topics in this course.

Glossary of Terms

- **Additive genetic variance:** The component of genetic variation due to the average effects of individual alleles, which is transmitted to offspring and directly exploited by selection.
- **Animal breeding:** The science and practice of changing the genetic composition of livestock populations through selection and mating to improve economically important traits.
- **Breeding objective:** A precise definition of the traits to be improved in a livestock population, weighted by their relative economic importance.
- **Breeding value:** The expected genetic contribution of an individual animal to the performance of its offspring, estimated from the animal's own performance and that of its relatives.
- **Environmental effect:** Any non-genetic factor, such as feeding level, climate, or management, that influences the phenotypic performance of an animal.
- **Generation interval:** The average age of parents when their offspring are born, which determines how many selection cycles can be completed per year.
- **Genetic gain (DG):** The improvement in the average genetic merit of a population per year, calculated using the breeder's equation as h2 x S divided by L.
- **Genomic selection:** A form of selection that uses dense DNA marker information across the entire genome to estimate breeding values at young ages with high accuracy.
- **Genotype:** The complete genetic constitution of an individual, comprising the alleles inherited from both parents at all gene loci.
- **Heritability (h2):** The proportion of phenotypic variation in a trait that is attributable to additive genetic differences among individuals in a population.
- **Phenotype:** The observable or measurable expression of an animal's genotype as modified by the environment, such as body weight, milk yield, or coat colour.

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- **Quantitative genetics:** The branch of genetics that explains the inheritance of continuously varying traits controlled by many genes, each contributing a small effect.
- **Selection:** The process of choosing which animals in a population will contribute offspring to the next generation, preferentially using individuals with superior genetic merit.
- **Selection differential (S):** The difference between the average performance of selected parents and the average performance of the population from which they were chosen.
- **Selection index:** A weighted combination of breeding objective traits that ranks animals by their total economic merit rather than performance on any single trait.

Concept Check Questions [Series 1]

Objective Questions

1. Define animal breeding. (Linked to SLO 1.1)
2. Which of the following traits has the highest heritability? a) Conception rate (h2 = 0.02) b) Litter size in pigs (h2 = 0.12) c) Carcass lean percentage (h2 = 0.50) d) Milk yield (h2 = 0.25) (Linked to SLO 1.4)
3. The annual rate of genetic gain is increased by: a) Lengthening the generation interval b) Reducing the selection differential c) Shortening the generation interval d) Reducing heritability (Linked to SLO 1.8)
4. The component of genetic variation directly exploited by mass selection is called _____ genetic variance. (Linked to SLO 1.5)
5. The difference between the average performance of selected parents and the population average is called the selection _____. (Linked to SLO 1.7)

Short Answer Questions

6. Distinguish between genotype and phenotype and write the basic model that relates them to environmental effects. (Linked to SLO 1.3)

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7. Explain what heritability measures and state its significance for choosing a selection strategy. (Linked to SLO 1.4)
8. State the breeder's equation for genetic gain per year and explain each component. (Linked to SLO 1.8)
9. Describe two breeding priorities specific to Nigerian cattle production that differ from those in temperate countries. (Linked to SLO 1.9)
10. Explain why most Nigerian poultry farmers purchase improved genetics rather than conducting their own breeding programmes. (Linked to SLO 1.9)

Long Answer Questions

11. Trace the historical development of animal breeding from early domestication to genomic selection, and evaluate its contribution to livestock productivity in Nigeria. (Linked to SLO 1.1, SLO 1.2, SLO 1.10)
12. Explain the concepts of genotype, phenotype, heritability, and genetic variation, and describe how these concepts guide the design of a livestock breeding programme. (Linked to SLO 1.3, SLO 1.4, SLO 1.5)
13. Describe the factors that determine the rate of genetic gain in a livestock breeding programme and discuss how each factor can be optimised in the context of cattle or small ruminant production in Nigeria. (Linked to SLO 1.6, SLO 1.7, SLO 1.8)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. Animal breeding is the science and practice of changing the genetic composition of livestock populations through selection and controlled mating to improve economically important traits over successive generations.
2. Correct answer: c) Carcass lean percentage (h2 = 0.50).

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3. Correct answer: c) Shortening the generation interval.
4. Additive.
5. Differential.

Short Answer Questions

6. Genotype is the animal's genetic constitution, while phenotype is the observable expression of that genotype as modified by the environment. The basic model is: Phenotype = Genotype + Environment + Genotype x Environment interaction.
7. Heritability measures the proportion of phenotypic variation due to additive genetic differences. A high h2 (above 0.30) means individual performance is a good predictor of breeding value, so individual mass selection is effective. A low h2 (below 0.15) means family or progeny testing is needed for accurate selection.
8. The breeder's equation is: DG per year = (h2 x S) / L. h2 is heritability (proportion of phenotypic variation that is genetic), S is the selection differential (superiority of selected parents over the population average), and L is the generation interval in years.
9. Two Nigerian-specific priorities are: trypanotolerance, which enables cattle to survive and produce in tsetse-infested areas of the Middle Belt and south; and heat tolerance, which maintains feed intake, growth, and reproduction under high ambient temperatures found throughout the country.
10. Nigerian poultry farmers purchase day-old chicks or hatching eggs from hatcheries supplied by multinational breeding companies. These companies operate highly specialised closed nucleus flocks requiring millions of birds, sophisticated genetic evaluation technology, and decades of accumulated genetic progress that individual farmers cannot replicate.

Long Answer Questions

11. Basic response: Animal breeding began with empirical selection at domestication (10,000 BC), advanced with Bakewell's systematic selection (18th century), gained a scientific basis from Mendel (1866) and quantitative genetics (1920s), was transformed by AI (1950s), and now uses genomic selection (2000s). In Nigeria, breeding improves indigenous breeds for productivity while maintaining adaptation.

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12. Value-added response: Each historical development built on the previous: Mendel explained single-gene traits; quantitative genetics extended this to multi-gene traits; AI allowed rapid dissemination of superior genetics; genomics allows selection before offspring performance is observed. For Nigeria, the most immediately applicable advances are AI programmes using locally evaluated sires, performance recording systems, and crossbreeding strategies that exploit heterosis while preserving local breed adaptation. Long-term, genomic tools could accelerate improvement in indigenous breeds if genotype-by-environment interactions are properly characterised.

13. Basic response: Genotype is the genetic constitution; phenotype equals genotype plus environment. Heritability ranges from 0 to 1 and determines whether individual or family selection is more effective. Additive genetic variance is the portion of genetic variation that responds to selection.

14. Value-added response: For breeding programme design, knowing h2 for each trait guides selection method choice. Traits like growth rate (h2 about 0.30 to 0.40) respond well to individual selection, while fertility traits (h2 about 0.02 to 0.05) require progeny testing or genetic marker assistance. Environmental correction is essential: comparing animals from different farms without adjustment for feeding level will confound genetic and environmental effects, leading to wrong selection decisions and slow genetic progress.

15. Basic response: Genetic gain per year = (h2 x S) / L. It increases with higher heritability, larger selection differential (more intense selection), and shorter generation interval. Accuracy of selection also contributes. Genomic selection achieves high accuracy at young age, shortening generation interval from six to two years in dairy cattle.

16. Value-added response: In Nigerian cattle, generation intervals are long (four to six years) and selection differentials are small because of inadequate performance recording. The priority actions are: establish milk recording and weight recording systems to provide data for genetic evaluation; use AI with proven bulls to increase selection differential on the sire path; and cull unproductive cows to maintain selection pressure on the dam path. For small ruminants, prolificacy (h2 about 0.10) requires large progeny groups for accurate sire evaluation, which can be organised through village-level recording cooperatives at relatively low cost.

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Answers to Pilot Questions [Series 1]

Part 1.1: Definition, Scope, and Importance of Animal Breeding

1. Animal breeding is the science and practice of changing the genetic composition of livestock through selection and mating to improve economically important traits. It is distinguished from animal husbandry in that husbandry focuses on the environmental management of individual animals, while breeding focuses specifically on changing the underlying genetic potential of the population.
2. The three main branches are: population genetics (gene frequencies and how they change), quantitative genetics (analysis of continuously varying traits), and reproductive technology (AI, embryo transfer, and related methods).
3. Robert Bakewell conducted the first scientifically deliberate livestock improvement programme in 18th-century England, systematically improving Longhorn cattle and Leicester sheep through rigorous within-breed selection and controlled inbreeding, demonstrating that desirable traits could be fixed and improved through deliberate selection.
4. AI allowed one genetically superior sire to produce hundreds of thousands of offspring annually instead of the few dozen possible through natural service. This dramatically increased the selection differential on the sire path and enabled the rapid dissemination of proven genetics across entire national cattle populations.
5. Three contributions are: permanently and cumulatively increasing the genetic potential of animals for production traits; improving adaptation of local breeds to tropical conditions through selection for trypanotolerance and heat tolerance; and increasing household food security and farm income through higher animal productivity.

Part 1.2: Key Concepts in Animal Breeding

1. Genotype is the complete genetic constitution of an animal, while phenotype is the observable expression of that genotype as influenced by the environment. The basic model is: Phenotype = Genotype + Environment + Genotype x Environment interaction.
2. Environmental effects such as feeding level and farm management cause differences in performance that are not genetic. If these are not corrected for, animals on better-managed farms

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will appear genetically superior even if they are not, leading to incorrect selection decisions and failure to achieve expected genetic gains.

3. Heritability (h2) is the proportion of phenotypic variation due to additive genetic differences. A heritability of 0.40 means that 40 percent of the phenotypic variation in a trait is genetic in origin, so individual performance is a moderately reliable predictor of genetic value and the trait will respond reasonably well to individual selection.

4. For traits with low heritability, much of the phenotypic variation is due to environment rather than genetics. An individual's own record is therefore a poor predictor of its breeding value. Averaging the records of many relatives (family selection or progeny testing) provides a more reliable estimate of genetic merit by averaging out environmental effects.

5. The three components are: additive genetic variance, dominance variance, and epistatic variance. Only additive genetic variance responds directly to mass selection, because it represents the average effects of alleles that are passed on to offspring.

Part 1.3: Goals and Criteria of Animal Breeding

1. A breeding objective defines the traits to be improved and the direction of desired change, weighted by their economic importance. Economic weights are assigned because different traits contribute differently to farm profit: a one-litre increase in milk yield may be worth more economically than a one-unit improvement in body condition score, so the milk yield trait receives a higher weight in the selection index.

2. A selection index combines all breeding objective traits, each weighted by its economic value, into a single score that ranks animals by their total economic merit. It is preferred over single-trait selection because selecting only on one trait ignores correlated changes in other traits, which may be negative, and fails to maximise overall economic return.

3. The selection differential is the average superiority of selected parents over the population from which they were chosen. It is increased in practice by selecting a smaller proportion of animals as parents (higher selection intensity), which is made possible by having a large candidate population and using AI to achieve high coverage from few superior sires.

4. The breeder's equation is: DG per year = (h2 x S) / L. h2 is heritability (the proportion of phenotypic variation that is additive genetic), S is the selection differential (superiority of selected

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parents), and L is the generation interval in years (average age of parents at birth of offspring). Increasing h2 or S, or reducing L, increases annual genetic gain.

5. Genomic selection uses dense DNA marker information to estimate breeding values at young ages, before any offspring performance is available. This allows bulls to be selected and used in AI at about 12 months of age instead of waiting four to six years for progeny test results, reducing the generation interval from about six years to about two years and more than tripling the annual rate of genetic gain.

Part 1.4: Overview of Livestock Species and Their Breeding Priorities

1. The primary beef cattle breeding objectives in Nigeria are: daily weight gain from weaning to market; feed conversion efficiency; carcass dressing percentage and lean:fat ratio; trypanotolerance in humid zones; heat tolerance; and tick and disease resistance.

2. Trypanosomiasis, transmitted by tsetse flies, causes wasting, anaemia, and death in susceptible cattle breeds. Much of Nigeria's Middle Belt and south lies within the tsetse belt. Trypanotolerant breeds such as N'dama and WAD cattle survive and produce in these areas without continuous trypanocidal drug treatment, reducing production costs and improving herd viability.

3. Pig breeding priorities in Nigeria are: litter size (number born alive), pre-weaning survival, post-weaning daily gain, feed conversion ratio, and carcass lean percentage. Heat tolerance is increasingly included because exotic Large White and Landrace breeds were selected under temperate conditions and suffer reduced feed intake, growth rate, and reproductive efficiency in Nigeria's hot, humid climate.

4. In the pyramid breeding structure, the apex is occupied by nucleus breeding companies that conduct genetic improvement. The multiplier tier produces parent stock from nucleus genetics. The commercial tier purchases parent stock from multipliers and produces day-old chicks for grow-out or egg production. Genetic improvement flows downward from nucleus to multiplier to commercial, while performance data and selection pressure are concentrated at the nucleus level.

5. Commercial genetic improvement in poultry requires millions of birds in closed nucleus flocks, sophisticated genomic and statistical evaluation tools, and decades of accumulated selection history. Nigerian poultry farmers lack the scale, technology, and capital to replicate this. Instead they benefit from the genetic progress achieved by multinational breeding companies by purchasing improved day-old chicks or hatching eggs from local hatcheries.

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Figures, Plates, Tables, and Boxes

- Figure 1.1: Key milestones in the history of animal breeding Attribution: AI generated. Suggested OER search string: "history animal breeding timeline milestones Bakewell Mendel quantitative genetics AI genomic selection OER diagram".
- Figure 1.2: The relationship between genotype, environment, and phenotype Attribution: AI generated. Suggested OER search string: "genotype phenotype environment interaction livestock breeding diagram P equals G plus E OER".
- Box 1.1: Components of phenotypic variation in livestock traits Attribution: AI generated. Suggested OER search string: "phenotypic variation components additive dominance epistatic environmental livestock breeding OER box".
- Figure 1.3: The animal breeding cycle Attribution: AI generated. Suggested OER search string: "animal breeding cycle steps objective selection mating offspring circular diagram OER".
- Table 1.1: Factors affecting the rate of genetic gain in livestock breeding programmes Attribution: AI generated. Suggested OER search string: "genetic gain factors heritability selection differential generation interval accuracy breeding table OER".
- Table 1.2: Breeding priorities for major livestock species in Nigeria Attribution: AI generated. Suggested OER search string: "livestock breeding priorities Nigeria beef dairy cattle sheep goat pig traits table OER".

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Course code: AGE 306

Course title: Introduction to Animal Breeding

Series 2: Reproduction and Breeding Management in Farm Animals

- **Part 2.1: Reproductive Anatomy and Physiology of Farm Animals**
  - Sub Part 2.1.1: Male reproductive anatomy and spermatogenesis
  - Sub Part 2.1.2: Female reproductive anatomy and the oestrous cycle
  - Sub Part 2.1.3: Fertilisation, implantation, and gestation
- **Part 2.2: Detection of Oestrus and Management of Sires**
  - Sub Part 2.2.1: Signs of oestrus and methods of detection
  - Sub Part 2.2.2: Management of breeding sires
  - Sub Part 2.2.3: Breeding soundness evaluation of sires
- **Part 2.3: Artificial Insemination in Farm Animals**
  - Sub Part 2.3.1: Principles and advantages of artificial insemination
  - Sub Part 2.3.2: Semen collection, evaluation, and processing
  - Sub Part 2.3.3: Insemination procedure and conception rate
- **Part 2.4: Pregnancy, Parturition, and Post-Partum Breeding Management**
  - Sub Part 2.4.1: Pregnancy diagnosis and care of the expectant dam
  - Sub Part 2.4.2: Parturition and immediate post-partum management
  - Sub Part 2.4.3: Post-partum breeding efficiency and reproductive records

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Introduction

Reproduction is the biological foundation of all animal breeding. Without efficient reproduction, no amount of genetic superiority in selected parents can be translated into offspring. The ability to detect oestrus accurately, manage sires effectively, apply artificial insemination correctly, and support pregnant and post-partum animals through to the next conception determines how rapidly a breeding programme can advance. Low reproductive efficiency is one of the most significant constraints to genetic improvement and farm profitability in Nigerian livestock systems.

This Series covers the reproductive physiology and breeding management practices that underpin a successful livestock breeding programme. We begin with the anatomy and physiology of the male and female reproductive tracts and the process of fertilisation. We then examine oestrus detection and sire management, followed by a detailed treatment of artificial insemination, including semen handling and insemination technique. The Series concludes with pregnancy diagnosis, care of the expectant dam, parturition management, and post-partum strategies to restore breeding efficiency.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- SLO 2.1 describe the male and female reproductive anatomy of farm animals and explain spermatogenesis and the oestrous cycle (Linked to Part 2.1),
- SLO 2.2 explain the process of fertilisation, implantation, and gestation in farm animals (Linked to Part 2.1),
- SLO 2.3 identify the signs of oestrus and describe the methods used to detect it in cattle, sheep, goats, and pigs (Linked to Part 2.2),
- SLO 2.4 describe the management of breeding sires and the components of a breeding soundness evaluation (Linked to Part 2.2),

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- SLO 2.5 explain the principles and advantages of artificial insemination in farm animals (Linked to Part 2.3),
- SLO 2.6 describe the collection, evaluation, and processing of semen for AI (Linked to Part 2.3),
- SLO 2.7 outline the insemination procedure and explain the factors that affect conception rate (Linked to Part 2.3),
- SLO 2.8 describe methods of pregnancy diagnosis and the management of the expectant dam (Linked to Part 2.4),
- SLO 2.9 explain parturition management and the immediate post-partum care of dam and offspring (Linked to Part 2.4), and
- SLO 2.10 describe post-partum breeding strategies and explain the importance of reproductive record keeping (Linked to Part 2.4).

2.1 Reproductive Anatomy and Physiology of Farm Animals

2.1.1 Male reproductive anatomy and spermatogenesis

The male reproductive tract consists of the **testes**, which produce spermatozoa and the hormone testosterone; the **epididymis**, where sperm mature and are stored; the **vas deferens**, which transports sperm from the epididymis to the urethra; the **accessory sex glands** (seminal vesicles, prostate, and bulbourethral glands), which contribute fluids that form the seminal plasma; and the **penis**, which deposits semen into the female tract during mating or serves as the site of semen collection. The testes are located in the **scrotum**, which maintains testicular temperature 2 to 6 degrees Celsius below body temperature, a prerequisite for normal spermatogenesis.

Spermatogenesis is the production of mature spermatozoa from spermatogonial stem cells in the seminiferous tubules of the testes. It occurs continuously from puberty and takes approximately 54 to 61 days in cattle, 47 days in rams, and 34 to 45 days in boars. Spermatogenesis proceeds through three phases: **mitosis** (multiplication of spermatogonia), **meiosis** (reduction of chromosome number from diploid to haploid), and **spermiogenesis** (differentiation of round

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spermatids into elongated, motile spermatozoa). High scrotal temperatures caused by fever, cryptorchidism, or insulating fat deposits impair spermatogenesis and reduce semen quality.

Fill in the blank: The organ where sperm cells mature and are stored after leaving the testes is the _____.

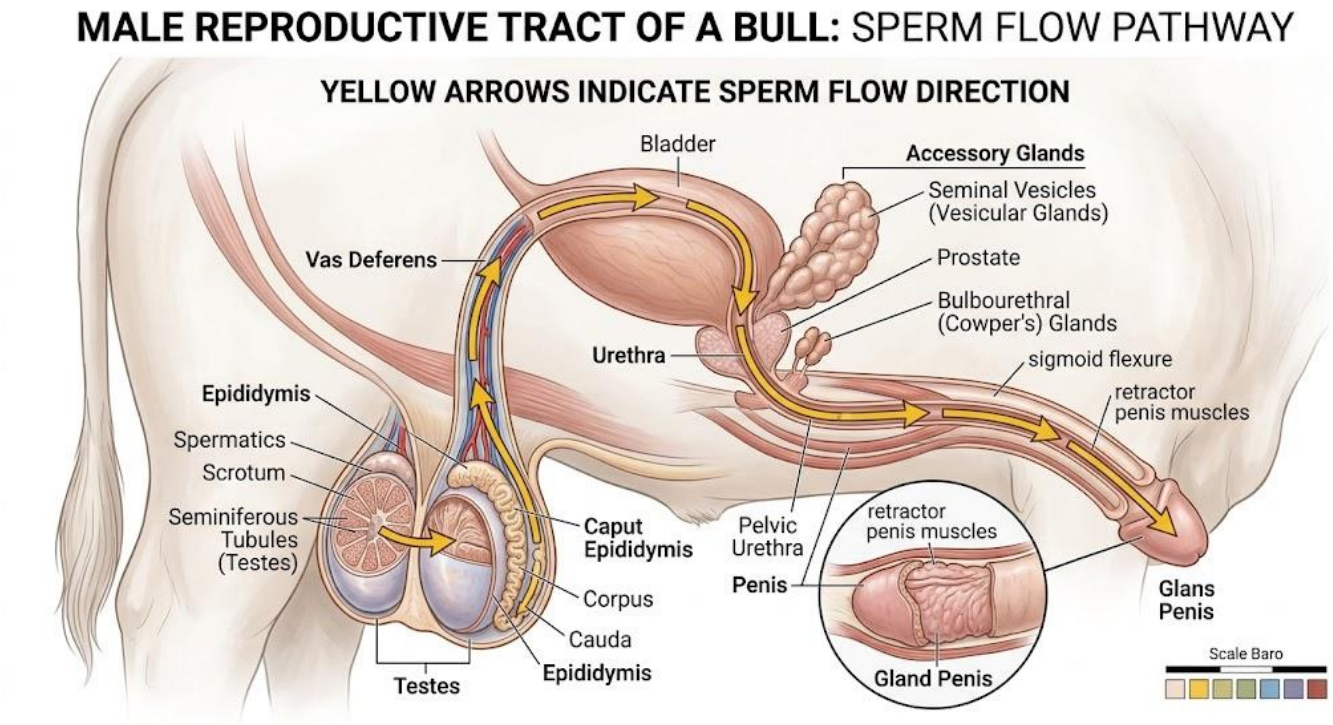

Figure 2.1: Labelled diagram of the male reproductive tract of a bull

2.1.2 Female reproductive anatomy and the oestrous cycle

The female reproductive tract consists of the **ovaries**, which produce ova and secrete oestrogen and progesterone; the **oviducts (fallopian tubes)**, which transport the ovum and are the site of fertilisation; the **uterine horns and uterus body**, which provide the environment for foetal development; the **cervix**, which acts as a barrier to infection and a site of semen deposition; and the **vagina**, which is the birth canal and the site of semen deposition in some species. The **vulva** is the external opening of the reproductive tract.

The **oestrous cycle** is regulated by a sequence of hormones: **GnRH** from the hypothalamus stimulates the anterior pituitary to release **FSH** (follicle-stimulating hormone) and **LH**

(luteinising hormone). FSH stimulates follicle growth and oestrogen secretion; the LH surge triggers ovulation. After ovulation, the ruptured follicle becomes the **corpus luteum**, which secretes progesterone to maintain the uterus for pregnancy. If pregnancy does not occur, prostaglandin F2-alpha from the uterus causes luteolysis (corpus luteum regression), progesterone falls, and the cycle restarts. Cycle length averages 21 days in cattle, 17 days in sheep and goats, and 21 days in pigs.

Fill in the blank: After ovulation, the ruptured follicle transforms into the _____, which secretes progesterone.

2.1.3 Fertilisation, implantation, and gestation

Fertilisation is the fusion of a spermatozoon with a secondary oocyte in the ampulla of the oviduct, forming a diploid zygote. For fertilisation to occur, viable sperm must reach the oviduct within the fertile window following ovulation: approximately 6 to 12 hours in cattle, 2 to 3 hours in sheep. Sperm undergo **capacitation** in the female tract, a biochemical maturation process that enables them to penetrate the zona pellucida of the oocyte. After fertilisation, the zygote undergoes cleavage divisions as it travels down the oviduct and enters the uterus as a morula or blastocyst.

Implantation is the attachment and embedding of the blastocyst into the uterine endometrium, establishing the placental connection through which the embryo receives nutrients and oxygen. Implantation occurs at approximately day 18 to 22 in cattle and day 12 to 14 in sheep. The gestation period, from fertilisation to parturition, averages 280 to 285 days in cattle, 147 to 152 days in sheep and goats, 114 days in pigs, and 22 days in poultry (incubation). Proper nutrition, freedom from stress, and control of infectious diseases are essential to support normal embryonic and foetal development throughout gestation.

Fill in the blank: The biochemical maturation process that sperm undergo in the female tract before they can fertilise an egg is called _____.

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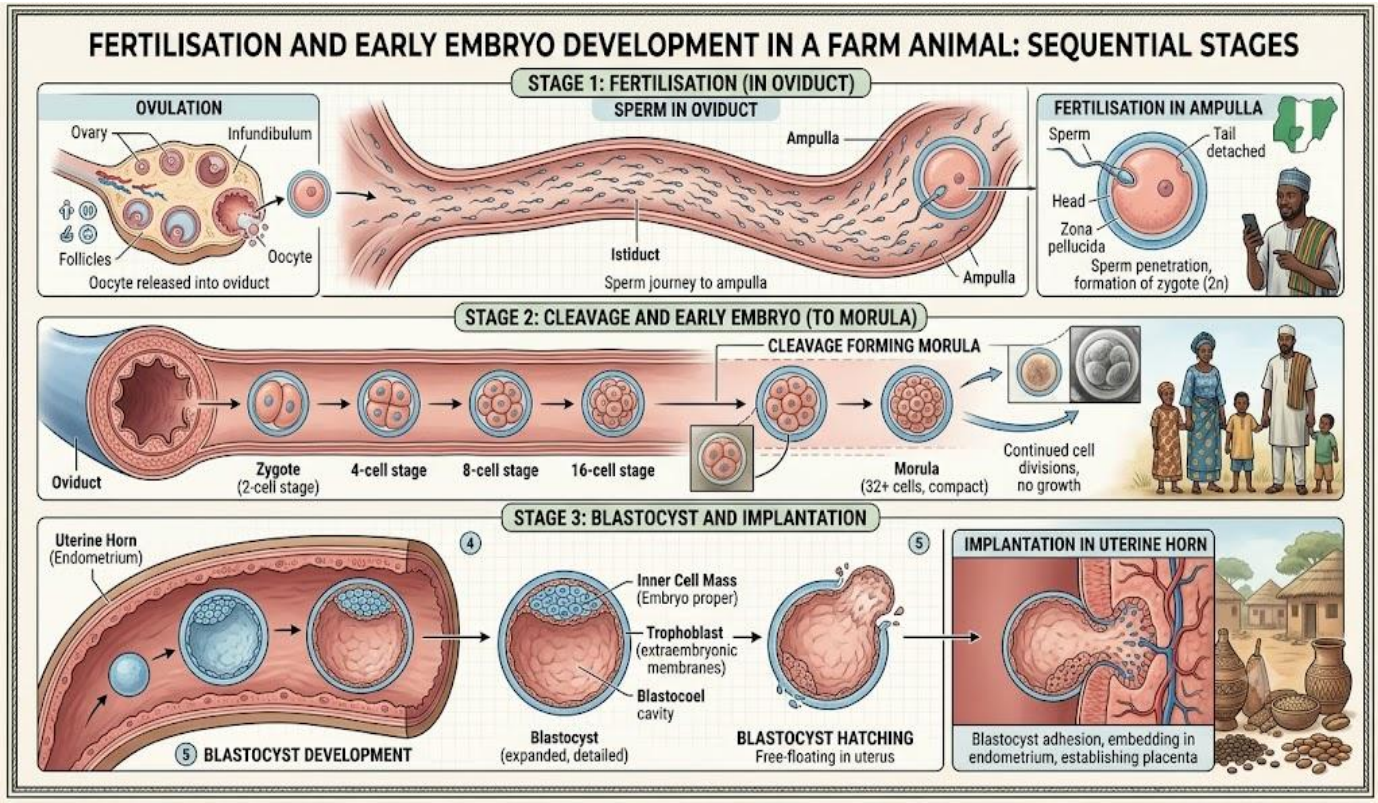

Figure 2.2: Fertilisation and early embryo development in farm animals

Pilot questions 2.1

1. Name the five main organs of the male reproductive tract and state the function of each.
2. Explain why testicular temperature must be maintained below body temperature for normal spermatogenesis.
3. Describe the role of FSH, LH, and progesterone in regulating the oestrous cycle.
4. What is capacitation and why is it necessary for fertilisation?
5. State the average gestation lengths for cattle, sheep, and pigs.

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2.2 Detection of Oestrus and Management of Sires

2.2.1 Signs of oestrus and methods of detection

Accurate oestrus detection is the single most critical management factor determining the success of an AI programme. In **cattle**, the primary sign of oestrus is **standing heat**: the cow stands immobile when mounted by a herd mate or a bull. Secondary signs include restlessness, bawling, decreased milk yield, clear mucus discharge from the vulva, and swelling and reddening of the vulva. Oestrus in cattle lasts 12 to 18 hours and ovulation occurs 10 to 12 hours after the end of standing heat.

In **sheep and goats**, oestrus signs are subtler than in cattle: females may seek the ram or buck, wag their tails, and show restlessness. A **teaser male** (vasectomised or aproned male) is widely used to detect females in oestrus, as females will stand for the teaser. In **pigs**, the sow in oestrus shows a characteristic **standing reflex** when back pressure is applied by the stockperson, ears become erect, and a firm swollen vulva is noted. Automated oestrus detection systems using activity monitors, progesterone assays in milk, or electronic pressure-sensing pedometers are used in larger dairy operations.

Fill in the blank: The primary sign of oestrus in cattle, in which the cow remains stationary when mounted, is called _____ heat.

Species	Oestrus Signs	Duration of Oestrus	Cycle Length	Ovulation Timing
Cattle	Restlessness, mounting others, standing to be mounted, vulval mucus discharge	12–18 hours	~21 days	10–14 hours after end of oestrus
Sheep	Seeking ram, restlessness, tail wagging, swollen vulva	24–36 hours	~17 days	Near end of oestrus
Goats	Bleating, tail wagging, frequent urination, swollen vulva	24–48 hours	~21 days	Late oestrus, just before end
Pigs (sows)	Standing reflex, swollen/red vulva, restlessness, seeking boar	2–3 days	~21 days	Mid to late oestrus

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Horses (mares)	Tail raising, frequent urination, winking of vulva, receptive to stallion	4–7 days	~21 days	24–48 hours before end of oestrus

Table 2.1: Oestrus characteristics of common farm animal species

2.2.2 Management of breeding sires

Breeding sires have a disproportionate genetic influence on the herd or flock: a single bull serving 25 to 30 cows per season will be the sire of every calf born that year. It is therefore essential that sires used in natural service are of high genetic merit for the breeding objective, are in good body condition, are free from reproductive and locomotor diseases, and have passed a breeding soundness evaluation before the breeding season. Overworked sires produce lower-quality semen and achieve lower conception rates; the recommended bull-to-cow ratio under natural service is 1:25 for young bulls and 1:30 to 35 for mature bulls.

Sire management includes: housing in a clean, spacious pen with adequate feed and water outside the breeding season; **condition scoring** and adjusting nutrition to maintain a body condition score of 3 to 3.5 on a 5-point scale; foot care and treatment of any lameness that would impair mounting; vaccination and parasite control; and **pre-season breeding soundness evaluation** (BSE) at least 60 days before the start of the breeding season to allow time for replacement if a sire fails. Young bulls introduced to their first breeding season should be observed to confirm they are mounting and mating effectively before being left unsupervised.

Fill in the blank: The recommended bull-to-cow ratio under natural service for a mature bull is 1:_____ to 35 cows.

2.2.3 Breeding soundness evaluation of sires

A **breeding soundness evaluation (BSE)** is a systematic assessment of a sire's reproductive fitness before he is used for breeding. The standard BSE in cattle comprises three components: **physical examination** (assessment of body condition, eyes, feet and legs, prepuce, and scrotal circumference); **semen evaluation** (assessment of sperm motility, morphology, and

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concentration from a fresh ejaculate); and **libido and mating ability** (observation of willingness to mount and copulate with a restrained female in oestrus).

Minimum semen quality standards for satisfactory BSE classification in cattle require at least 30 percent progressively motile sperm and at least 70 percent morphologically normal sperm. Scrotal circumference, which is positively correlated with both sperm production capacity and the age at puberty of daughters, should meet breed-specific minimums (typically 30 cm or more in mature Bos taurus and Bos indicus bulls at 15 months). A bull that fails BSE should be re-evaluated after 60 days or replaced. BSE results are recorded and filed as part of the farm's breeding records.

Fill in the blank: In the breeding soundness evaluation, the assessment of willingness to mount and mate with a female is called the _____ and mating ability test.

Component	Definition	Minimum Passing Standard
Physical Examination	Assessment of general health, body condition, feet and legs, scrotal circumference, and reproductive organs	Scrotal circumference ≥ 32 cm at 2 years; no physical defects that impair breeding
Semen Evaluation	Microscopic examination of semen for motility, morphology, and concentration	≥ 30% progressive motility; ≥ 70% normal morphology
Libido Test	Observation of mating behavior and ability to serve females	Bull must show adequate sexual interest and complete at least one successful service

Box 2.1: Components and minimum standards of the breeding soundness evaluation for bulls

Pilot questions 2.2

1. Describe the primary and secondary signs of oestrus in cattle.
2. Explain how a teaser male is used to detect oestrus in sheep and goats.
3. Why is it important to maintain the correct bull-to-cow ratio in natural service?
4. List the three components of a breeding soundness evaluation in bulls.
5. State the minimum semen quality standards required for a satisfactory BSE classification in cattle.

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2.3 Artificial Insemination in Farm Animals

2.3.1 Principles and advantages of artificial insemination

Artificial insemination (AI) is the technique of collecting semen from a male, processing and preserving it, and depositing it into the female reproductive tract by mechanical means rather than through natural mating. The principle underlying AI is that a single ejaculate, which contains billions of spermatozoa, can be diluted and extended to produce hundreds or thousands of insemination doses, each containing sufficient sperm to achieve fertilisation. Frozen semen stored in liquid nitrogen at -196 degrees Celsius remains viable indefinitely and can be shipped anywhere in the world.

The advantages of AI over natural service are numerous: it allows one genetically superior sire to influence the genetics of thousands of females per year, dramatically increasing the selection differential on the sire path; it eliminates the cost and risk of maintaining a bull; it prevents the spread of venereal diseases transmitted during natural mating; it enables the use of semen from sires that are geographically distant or deceased; and it allows accurate recording of parentage, which is essential for genetic evaluation. The main disadvantages are the requirement for accurate oestrus detection, skilled personnel, specialised equipment, and a reliable cold chain for semen storage.

Fill in the blank: Frozen semen is stored in liquid nitrogen at _____ degrees Celsius and remains viable indefinitely.

2.3.2 Semen collection, evaluation, and processing

Semen is collected from bulls using an **artificial vagina (AV)**, which mimics the warmth and pressure of the natural vagina. The bull mounts a restrained teaser animal while the AV is directed over the penis. Electroejaculation, which uses rectal probe stimulation, is used for bulls that will not mount or for collection under field conditions. Rams and bucks are also collected by AV or electroejaculation. Boars are collected by the gloved hand method, in which the stockperson applies manual pressure to the penis as the boar mounts a dummy sow.

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Freshly collected semen is evaluated for **volume**, **colour and appearance**, **sperm concentration** (using a haemocytometer or spectrophotometer), **progressive motility** (percentage of sperm swimming forward, assessed under a microscope), and **morphology** (percentage of structurally normal sperm). Semen meeting minimum quality standards is extended with a diluent containing an energy source (egg yolk or soy lecithin), a cryoprotectant (glycerol for freezing), antibiotics, and a buffering agent. Extended semen is loaded into 0.25 or 0.5 ml plastic straws, equilibrated at 5 degrees Celsius, and plunged into liquid nitrogen vapour for freezing.

Fill in the blank: The substance added to semen before freezing to protect sperm cells from ice crystal damage is called a _____.

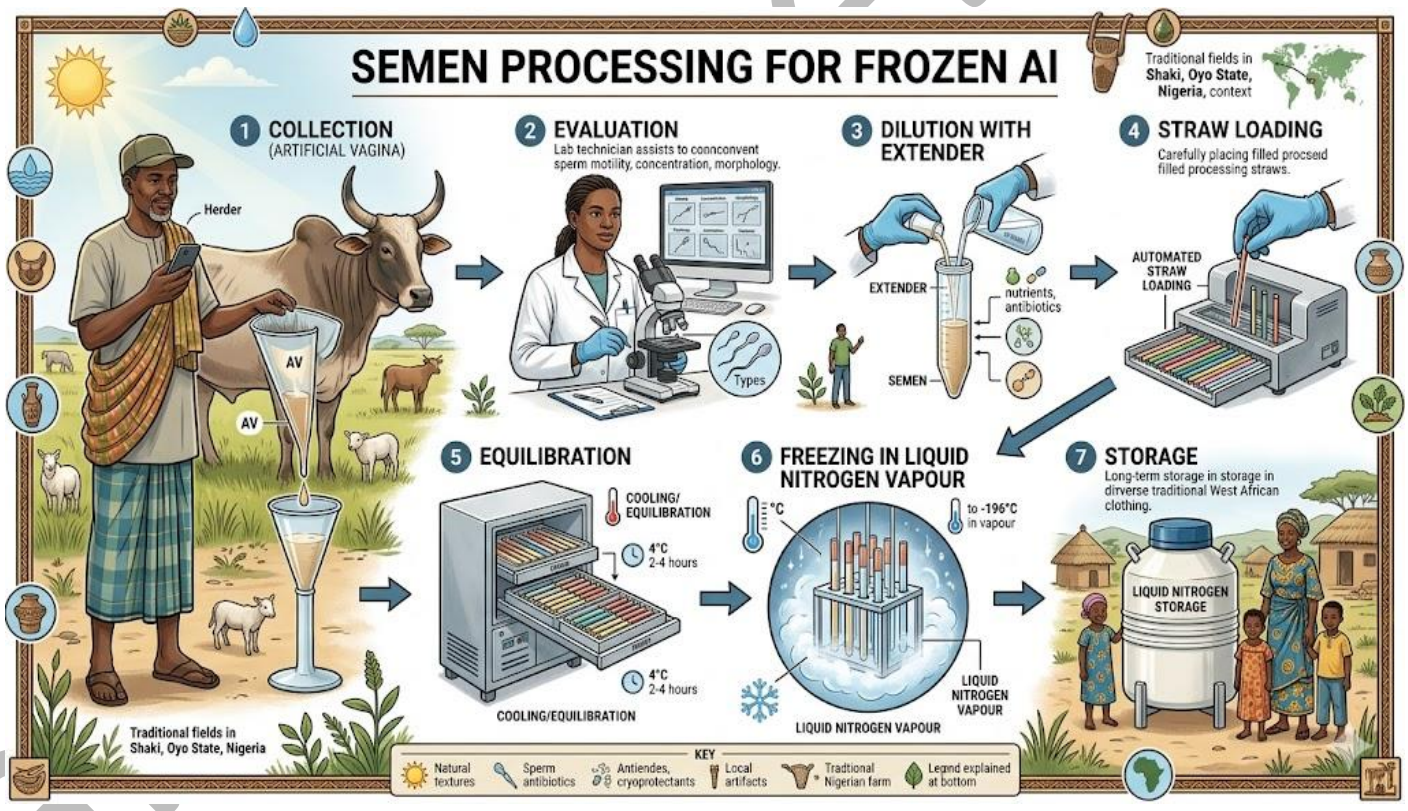

Figure 2.3: Steps in semen collection, processing, and cryopreservation for AI

2.3.3 Insemination procedure and conception rate

In cattle, the standard AI technique is the **recto-vaginal method**: the inseminator's left hand enters the rectum to locate and stabilise the cervix through the rectal wall, while the right hand

guides the AI gun through the vulva and vagina and through the cervical rings into the body of the uterus, where the semen is deposited. The frozen semen straw is thawed in a water bath at 35 to 37 degrees Celsius for 30 to 60 seconds immediately before use. The entire procedure from thawing to deposition must be completed within 60 seconds to minimise temperature shock and sperm death.

Conception rate (the percentage of inseminated females that become pregnant) in cattle AI programmes typically ranges from 50 to 65 percent per service under good management, compared to 85 to 90 percent for natural service. Factors that reduce conception rate include poor oestrus detection leading to incorrect timing of insemination, poor semen handling and thawing technique, low semen quality, female reproductive abnormalities, nutritional deficiencies in the female, and inseminator skill. The optimal time to inseminate cattle is 12 to 18 hours after the onset of standing oestrus, which corresponds to 4 to 12 hours before ovulation.

Fill in the blank: In the recto-vaginal AI technique, semen is deposited into the _____ of the uterus.

Pilot questions 2.3

1. State four advantages of artificial insemination over natural service in livestock breeding.
2. Describe two methods used to collect semen from bulls and state when each is appropriate.
3. Name four parameters evaluated in a semen quality assessment and state what each measures.
4. Describe the recto-vaginal AI technique in cattle, step by step.
5. State the optimal timing for AI in cattle and explain why correct timing is critical for conception.

2.4 Pregnancy, Parturition, and Post-Partum Breeding Management

2.4.1 Pregnancy diagnosis and care of the expectant dam

Pregnancy diagnosis allows the producer to confirm conception, identify non-pregnant females early for re-breeding, and plan feeding and housing adjustments for pregnant animals. Methods

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include: **non-return to oestrus** (failure to show oestrus 18 to 24 days after service is an indirect indicator of pregnancy but is not reliable); **rectal palpation** (direct palpation of uterine horns and foetus through the rectal wall, reliable from day 35 to 45 in cattle); **ultrasonography** (visualisation of the embryo and foetal heartbeat from as early as day 25 in cattle and day 18 in sheep using a rectal or transabdominal probe); and **progesterone assay** (measurement of progesterone in milk or blood at day 21 to 24 post-service, high progesterone indicating an active corpus luteum and probable pregnancy).

Care of the expectant dam focuses on meeting the increasing nutritional demands of the developing foetus, particularly in the last trimester when foetal growth is most rapid. Steaming up, the provision of additional concentrate feed in the last six weeks before parturition, prepares the dam for the energy demands of milk production and reduces the risk of metabolic diseases such as milk fever and ketosis. Pregnant animals should be protected from stressors such as fighting, slippery floors, and rough handling that could cause abortion. A clean, dry, well-bedded maternity pen should be prepared for use two weeks before the expected parturition date.

Fill in the blank: The most reliable early pregnancy diagnosis method in cattle, which can confirm pregnancy from day 25 onwards, is _____.

2.4.2 Parturition and immediate post-partum management

Parturition (birth) is initiated by a complex hormonal cascade involving cortisol from the foetal adrenal glands, which triggers a drop in progesterone and a rise in oestrogen and prostaglandins, leading to cervical dilation, uterine contractions, and expulsion of the foetus. The three stages of parturition are: **preparatory stage** (cervical dilation, positioning of foetus, lasting several hours); **expulsion stage** (active straining and delivery of the foetus, normally 30 to 60 minutes in cattle); and **placental stage** (expulsion of the foetal membranes within 2 to 6 hours in cattle). Assisted delivery should be provided if the expulsion stage exceeds two hours without progress in cattle, or 30 minutes in small ruminants.

Immediate post-partum management of the dam includes checking for completeness of placental expulsion (retained placenta requires veterinary attention after 12 to 24 hours), monitoring for uterine haemorrhage, ensuring adequate feed and water intake to support colostrum production,

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and observing for signs of metabolic disease. For the neonate, priorities are clearing airways, drying and warming, ensuring colostrum intake within two hours, disinfecting the navel, and individual identification. Accurate recording of parturition date, sex of offspring, birth weight, and any complications is essential for reproductive records.

Fill in the blank: Expulsion of the placenta after delivery of the foetus is called the _____ stage of parturition.

Subject	Key Actions
Dam (Mother)	• Ensure expulsion of placenta within 12 hours • Check for signs of hemorrhage or retained placenta • Provide clean water and adequate feed • Monitor temperature and general health • Observe udder for milk let-down and mastitis signs
Neonate (Offspring)	• Clear airways and ensure breathing • Dry and warm the neonate to prevent hypothermia • Dip navel in iodine to prevent infection • Ensure intake of colostrum within first 6 hours (minimum 10% of body weight in 24h) • Monitor vigor, suckling reflex, and body temperature

Box 2.2: Immediate post-partum management checklist for dam and neonate

2.4.3 Post-partum breeding efficiency and reproductive records

The **post-partum interval (PPI)** is the time from parturition to first oestrus and conception. Shortening the PPI is a major goal of breeding management because a long PPI extends the calving interval and reduces the number of offspring produced per dam per year. In beef cows, the PPI averages 50 to 80 days under good nutrition, but can extend to 100 to 200 days in cows in poor body condition at calving or subjected to continuous suckling by the calf. In dairy cows, the target is to achieve first ovulation by 21 days and first service by 50 to 70 days post-partum.

Management strategies to shorten the PPI include: maintaining adequate body condition at parturition (BCS 3.0 to 3.5); supplementing thin cows with energy-dense feeds after calving; early weaning or controlled suckling to reduce the suckling-induced suppression of LH secretion; and the use of progesterone priming or GnRH-based synchronisation protocols to restart ovarian

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activity. Comprehensive reproductive record keeping, tracking service dates, conception rates, calving dates, and calving intervals for every dam, is essential to identify reproductive inefficiencies and evaluate the impact of management changes on herd fertility.

Fill in the blank: The period from parturition to first conception is called the post-partum _____.

Indicator	Definition	Target – Cattle	Target – Small Ruminants	Consequences of Poor Values
Calving interval	Time between successive calvings	12–13 months	8–9 months (lambing/kidding interval)	Reduced lifetime productivity, fewer offspring, lower herd growth
Conception rate	% of females conceiving after service/insemination	≥ 60–70%	≥ 70–80%	Increased breeding costs, delayed herd replacement
Days open	Days from calving to successful conception	≤ 85 days	≤ 60 days	Longer calving intervals, reduced milk/meat output
Post-partum interval	Time from parturition to first fertile oestrus	45–60 days	30–45 days	Delayed rebreeding, extended non-productive period
Services per conception	Number of matings/inseminations needed for conception	1.5–2 services	1–1.5 services	Higher AI costs, wasted semen, reduced efficiency

Table 2.2: Key reproductive performance indicators for livestock breeding management

Pilot questions 2.4

6. Describe three methods of pregnancy diagnosis in cattle and state when each can be first used.
7. Explain why steaming up is practised in the last six weeks before parturition.
8. Describe the three stages of parturition and state the normal duration of each stage in cattle.

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9. What is the post-partum interval and name two management strategies to shorten it in beef cows?
10. State five reproductive performance indicators that should be recorded for every dam in a breeding herd.

Series Summary

This Series has provided a comprehensive account of the reproductive physiology and breeding management practices that underpin livestock genetic improvement. We began with the anatomy of the male and female reproductive tracts, the hormonal regulation of the oestrous cycle, and the processes of fertilisation, implantation, and gestation. We then examined oestrus detection methods for different species, sire management principles, and the components of a breeding soundness evaluation that must be completed before sires are used.

The treatment of artificial insemination covered its principles and advantages, semen collection and cryopreservation, and the recto-vaginal insemination technique in cattle, including the factors that determine conception rate. The Series concluded with pregnancy diagnosis and management of the expectant dam, parturition management and immediate post-partum care, and the post-partum strategies and reproductive records needed to maintain high herd fertility. Together, these topics equip you with the reproductive management knowledge needed to support a productive breeding programme in any farm animal species.

Glossary of Terms

- **Artificial insemination (AI):** The technique of collecting, processing, and mechanically depositing semen into the female reproductive tract to achieve fertilisation without natural mating.
- **Breeding soundness evaluation (BSE):** A systematic pre-breeding assessment of a sire's physical condition, semen quality, and libido to confirm reproductive fitness.

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- **Calving interval:** The average number of days between successive calvings of a cow, a key measure of reproductive efficiency.
- **Capacitation:** The biochemical maturation process that sperm undergo in the female reproductive tract, enabling them to penetrate and fertilise the oocyte.
- **Conception rate:** The percentage of inseminated or served females that become pregnant, used to measure the efficiency of a breeding programme.
- **Corpus luteum:** The temporary endocrine gland formed from the ruptured ovarian follicle after ovulation, which secretes progesterone to maintain pregnancy.
- **Cryoprotectant:** A substance, typically glycerol, added to semen extender to protect sperm cells from ice crystal damage during freezing.
- **Oestrous cycle:** The recurring hormonal and physiological process that prepares the female reproductive tract for mating, averaging 21 days in cattle and pigs and 17 days in sheep and goats.
- **Oestrus:** The period of sexual receptivity in the female during which she will accept mating; the optimal time for insemination.
- **Post-partum interval (PPI):** The period from parturition to the first subsequent conception, a key determinant of the calving or lambing interval.
- **Progesterone:** A steroid hormone secreted by the corpus luteum that maintains the uterine environment for pregnancy and inhibits the LH surge during the luteal phase.
- **Recto-vaginal technique:** The standard AI method in cattle in which one hand in the rectum manipulates the cervix while the other hand guides the AI gun through the vagina into the uterus.
- **Spermatogenesis:** The continuous process of producing mature spermatozoa from spermatogonial stem cells in the seminiferous tubules of the testes.
- **Steaming up:** The practice of increasing concentrate feeding in the last six weeks of pregnancy to prepare the dam for parturition and early lactation.
- **Ultrasonography:** A diagnostic imaging technique using high-frequency sound waves to visualise the uterus, ovaries, and embryo, enabling early pregnancy diagnosis from day 18 to 25 in farm animals.

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Concept Check Questions [Series 2]

Objective Questions

1. Define spermatogenesis. (Linked to SLO 2.1)
2. Which hormone triggers ovulation in farm animals? a) FSH b) Progesterone c) LH surge d) Oestrogen (Linked to SLO 2.1)
3. The primary sign of oestrus in cattle is: a) Reduced milk yield b) Standing heat (standing to be mounted) c) Clear mucus discharge d) Increased appetite (Linked to SLO 2.3)
4. Semen is deposited in the body of the uterus in the recto-vaginal technique by inserting the AI gun through the _____. (Linked to SLO 2.7)
5. The period from parturition to first conception is called the post-partum _____. (Linked to SLO 2.10)

Short Answer Questions

1. Describe the role of the corpus luteum in the oestrous cycle and in early pregnancy. (Linked to SLO 2.1)
2. State four advantages of artificial insemination over natural service in livestock. (Linked to SLO 2.5)
3. List the three components of a breeding soundness evaluation for bulls. (Linked to SLO 2.4)
4. Explain why correct timing of AI is critical for achieving high conception rates in cattle. (Linked to SLO 2.7)
5. Describe two management strategies that can shorten the post-partum interval in beef cows. (Linked to SLO 2.10)

Long Answer Questions

1. Describe the hormonal regulation of the oestrous cycle in cattle, from GnRH release through ovulation and corpus luteum formation to luteolysis and cycle restart. (Linked to SLO 2.1)
2. Explain the complete process of artificial insemination in cattle, from oestrus detection through semen collection and processing to insemination technique, and evaluate the factors that determine conception rate. (Linked to SLO 2.3, SLO 2.5, SLO 2.6, SLO 2.7)

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3. Describe the management of a pregnant cow from diagnosis of pregnancy through parturition to post-partum re-breeding, explaining the physiological basis for each management practice. (Linked to SLO 2.8, SLO 2.9, SLO 2.10)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. Spermatogenesis is the continuous process of producing mature spermatozoa from spermatogonial stem cells in the seminiferous tubules of the testes, proceeding through mitosis, meiosis, and spermiogenesis.
2. Correct answer: c) LH surge.
3. Correct answer: b) Standing heat (standing to be mounted).
4. Cervix.
5. Interval.

Short Answer Questions

1. The corpus luteum forms from the ruptured ovarian follicle after ovulation and secretes progesterone, which prepares and maintains the uterine endometrium for pregnancy. If pregnancy occurs, the corpus luteum persists and continues progesterone secretion. If pregnancy does not occur, prostaglandin F2-alpha from the uterus causes luteolysis, progesterone falls, and the cycle restarts.
2. Four advantages are: one superior sire can produce thousands of offspring per year; venereal diseases are not transmitted; semen from geographically distant or deceased sires can be used; and parentage recording is accurate, enabling valid genetic evaluation.
3. The three components are: physical examination (body condition, eyes, feet and legs, prepuce, scrotal circumference); semen evaluation (motility, morphology, and concentration); and libido and mating ability assessment.
4. Ovulation in cattle occurs 10 to 12 hours after the end of standing oestrus. Sperm must be present in the oviduct before the egg arrives. The optimal insemination time is 12 to 18 hours after the onset of oestrus. Inseminating too early or too late means sperm or egg are no longer viable at the time they meet, causing a missed conception.
5. Two strategies are: maintaining adequate body condition at calving (BCS 3.0 to 3.5) by providing energy-dense supplementary feed post-calving; and reducing the suckling stimulus

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by early weaning or controlled suckling, which removes the inhibitory effect of suckling on LH secretion and allows ovarian cyclicity to resume sooner.

Long Answer Questions

1. Basic response: GnRH from the hypothalamus stimulates FSH and LH release from the anterior pituitary. FSH stimulates follicle growth and oestrogen secretion. Rising oestrogen triggers the LH surge, which causes ovulation. The ruptured follicle becomes the corpus luteum, secreting progesterone. Without pregnancy, prostaglandin from the uterus causes luteolysis, progesterone falls, and FSH rises again to start a new cycle.
2. Value-added response: The negative feedback of progesterone on the hypothalamus-pituitary axis during the luteal phase is the mechanism that prevents another ovulation during pregnancy. The positive feedback of rising oestrogen at the end of the follicular phase is unusual among hormones and triggers the pre-ovulatory LH surge. In synchronisation protocols, exogenous progesterone (CIDR) mimics the luteal phase, and its removal triggers the follicular phase, allowing timed AI without visual oestrus detection.
3. Basic response: Oestrus is detected by standing behaviour in cattle; AI is timed 12 to 18 hours after onset. Semen is collected by AV, evaluated, extended with glycerol-containing diluent, loaded into straws, and frozen in liquid nitrogen. Insemination uses the recto-vaginal technique, depositing semen in the uterine body. Conception rate is 50 to 65 percent and is affected by timing, semen quality, technique, and female nutrition.
4. Value-added response: Each step in the AI chain is a potential point of failure. A semen batch that passes initial quality evaluation may still fail if the thaw protocol is incorrect (wrong water temperature or time) or if post-thaw motility is not checked. The inseminator must pass the AI gun through the cervical rings without force, as trauma to the cervix increases uterine inflammation and reduces conception. Nutritional status of the female is the most underappreciated determinant of conception: thin cows (BCS below 2.5) have a significantly lower LH pulsatility, poorer oocyte quality, and lower conception rate than cows in adequate condition.
5. Basic response: Pregnancy is confirmed by ultrasonography from day 25, or rectal palpation from day 35 to 45. The pregnant cow receives steaming up in the last six weeks. At parturition, the three stages proceed: preparatory (cervical dilation), expulsion (foetal delivery), and placental (foetal membrane expulsion). Post-partum, the dam is monitored for

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retained placenta and metabolic disease, and re-breeding is targeted from 50 to 70 days after calving.

6. Value-added response: The transition period (three weeks before and after calving) is the most metabolically demanding phase of the cow's productive life. Negative energy balance at this time suppresses IGF-1 and LH pulsatility, delaying the return to oestrus and reducing oocyte quality. Nutritional management from dry-off through transition is therefore the most important determinant of post-partum reproductive performance. Record keeping that links each cow's calving date, body condition score at calving, and days to first service creates the data needed to identify nutritional management failures before they become whole-herd fertility problems.

Answers to Pilot Questions [Series 2]

Part 2.1: Reproductive Anatomy and Physiology

1. The five main organs and their functions are: testes (produce spermatozoa and testosterone); epididymis (sperm maturation and storage); vas deferens (sperm transport to urethra); accessory sex glands (produce seminal plasma that nourishes and transports sperm); penis (deposits semen in the female tract).
2. Spermatogenesis requires a temperature 2 to 6 degrees Celsius below body temperature for normal cell division and sperm development. If the testes are too warm, due to fever, cryptorchidism, or excessive scrotal fat, meiosis and spermiogenesis are disrupted, leading to increased abnormal sperm and reduced motility, causing temporary or permanent infertility.
3. FSH stimulates follicle growth and oestrogen secretion during the follicular phase. The pre-ovulatory LH surge, triggered by rising oestrogen, causes ovulation. After ovulation, the corpus luteum secretes progesterone, which prepares the uterus for pregnancy and suppresses further follicular development. If no pregnancy occurs, prostaglandin causes luteolysis, progesterone falls, and FSH rises to begin the next cycle.
4. Capacitation is a series of biochemical changes sperm undergo in the female reproductive tract that destabilise the sperm plasma membrane and enable the acrosome reaction, which is necessary for sperm to penetrate the zona pellucida of the oocyte and achieve fertilisation. Sperm collected directly from the epididymis cannot fertilise an egg without capacitation.

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5. Average gestation lengths are: cattle, 280 to 285 days; sheep and goats, 147 to 152 days; pigs, 114 days (three months, three weeks, and three days).

Part 2.2: Detection of Oestrus and Management of Sires

1. Primary sign: standing heat, in which the cow remains immobile when mounted by a herd mate or bull. Secondary signs include restlessness and bawling, clear mucus discharge from the vulva, swelling and reddening of the vulva, reduced milk yield, and attempting to mount other cows.
2. A teaser male is a vasectomised or aproned ram or buck that is introduced to the female group. Because he cannot impregnate females, he can be left with the flock to seek out and mount females in oestrus. Females that stand for the teaser are recorded as in oestrus and marked with a chin-ball marking harness worn by the teaser, enabling easy identification of oestrus females without constant human observation.
3. The bull-to-cow ratio must be correct because one bull serves all cows in the group. If the ratio is too high (too many cows per bull), the bull becomes overworked, semen quality declines, and conception rate falls. If the ratio is too low (too few cows per bull), resources are wasted on maintaining excess bulls.
4. The three components are: physical examination (body condition, eyes, feet and legs, prepuce, and scrotal circumference); semen evaluation (motility, morphology, and concentration); and libido and mating ability assessment.
5. Minimum standards for a satisfactory BSE classification in cattle are: at least 30 percent progressively motile sperm; and at least 70 percent morphologically normal sperm. Scrotal circumference should meet the breed-specific minimum, typically 30 cm or more in mature bulls.

Part 2.3: Artificial Insemination

6. Four advantages are: one superior sire can sire thousands of offspring per year, greatly increasing selection intensity; venereal disease transmission is prevented; semen from geographically distant or deceased sires can be used; and parentage is accurately recorded, enabling genetic evaluation.
7. Artificial vagina (AV): the bull mounts a restrained teaser animal while the AV is directed over the penis to collect ejaculate. Used when the bull has a normal mounting reflex.
   Electroejaculation: a rectal probe delivers electrical stimulation to cause ejaculation without

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mounting. Used for bulls that will not mount, for field collection, or for semen collection from anaesthetised animals.

8. Volume (total amount of ejaculate collected); progressive motility (percentage of sperm swimming forward, indicating functional vitality); morphology (percentage of structurally normal sperm, assessing developmental quality); concentration (number of sperm per millilitre, used to calculate the total sperm count and number of doses that can be produced).

9. Step 1: Confirm the cow is in standing oestrus. Step 2: Thaw the semen straw in a 35 to 37 degree Celsius water bath for 30 to 60 seconds. Step 3: Load the straw into the AI gun. Step 4: Restrain the cow in a crush. Step 5: Insert the left hand into the rectum and grasp the cervix through the rectal wall. Step 6: Insert the AI gun through the vulva and vagina with the right hand, guided by the left hand through the rectal wall. Step 7: Pass the gun through the cervical rings into the uterine body. Step 8: Deposit semen by depressing the plunger. Complete within 60 seconds of thawing.

10. The optimal time for AI in cattle is 12 to 18 hours after the onset of standing oestrus. Ovulation occurs 10 to 12 hours after the end of oestrus. Sperm need several hours to capacitate and reach the oviduct. Inseminating at the correct time ensures viable sperm are present in the oviduct when ovulation occurs. Inseminating too early means sperm die before the egg arrives; too late means the egg is no longer fertile.

Part 2.4: Pregnancy, Parturition, and Post-Partum Breeding Management

1. Three methods are: ultrasonography, which can detect the embryo and foetal heartbeat from day 25 in cattle; rectal palpation, which can detect uterine asymmetry and foetal membranes from day 35 to 45; and progesterone assay in milk or blood at day 21 to 24 post-service, where elevated progesterone indicates an active corpus luteum and probable pregnancy.
2. Steaming up is practised because foetal growth in the last six weeks of pregnancy is rapid and places high energy and protein demands on the dam. Providing additional concentrate feed during this period ensures adequate colostrum production, reduces the risk of metabolic diseases (milk fever and ketosis) in early lactation, and supports the dam's body condition for the post-partum period.
3. The three stages are: preparatory stage (cervical dilation and positioning of the foetus, lasting several hours); expulsion stage (active straining and delivery of the foetus, normally 30 to 60

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minutes in cattle, up to two hours maximum); and placental stage (expulsion of the foetal membranes, normally within two to six hours of delivery in cattle).

4. The post-partum interval (PPI) is the period from parturition to first conception. Two strategies to shorten it are: maintaining adequate body condition at calving (BCS 3.0 to 3.5) by feeding energy-dense supplements to thin cows; and practising early weaning or controlled suckling to reduce the suckling-induced suppression of LH pulses that delays return to oestrus.
5. Five reproductive performance indicators are: calving or lambing date; date of first post-partum oestrus or service; conception rate (number of services per conception); calving or lambing interval (days between successive calvings); and days open (days from calving to conception).

References and Attributions [Series 2]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 2.1: Labelled diagram of the male reproductive tract of a bull Attribution: AI generated. Suggested OER search string: "bull male reproductive tract anatomy labelled diagram testes epididymis vas deferens penis OER".

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- Figure 2.2: Fertilisation and early embryo development in farm animals Attribution: AI generated. Suggested OER search string: "fertilisation embryo development farm animal oviduct ovulation morula blastocyst implantation OER diagram".
- Table 2.1: Oestrus characteristics of common farm animal species Attribution: AI generated. Suggested OER search string: "oestrus characteristics farm animals cattle sheep goat pig cycle length ovulation timing table OER".
- Box 2.1: Components and minimum standards of the breeding soundness evaluation for bulls Attribution: AI generated. Suggested OER search string: "bull breeding soundness evaluation BSE components semen motility morphology scrotal circumference libido OER box".
- Figure 2.3: Steps in semen collection, processing, and cryopreservation for AI Attribution: AI generated. Suggested OER search string: "semen collection processing cryopreservation AI artificial vagina extender straw freezing liquid nitrogen OER diagram".
- Box 2.2: Immediate post-partum management checklist for dam and neonate Attribution: AI generated. Suggested OER search string: "post-partum management checklist dam neonate parturition colostrum navel placental expulsion OER box".
- Table 2.2: Key reproductive performance indicators for livestock breeding management Attribution: AI generated. Suggested OER search string: "reproductive performance indicators livestock calving interval conception rate days open services per conception table OER".

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Course code: AGE 306

Course title: Introduction to Animal Breeding

Course credit load: 2 Units

Series 3: Genes, Inheritance, and Economic Traits in Livestock

- **Part 3.1: Structure and Function of Genes**
  - Sub Part 3.1.1: DNA, chromosomes, and gene structure
  - Sub Part 3.1.2: Gene expression: transcription and translation
  - Sub Part 3.1.3: Mutation and its effects on livestock traits
- **Part 3.2: Mendelian Inheritance in Farm Animals**
  - Sub Part 3.2.1: Mendel's laws and their application to livestock
  - Sub Part 3.2.2: Dominance, recessiveness, and codominance
  - Sub Part 3.2.3: Lethal alleles and inherited defects in livestock
- **Part 3.3: Modes of Gene Action and Quantitative Traits**
  - Sub Part 3.3.1: Additive, dominance, and epistatic gene action
  - Sub Part 3.3.2: Polygenic inheritance and quantitative traits
  - Sub Part 3.3.3: Genotype-by-environment interaction in livestock
- **Part 3.4: Inheritance of Economic Traits in Livestock**
  - Sub Part 3.4.1: Heritability estimates for production and reproduction traits
  - Sub Part 3.4.2: Genetic correlations among economic traits
  - Sub Part 3.4.3: Implications for selection and breeding programme design

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Introduction

An understanding of how genes work, how they are transmitted from parents to offspring, and how they determine the economically important traits of farm animals is fundamental to the practice of animal breeding. Without this genetic foundation, selection decisions become guesswork, and the expected responses to selection cannot be predicted or interpreted. The molecular and classical genetics covered in this Series bridge the gap between the abstract concept of the gene and the practical decisions breeders make every day.

This Series examines genes from the molecular level up to their effects on economically important livestock traits. We begin with the structure and function of genes, including DNA organisation, gene expression, and the consequences of mutation. We then revisit Mendelian inheritance and extend it to more complex modes of gene action, including additive effects, dominance, and epistasis, before examining how these operate in polygenic quantitative traits. The Series concludes by reviewing heritability estimates and genetic correlations for the major economic traits in livestock, and drawing out their implications for breeding programme design.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- SLO 3.1 describe the structure of DNA and chromosomes and explain how genes are organised in the genome (Linked to Part 3.1),
- SLO 3.2 explain the processes of transcription and translation by which genes direct protein synthesis (Linked to Part 3.1),
- SLO 3.3 describe the nature and effects of mutation on livestock traits (Linked to Part 3.1),
- SLO 3.4 apply Mendel's laws to predict offspring genotype and phenotype ratios in farm animals (Linked to Part 3.2),
- SLO 3.5 distinguish between dominance, recessiveness, and codominance and give livestock examples of each (Linked to Part 3.2),

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- SLO 3.6 identify inherited defects caused by lethal or deleterious alleles in livestock (Linked to Part 3.2),
- SLO 3.7 explain additive, dominance, and epistatic modes of gene action and their relevance to selection (Linked to Part 3.3),
- SLO 3.8 describe how polygenic inheritance gives rise to continuous variation in quantitative traits (Linked to Part 3.3),
- SLO 3.9 explain genotype-by-environment interaction and its implications for livestock breeding in Nigeria (Linked to Part 3.3),
- SLO 3.10 interpret heritability estimates and genetic correlations for economic traits in livestock and apply them to breeding decisions (Linked to Part 3.4).

3.1 Structure and Function of Genes

3.1.1 DNA, chromosomes, and gene structure

Deoxyribonucleic acid (DNA) is the chemical carrier of genetic information in all living organisms. It is a double-stranded helix composed of nucleotide units, each consisting of a deoxyribose sugar, a phosphate group, and one of four nitrogenous bases: **adenine (A)**, **thymine (T)**, **guanine (G)**, and **cytosine (C)**. The two strands are held together by hydrogen bonds between complementary base pairs (A-T and G-C). The specific sequence of bases along a strand encodes the genetic information.

In eukaryotes such as farm animals, DNA is packaged into **chromosomes** within the cell nucleus. Each chromosome consists of a continuous DNA molecule wound around histone proteins to form chromatin. Livestock species have characteristic chromosome numbers: cattle have 60 chromosomes (30 pairs), sheep have 54 (27 pairs), goats have 60 (30 pairs), and pigs have 38 (19 pairs). A **gene** is a defined segment of DNA that encodes a functional product, usually a protein. Each gene occupies a specific chromosomal position called its **locus**. The different versions of a gene that can occupy a locus are called **alleles**. An animal with two identical alleles at a locus is **homozygous**; one with two different alleles is **heterozygous**.

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Fill in the blank: The specific chromosomal position occupied by a gene is called its _____.

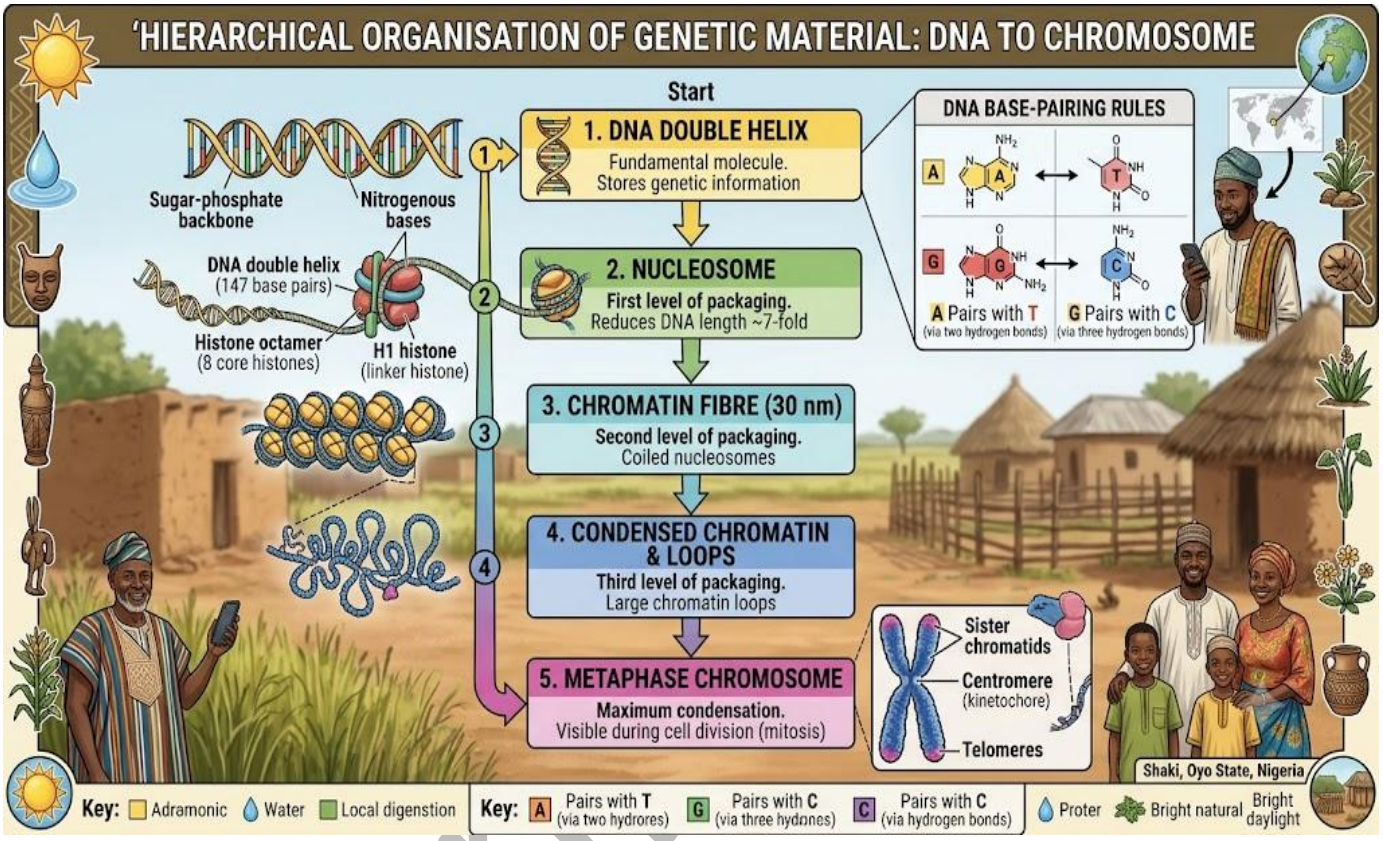

Figure 3.1: Organisation of genetic material from DNA to chromosome

3.1.2 Gene expression: transcription and translation

Gene expression is the process by which the information encoded in a gene is used to produce a functional protein. It proceeds in two stages: **transcription** and **translation**. In transcription, the enzyme RNA polymerase unwinds the DNA double helix and synthesises a complementary strand of **messenger RNA (mRNA)** from the template DNA strand. The mRNA carries the genetic code in triplets of bases called **codons**, each specifying a particular amino acid or a stop signal. The mRNA then moves from the nucleus to the cytoplasm.

In translation, ribosomes read the mRNA codons and assemble amino acids into a polypeptide chain, using transfer RNA (tRNA) molecules to deliver the correct amino acid for each codon. The resulting polypeptide folds into a three-dimensional protein that carries out the structural, enzymatic, hormonal, or regulatory function encoded by the gene. The specific sequence of

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amino acids, and therefore the function of the protein, is ultimately determined by the DNA base sequence. Mutations that alter this sequence can change protein function and, by extension, the phenotypic trait the protein influences.

Fill in the blank: The triplet of bases on mRNA that specifies a particular amino acid is called a _____.

3.1.3 Mutation and its effects on livestock traits

A **mutation** is a heritable change in the DNA sequence of a gene or chromosome. Point mutations involve a change in a single nucleotide base (substitution, insertion, or deletion), while chromosomal mutations involve larger structural changes such as deletions, duplications, inversions, or translocations of chromosomal segments. Most mutations are either neutral (no effect on phenotype) or deleterious (harmful), because they disrupt the function of existing well-adapted proteins. Beneficial mutations are rare but are the ultimate source of new genetic variation on which selection can act.

In livestock, mutations have produced both commercially valuable and harmful outcomes. Valuable mutations include the myostatin gene mutation responsible for extreme muscling (double muscling) in Belgian Blue cattle, which has been deliberately selected for to maximise beef yield. Harmful mutations include the genetic defects prevalent in certain breeds, such as Factor XI deficiency (a blood-clotting disorder) in Holstein cattle, spider lamb syndrome (a skeletal deformity) in Suffolk sheep, and Halothane sensitivity (porcine stress syndrome) in Pietrain pigs. Genetic testing allows carriers of these deleterious recessive alleles to be identified and excluded from breeding programmes.

Fill in the blank: The mutation in the _____ gene that disrupts normal muscle growth regulation is responsible for double muscling in Belgian Blue cattle.

Pilot questions 3.1

1. Describe the structure of DNA, naming the four nitrogenous bases and the base-pairing rules.
2. State the chromosome numbers of cattle, sheep, goats, and pigs.

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3. Distinguish between transcription and translation in gene expression.
4. Define mutation and distinguish between point mutations and chromosomal mutations.
5. Name two commercially valuable and two harmful mutations found in livestock breeds.

3.2 Mendelian Inheritance in Farm Animals

3.2.1 Mendel's laws and their application to livestock

Gregor Mendel formulated two fundamental laws of inheritance from his pea plant experiments. The **Law of Segregation** states that each individual carries two alleles for each trait, and these segregate (separate) during gamete formation so that each gamete carries only one allele. Offspring receive one allele from each parent, restoring the paired condition. The **Law of Independent Assortment** states that alleles at different gene loci assort independently into gametes, provided the loci are on different chromosomes (not linked). These laws allow breeders to predict the expected frequencies of genotypes and phenotypes in offspring when the parental genotypes are known.

A monohybrid cross involves one gene with two alleles. When two heterozygous parents (Aa x Aa) are crossed, the expected offspring genotype ratio is 1 AA : 2 Aa : 1 aa, and the phenotype ratio is 3 dominant phenotype : 1 recessive phenotype, provided one allele is completely dominant. A dihybrid cross involves two independently assorting genes (AaBb x AaBb) and yields a 9:3:3:1 phenotype ratio. In livestock, these principles are applied to predict the inheritance of coat colour, horn status, blood groups, and simple genetic defects.

Fill in the blank: Mendel's Law of _____ states that alleles at different loci on different chromosomes assort independently into gametes.

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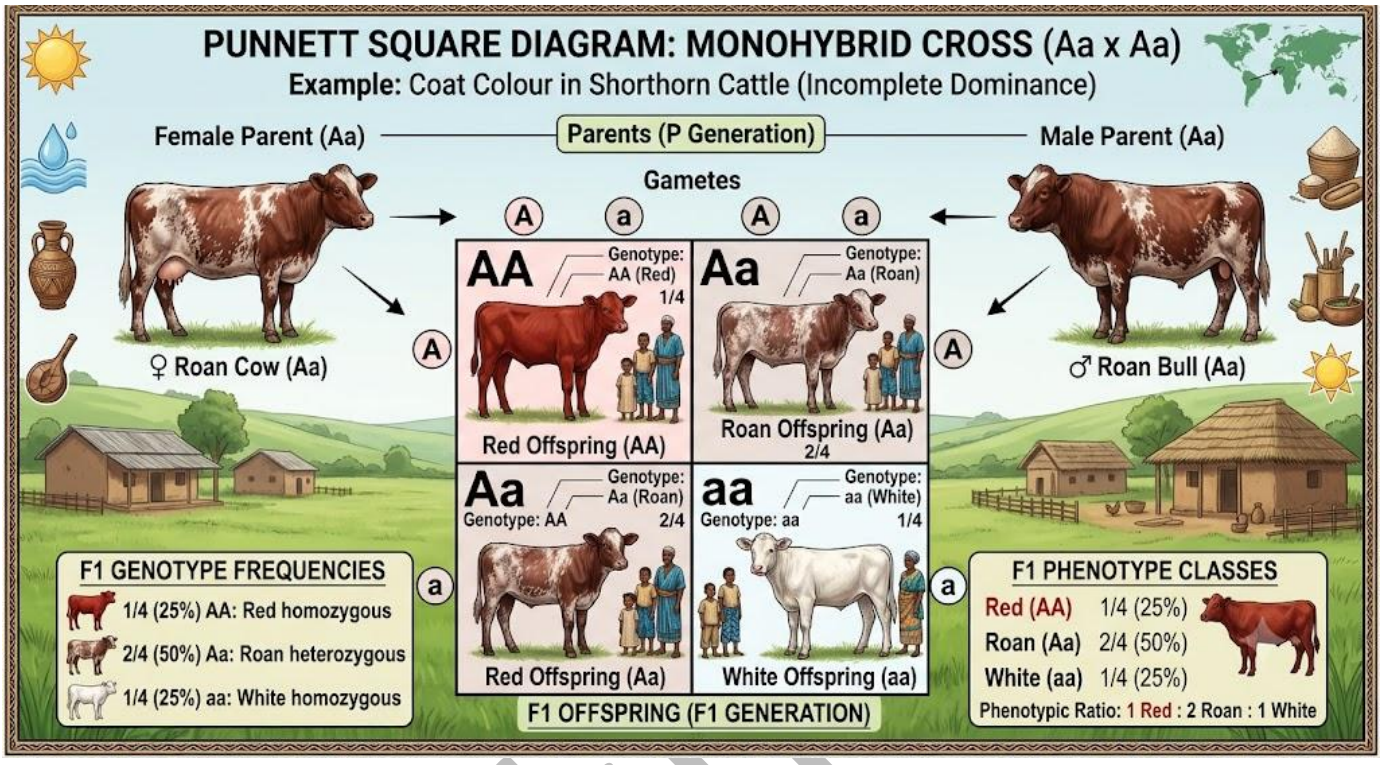

Figure 3.2: Punnett square for a monohybrid cross in livestock (Aa x Aa)

3.2.2 Dominance, recessiveness, and codominance

When an animal is heterozygous (Aa) at a locus, the relationship between the two alleles determines which phenotype is expressed. With **complete dominance**, one allele (A) completely masks the expression of the other (a), so Aa looks identical to AA. With **recessiveness**, the a allele is only expressed in the homozygous state (aa). With **codominance**, both alleles are expressed simultaneously in the heterozygote, producing a phenotype distinct from either homozygote. With **incomplete dominance**, the heterozygote shows a phenotype intermediate between the two homozygotes.

Livestock examples are instructive. In Hereford cattle, the polled (hornless) allele P is dominant over the horned allele p, so PP and Pp animals are polled and only pp animals have horns: a case of complete dominance. In Shorthorn cattle, the red coat allele R and white coat allele R' are codominant: RR animals are red, R'R' animals are white, and RR' animals are roan (a mixture of red and white hairs), a phenotype not seen in either homozygote. In Andalusian fowl, black and white plumage alleles show incomplete dominance, producing blue-splashed heterozygotes.

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Fill in the blank: In Shorthorn cattle, the roan coat colour of heterozygotes results from _____ between the red and white alleles.

3.2.3 Lethal alleles and inherited defects in livestock

A **lethal allele** is one that, when present in the homozygous state, causes death of the animal, either before birth (embryonic lethal) or early in postnatal life. The yellow coat colour gene (A**y**) in mice is a classic example: Ay/ay animals are yellow-coated and viable, but A**y**/A**y** embryos die before implantation. In livestock, the **Mannosidosis allele** in Angus cattle causes a lethal neurological disease in homozygous calves. Recessive lethal alleles are maintained in populations because heterozygous carriers are phenotypically normal and may be superior in production traits, making carrier identification by DNA testing essential.

Non-lethal inherited defects (genetic disorders that impair health or production without necessarily causing death) include Bovine Leukocyte Adhesion Deficiency (BLAD) in Holstein cattle, which causes recurrent infections and early death; Citrullinaemia in Friesian cattle, a metabolic disorder causing neurological signs; and Progressive Ataxia in Charolais cattle. Many of these defects are recessive and were spread widely through AI programmes before DNA tests became available. Modern screening programmes now test AI bulls and their daughters before widespread use, and carriers are identified and managed appropriately.

Fill in the blank: Bovine Leukocyte Adhesion Deficiency (BLAD) is an inherited defect most commonly found in _____ cattle.

Defect	Species/Breed	Mode of Inheritance	Main Clinical Signs	DNA Test Availability
BLAD (Bovine Leukocyte Adhesion Deficiency)	Cattle (Holstein)	Autosomal recessive	Recurrent infections, poor wound healing, early mortality	Available (Holstein cattle)
Spider Lamb Syndrome	Sheep (Suffolk, Hampshire)	Autosomal recessive	Skeletal deformities (long limbs, bent spine, facial defects)	Available

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Halothane Sensitivity (Porcine Stress Syndrome)	Pigs (various breeds, esp. Pietrain)	Autosomal recessive	Malignant hyperthermia, muscle rigidity, sudden death under stress/anesthesia	Available
Factor XI Deficiency	Cattle (Holstein, Jersey)	Autosomal recessive	Prolonged bleeding, poor clotting, hemorrhage after injury or surgery	Available

Table 3.1: Common inherited defects in farm animals

Pilot questions 3.2

1. State Mendel's two laws of inheritance and explain how each applies to livestock breeding.
2. Use a Punnett square to show the expected offspring ratio from mating two heterozygous polled cattle (Pp x Pp).
3. Distinguish between complete dominance, codominance, and incomplete dominance, with a livestock example of each.
4. Explain what a lethal allele is and describe how recessive lethal alleles are maintained in livestock populations.
5. Name two inherited defects in dairy cattle breeds and describe how AI programmes spread them widely.

3.3 Modes of Gene Action and Quantitative Traits

3.3.1 Additive, dominance, and epistatic gene action

The way in which alleles at a locus interact to produce a phenotype is described by the mode of gene action. **Additive gene action** occurs when each allele contributes independently to the phenotype, so the heterozygote is exactly intermediate between the two homozygotes. Additive effects are the most important for breeding because they are directly transmitted to offspring and constitute the **additive genetic variance** that heritability measures. **Dominance gene action** occurs when the heterozygote deviates from the midpoint between the homozygotes, either

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toward the superior (positive dominance) or inferior (negative dominance) homozygote. Dominance contributes to heterosis in crossbred animals.

Epistasis refers to interactions between alleles at different gene loci, where the expression of one locus depends on the genotype at another. For example, the expression of coat colour genes in many species is influenced by the presence of an extension locus that controls whether pigment is deposited at all. Epistatic variance is not consistently transmitted from parents to offspring and is therefore not exploited by individual selection, but it can contribute to the performance of specific breed crosses. The relative importance of additive, dominance, and epistatic effects varies by trait and population.

Fill in the blank: The mode of gene action in which one gene's expression depends on the genotype at a different locus is called _____.

3.3.2 Polygenic inheritance and quantitative traits

Most economically important livestock traits, such as milk yield, growth rate, litter size, feed conversion efficiency, and carcass lean percentage, are **quantitative traits** controlled by many genes (**polygenes**), each contributing a small effect. The combined action of many genes, plus environmental variation, produces the continuous distribution of phenotypes characteristic of quantitative traits. This is in contrast to qualitative traits (such as coat colour or horn presence), which are controlled by one or a few genes and show discrete phenotypic classes.

The key statistical descriptors of quantitative traits are the mean (average value in the population), the variance (spread of values around the mean), and the standard deviation (square root of variance). A normal (bell-shaped) distribution is characteristic of quantitative traits in large populations. The proportion of phenotypic variance that is additive genetic, which is the heritability, determines how rapidly the population mean can be shifted by selection. Traits with high heritability (above 0.30) respond well to individual selection; traits with low heritability (below 0.15) require family-based or progeny-test selection.

Fill in the blank: Traits controlled by many genes each with small individual effects are called _____ traits.

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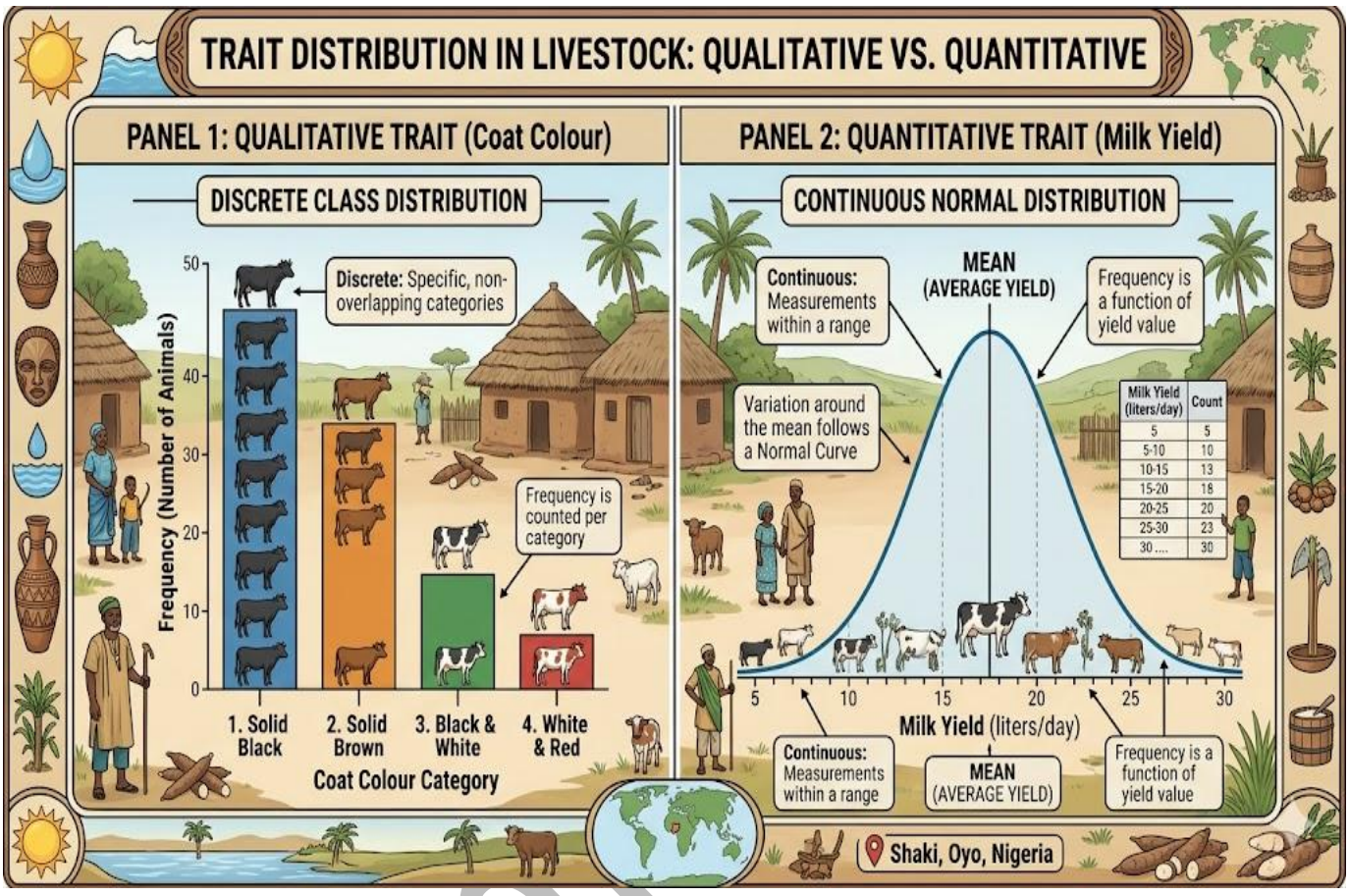

Figure 3.3: Contrasting phenotypic distributions of qualitative and quantitative traits in livestock

3.3.3 Genotype-by-environment interaction in livestock

Genotype-by-environment interaction (GxE interaction) occurs when the relative performance of different genotypes changes depending on the environment in which they are evaluated. If a breed or genotype that excels in one environment does not rank as highly in another environment, a GxE interaction is present. The simplest form is a change in scale (the ranking of genotypes remains the same but differences in magnitude vary across environments), which does not mislead selection decisions. The more problematic form is a **crossover interaction**, where the best genotype in one environment is the worst in another, meaning genotypes selected under one set of conditions cannot be expected to perform optimally in a different environment.

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GxE interaction is particularly relevant to livestock breeding in Nigeria because much of the genetic improvement achieved in temperate breeds under high-input conditions does not translate directly to low-input tropical environments. High-producing Holstein dairy cattle selected in Europe may show substantially reduced milk yield and higher disease susceptibility when moved to Nigeria's hot, humid conditions. This is why breeding programmes that evaluate animals under local conditions, and use locally generated performance data for genetic evaluation, are essential for sustainable genetic improvement in Nigerian livestock.

Fill in the blank: The type of GxE interaction in which the best genotype in one environment becomes the worst in another is called a _____ interaction.

Pilot questions 3.3

1. Distinguish between additive, dominance, and epistatic gene action and state which is most important for mass selection.
2. Define polygenic inheritance and explain why quantitative traits show continuous variation.
3. What statistical measures describe the distribution of a quantitative trait in a livestock population?
4. Define GxE interaction and distinguish between a scale interaction and a crossover interaction.
5. Explain why locally generated performance data are essential for genetic evaluation in Nigerian livestock.

3.4 Inheritance of Economic Traits in Livestock

3.4.1 Heritability estimates for production and reproduction traits

Heritability estimates for economic traits in livestock have been accumulated over decades of research and provide the breeders' reference for predicting response to selection. Production traits generally have moderate to high heritabilities, while reproduction and fitness traits tend to have low heritabilities, reflecting the stronger influence of the environment on survival-related

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traits. The following represent typical heritability ranges based on published literature for major livestock species.

In cattle, milk yield has h2 of 0.25 to 0.35; milk fat percentage, 0.40 to 0.55; live weight and daily gain, 0.35 to 0.45; carcass lean percentage, 0.40 to 0.55; age at first calving, 0.15 to 0.25; and calving interval, 0.05 to 0.10. In **sheep**, fleece weight has h2 of 0.35 to 0.50; body weight at weaning, 0.20 to 0.35; and litter size, 0.10 to 0.15. In **pigs**, daily gain has h2 of 0.30 to 0.40; feed conversion ratio, 0.35 to 0.45; litter size at birth, 0.10 to 0.15; and carcass lean percentage, 0.40 to 0.55. In **poultry**, egg number per hen has h2 of 0.10 to 0.20; egg weight, 0.50 to 0.60; and body weight at market age, 0.40 to 0.55.

Fill in the blank: Among cattle traits, calving interval has a very low heritability of 0.05 to 0.10 because most of its variation is caused by _____ rather than genetic differences.

Trait	Species	Heritability Range	Recommended Selection Method
Milk yield	Cattle	Low–moderate (0.20–0.30)	Progeny testing, genomic selection
Growth rate	Sheep	Moderate (0.30–0.40)	Mass selection, performance recording
Carcass quality (lean meat %)	Pigs	Moderate–high (0.40–0.50)	Individual selection, family selection
Egg production	Poultry	Low–moderate (0.15–0.25)	Family selection, genomic selection
Fertility traits (days open, conception rate)	Cattle	Low (0.05–0.15)	Marker-assisted/genomic selection, management improvement
Wool quality (fiber diameter, staple length)	Sheep	Moderate–high (0.40–0.60)	Individual selection, sire referencing schemes
Feed conversion efficiency	Pigs	Moderate (0.25–0.35)	Performance testing, genomic selection
Egg quality (shell strength, albumen height)	Poultry	Moderate (0.30–0.40)	Family selection, index selection

Table 3.2: Heritability estimates for economic traits in livestock and recommended selection methods

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3.4.2 Genetic correlations among economic traits

A **genetic correlation (rg)** is a measure of the degree to which two traits share the same genetic basis, caused by pleiotropic gene effects (single genes affecting more than one trait) or linkage disequilibrium (alleles at different loci inherited together more often than by chance). Genetic correlations range from -1 (perfect negative association) to +1 (perfect positive association). A positive genetic correlation between two traits means that selecting for one trait will automatically improve the other. A negative genetic correlation means that selecting for one trait will cause the other to deteriorate.

Important genetic correlations in livestock include: a positive genetic correlation between daily gain and feed intake in cattle (rg approximately +0.60), meaning that fast-growing animals eat more; a negative genetic correlation between milk yield and milk fat percentage in dairy cattle (rg approximately -0.30 to -0.40), meaning that selection purely for milk volume tends to dilute fat concentration; a positive genetic correlation between litter size and birth weight in pigs (rg approximately -0.30), where larger litters have lower individual birth weights, increasing pre-weaning mortality. Understanding these correlations is essential for designing selection indices that optimise overall economic merit rather than inadvertently damaging important traits.

Fill in the blank: A genetic correlation occurs because a single gene affects more than one trait, a phenomenon called _____.

Traits Correlated	Species	Sign & Magnitude	Practical Implication
Milk yield vs fertility	Dairy cattle	Negative, moderate (−0.3 to −0.4)	Selecting for higher milk yield may reduce fertility; balanced breeding goals needed
Growth rate vs fat deposition	Beef cattle, pigs	Negative, moderate (−0.3 to −0.5)	Faster growth reduces fat cover; may affect carcass quality and meat grading
Wool fiber diameter vs fleece weight	Sheep	Positive, moderate (0.4 to 0.6)	Heavier fleece often has coarser fibers; selection must balance quality vs quantity

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Litter size vs piglet survival	Pigs	Negative, low to moderate (−0.2 to −0.3)	Larger litters increase mortality risk; management and genetics must improve survival
Egg production vs egg weight	Poultry	Negative, moderate (−0.3 to −0.4)	Higher egg numbers often reduce average egg size; breeding programs must balance both

Box 3.1: Important genetic correlations among economic traits in livestock

3.4.3 Implications for selection and breeding programme design

The heritabilities and genetic correlations of economic traits have direct and practical implications for the design of livestock breeding programmes. High-heritability traits such as carcass composition and growth rate can be improved rapidly by individual phenotypic selection, and their improvement will be proportional to the selection differential applied. Low-heritability traits such as fertility and survival require either very large selection differentials, progeny testing, or the use of correlated indicator traits with higher heritability to achieve meaningful improvement.

Genetic correlations must be incorporated into selection indices to prevent unintended deterioration of correlated traits. For example, selecting only for milk volume in a dairy programme without including udder health or fertility in the index will eventually increase somatic cell count and reduce conception rates, as these traits are genetically antagonistic to high milk yield. In practice, a well-designed selection index that includes all economically important traits, weighted by their economic values and accounting for genetic correlations, maximises the aggregate genetic improvement per generation while protecting against inadvertent losses in traits not explicitly included in the objective.

Fill in the blank: A selection index that includes all economically important traits weighted by their economic values and accounting for genetic correlations maximises _____ genetic improvement per generation.

Pilot questions 3.4

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1. Explain why production traits typically have higher heritabilities than reproduction traits in livestock.
2. State the heritability range for milk yield, litter size in pigs, and carcass lean percentage in cattle.
3. Define genetic correlation and explain the difference between a positive and a negative genetic correlation.
4. Describe the genetic correlation between milk yield and milk fat percentage in dairy cattle and its implication for selection.
5. Explain why low-heritability traits require progeny testing rather than individual selection.

Series Summary

This Series has built the genetic knowledge base required to understand and design livestock breeding programmes. We began at the molecular level with DNA structure, chromosomal organisation, and the gene expression pathway from transcription to translation, and examined how mutations create new variation or cause inherited defects in livestock. We then applied Mendelian principles to predict offspring phenotype ratios from known parental genotypes, explored dominance relationships from complete dominance through codominance to incomplete dominance, and described the lethal and deleterious alleles that affect livestock breed health.

The Series then moved to more complex modes of gene action, distinguishing additive, dominance, and epistatic effects, and explained how polygenic inheritance of many small-effect genes produces the continuous variation seen in quantitative economic traits. The critical concept of genotype-by-environment interaction was examined, with emphasis on its implications for using temperate-derived genetics in Nigerian conditions. The Series concluded by reviewing heritability estimates and genetic correlations for the major livestock economic traits, and drawing out their practical implications for selection strategy and breeding programme design.

Glossary of Terms

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- **Additive gene action:** The mode of gene action in which each allele contributes independently and equally to the phenotype, so the heterozygote is exactly midway between the two homozygotes.
- **Allele:** One of two or more alternative versions of a gene that can occupy the same chromosomal locus.
- **Codominance:** A mode of inheritance in which both alleles of a heterozygote are fully expressed, producing a phenotype distinct from either homozygote.
- **Dominance (gene action):** A mode of gene action in which the heterozygote deviates from the midpoint between the two homozygotes, either toward the superior or inferior homozygote.
- **Epistasis:** Interaction between alleles at two or more different gene loci, where the expression of one locus depends on the genotype at another.
- **Genetic correlation:** A measure of the degree to which two traits share the same genetic basis, caused by pleiotropic gene effects or linkage disequilibrium; ranges from -1 to +1.
- **Genotype-by-environment interaction (GxE):** A situation in which the relative performance or ranking of genotypes changes across different environments.
- **Heritability (h2):** The proportion of phenotypic variation in a trait attributable to additive genetic differences; determines the expected response to individual selection.
- **Homozygous:** Having two identical alleles at a specific gene locus, either both dominant (AA) or both recessive (aa).
- **Heterozygous:** Having two different alleles at a specific gene locus (Aa).
- **Lethal allele:** An allele that, when present in the homozygous state, causes the death of the organism before or shortly after birth.
- **Locus:** The specific position on a chromosome occupied by a gene or genetic marker.
- **Mutation:** A heritable change in the DNA base sequence of a gene or in the structure or number of chromosomes.
- **Pleiotropy:** The phenomenon in which a single gene influences two or more seemingly unrelated phenotypic traits, giving rise to genetic correlations between traits.

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- **Quantitative trait:** A trait controlled by many genes (polygenes), each contributing a small effect, producing a continuous distribution of phenotypic values in a population.

Concept Check Questions [Series 3]

Objective Questions

1. Define a gene locus. (Linked to SLO 3.1)
2. Cattle have how many pairs of chromosomes? a) 19 pairs b) 27 pairs c) 30 pairs d) 32 pairs (Linked to SLO 3.1)
3. In Shorthorn cattle, roan coat colour in heterozygotes is an example of: a) Complete dominance b) Incomplete dominance c) Codominance d) Epistasis (Linked to SLO 3.5)
4. The mode of gene action most important for mass selection because it is transmitted directly to offspring is _____ gene action. (Linked to SLO 3.7)
5. A genetic correlation of -0.35 between milk yield and milk fat percentage means that selecting for higher milk yield will tend to _____ milk fat percentage. (Linked to SLO 3.10)

Short Answer Questions

1. Describe the two stages of gene expression (transcription and translation) and state what product results from each. (Linked to SLO 3.2)
2. State Mendel's Law of Segregation and apply it to predict the offspring genotype ratio from a cross between two heterozygous polled cattle (Pp x Pp). (Linked to SLO 3.4)
3. Distinguish between a quantitative trait and a qualitative trait in livestock, giving one example of each. (Linked to SLO 3.8)
4. What is a crossover GxE interaction and why is it problematic for livestock breed importation into Nigeria? (Linked to SLO 3.9)
5. Explain why a negative genetic correlation between two traits complicates breeding programme design. (Linked to SLO 3.10)

Long Answer Questions

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1. Describe the structure of DNA and chromosomes, explain the process of gene expression from transcription through translation, and evaluate how mutations have affected economically important traits in livestock. (Linked to SLO 3.1, SLO 3.2, SLO 3.3)
2. Explain Mendel's laws and the different modes of dominance in livestock, and describe the genetic basis and management implications of lethal alleles and inherited defects in farm animal breeds. (Linked to SLO 3.4, SLO 3.5, SLO 3.6)
3. Discuss heritability estimates and genetic correlations for economic traits in livestock and explain their implications for the design of a selection index for a Nigerian cattle breeding programme. (Linked to SLO 3.7, SLO 3.8, SLO 3.9, SLO 3.10)

Answers to Concept Check Questions [Series 3]

Objective Questions

1. A gene locus is the specific position occupied by a gene on a chromosome; it is fixed for a given gene in a species.
2. Correct answer: c) 30 pairs.
3. Correct answer: c) Codominance.
4. Additive.
5. Decrease (reduce).

Short Answer Questions

1. In transcription, RNA polymerase reads the DNA template strand and produces a complementary mRNA strand; the product is mRNA. In translation, ribosomes read the mRNA codons and assemble amino acids into a polypeptide chain using tRNA; the product is a protein.
2. Mendel's Law of Segregation states that each individual carries two alleles for a trait and these separate during gamete formation, so each gamete carries only one allele. From Pp x Pp: gametes from each parent are P or p (50:50). Punnett square gives: 1 PP : 2 Pp : 1 pp, so 3 polled : 1 horned phenotype ratio.
3. A quantitative trait is controlled by many genes each with small effects, producing continuous variation (e.g., milk yield in litres per lactation). A qualitative trait is controlled by one or a few genes and shows discrete phenotypic classes (e.g., coat colour as black, roan, or white in Shorthorn cattle).

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4. A crossover GxE interaction occurs when the best genotype in one environment becomes the worst in another. It is problematic for breed importation because a high-producing temperate breed such as Holstein, selected in a cool, high-input European environment, may rank far below local breeds in Nigeria's hot, humid, low-input conditions, meaning imported genetics do not deliver the expected improvement.
5. A negative genetic correlation means that selecting for improvement in one trait automatically causes deterioration in the other. Without including both traits in a selection index with appropriate economic weights, genetic improvement in the desired trait comes at the cost of reducing performance in the correlated trait, worsening overall farm profitability.

Long Answer Questions

1. Basic response: DNA is a double helix of nucleotides with bases A, T, G, C paired A-T and G-C. Chromosomes package DNA with histones. Transcription produces mRNA from the DNA template; translation converts mRNA codons into amino acid sequences that fold into proteins. Mutations are heritable changes in DNA; they can be beneficial (myostatin mutation causing double muscling) or harmful (Factor XI deficiency, BLAD).
2. Value-added response: The genetic code is degenerate (multiple codons specify the same amino acid), which buffers some point mutations. The most commercially significant livestock mutations are those affecting structural proteins (myostatin) or metabolic enzymes (BLAD, Mannosidosis). The spread of harmful recessive alleles through popular AI sires illustrates the risk of intense selection on single traits without genetic health screening: the same bulls that improved milk yield also unknowingly spread deleterious recessives. Mandatory genotyping of AI bulls now prevents this.
3. Basic response: Mendel's Law of Segregation and Law of Independent Assortment allow prediction of offspring genotype and phenotype ratios. Dominance relationships include complete dominance (polled in cattle), codominance (roan in Shorthorn), and incomplete dominance (blue Andalusian fowl). Lethal alleles kill in homozygous state; carriers are normal but spread the allele. BLAD and Factor XI in Holsteins are examples spread by AI.
4. Value-added response: The maintenance of recessive lethals in populations is a consequence of the carrier advantage or neutral status of heterozygotes. From a breeding programme design perspective, the challenge is that the most productive animals in a breed may disproportionately be carriers of deleterious recessives, because the same selection history that improved production may have co-selected linked deleterious alleles. Genomic testing

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now allows simultaneous evaluation of production merit and carrier status, enabling informed culling decisions.

5. Basic response: Production traits (milk yield h2 0.25 to 0.35; carcass lean h2 0.40 to 0.55) have moderate to high heritability and respond well to individual selection. Fertility traits (calving interval h2 0.05 to 0.10) have low heritability and need progeny testing. Negative genetic correlations (milk yield vs fat percentage; daily gain vs feed intake) must be managed through selection indices.
6. Value-added response: For a Nigerian cattle breeding programme, the selection index should include milk yield, calving interval, and udder health (SCC) for dairy cattle, with economic weights reflecting Nigerian milk prices, veterinary costs, and calf values. The negative genetic correlation between milk yield and fertility means that putting all selection pressure on milk yield will increase calving interval and reduce overall revenue per cow-year. Including fertility in the index with a positive economic weight offsets this risk. GxE interaction argues strongly for evaluating candidate sires under Nigerian conditions before widespread AI use, as European sire EBVs will not translate reliably to Nigerian farm performance.

Answers to Pilot Questions [Series 3]

Part 3.1: Structure and Function of Genes

1. DNA is a double-stranded helix of nucleotides. Each nucleotide contains a deoxyribose sugar, a phosphate group, and one of four bases: adenine (A), thymine (T), guanine (G), or cytosine (C). The two strands are held by hydrogen bonds between complementary base pairs: A pairs with T and G pairs with C.
2. Cattle: 60 chromosomes (30 pairs). Sheep: 54 chromosomes (27 pairs). Goats: 60 chromosomes (30 pairs). Pigs: 38 chromosomes (19 pairs).
3. Transcription: RNA polymerase reads the DNA template strand and synthesises a complementary mRNA strand in the nucleus; the genetic code is transcribed from DNA to RNA. Translation: ribosomes in the cytoplasm read mRNA codons and, using tRNA, assemble amino acids into a polypeptide chain that becomes a protein.

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4. A mutation is a heritable change in the DNA sequence. Point mutations affect a single nucleotide base (substitution, insertion, or deletion of one base). Chromosomal mutations involve larger structural changes such as deletions, duplications, inversions, or translocations of whole chromosomal segments.
5. Commercially valuable mutations: myostatin gene mutation causing double muscling in Belgian Blue cattle; polled (hornless) mutation in Hereford and Angus cattle. Harmful mutations: BLAD in Holstein cattle causing recurrent infections; Halothane sensitivity in Pietrain pigs causing porcine stress syndrome.

Part 3.2: Mendelian Inheritance

1. Law of Segregation: each individual carries two alleles for a trait; these separate during gamete formation so each gamete has one allele. In livestock, this means heterozygous carriers of a recessive defect allele (e.g., Pp polled carriers) will produce some homozygous recessive (pp horned) offspring. Law of Independent Assortment: alleles at different loci on different chromosomes segregate independently. This allows breeders to predict offspring genotype frequencies for two or more traits simultaneously.
2. Cross: Pp x Pp. Gametes from each parent: P or p. Punnett square gives: PP (1/4), Pp (2/4), pp (1/4). Phenotype ratio: 3 polled (PP + Pp) : 1 horned (pp).
3. Complete dominance: one allele fully masks the other in the heterozygote; example: polled (P) is completely dominant over horned (p) in Hereford cattle. Codominance: both alleles are expressed in the heterozygote; example: roan coat colour (RR') in Shorthorn cattle, where both red and white hair pigments are produced. Incomplete dominance: the heterozygote is intermediate between the two homozygotes; example: blue-splashed plumage in Andalusian fowl.
4. A lethal allele causes death when homozygous. Recessive lethal alleles are maintained in populations because heterozygous carriers (Ll) are phenotypically normal and may be selected as high producers. The lethal allele is not exposed to selection in the carrier state, so it persists generation after generation. Only when two carriers mate does the homozygous lethal (ll) appear, resulting in embryonic death or early postnatal death.
5. BLAD (Bovine Leukocyte Adhesion Deficiency) in Holstein cattle causes recurrent bacterial infections and early death due to defective neutrophil adhesion. Citrullinaemia in Friesian cattle is a metabolic disorder causing neurological signs. AI programmes spread these defects because a single popular sire with high milk EBV was used on thousands of cows; if he was a

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carrier of a recessive defect, thousands of daughters became carriers before the problem was identified. Mandatory DNA testing of AI bulls now prevents this.

Part 3.3: Modes of Gene Action and Quantitative Traits

1. Additive gene action: each allele contributes independently; the heterozygote is exactly midway between the two homozygotes. Most important for mass selection because additive effects are transmitted to offspring and constitute heritability. Dominance gene action: the heterozygote deviates from the midpoint; it contributes to heterosis but is not consistently transmitted to offspring. Epistasis: one locus's expression depends on the genotype at another locus; contributes to specific cross performance but is not exploited by individual selection.
2. Polygenic inheritance means many genes, each with small effect, together control a trait. Because each gene contributes a small increment, the combined action of many genes produces a continuous range of phenotypic values from very low to very high, with most individuals falling near the population mean. This continuous variation, further spread by environmental effects, produces the bell-shaped normal distribution characteristic of quantitative traits.
3. The mean (average phenotypic value of the population), the variance (average squared deviation from the mean, measuring total spread), and the standard deviation (square root of variance, measuring spread in the same units as the trait).
4. GxE interaction occurs when the relative performance of genotypes differs across environments. A scale interaction means differences in magnitude change across environments but rankings stay the same, and it does not misguide selection. A crossover interaction means the best genotype in one environment is not the best in another, so selection decisions made in one environment do not transfer to another environment.
5. Locally generated data are essential because GxE interactions mean that EBVs estimated in temperate high-input environments do not accurately predict breeding values under Nigerian tropical low-input conditions. Animals must be evaluated in the environment where their offspring will produce, so performance records from Nigerian herds, under Nigerian feeding and disease conditions, are needed to produce valid genetic evaluations for Nigerian producers.

Part 3.4: Inheritance of Economic Traits

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1. Production traits such as milk yield and growth rate are primarily determined by the metabolic capacity of the animal, which is largely under genetic control and less sensitive to short-term environmental fluctuations. Reproduction and fertility traits such as calving interval and conception rate are highly sensitive to nutritional status, disease, management, and climate, so most of their variation is environmental, leaving a small genetic fraction (low heritability).
2. Milk yield in cattle: h2 = 0.25 to 0.35. Litter size in pigs: h2 = 0.10 to 0.15. Carcass lean percentage in cattle: h2 = 0.40 to 0.55.
3. A genetic correlation measures the degree to which two traits share the same genetic cause, due to pleiotropy or linkage disequilibrium. A positive genetic correlation (e.g., rg = +0.60) means that genetic improvement in one trait is automatically accompanied by improvement in the other. A negative genetic correlation (e.g., rg = -0.35) means that selecting for one trait causes the other to deteriorate.
4. The genetic correlation between milk yield and milk fat percentage in dairy cattle is approximately -0.30 to -0.40. This means that selecting purely for higher milk volume tends to produce cows with lower fat percentage. The practical implication is that milk fat percentage must be included as a separate trait in the selection index with its own economic weight to prevent progressive dilution of fat content as milk volume is increased.
5. Low-heritability traits have high environmental variance relative to genetic variance, meaning an individual's own phenotypic record is a poor predictor of its breeding value. Progeny testing averages the performance of many offspring, which dilutes the environmental variation and provides a more accurate estimate of the parent's additive genetic merit. The more progeny tested, the higher the accuracy of the resulting EBV for a low-heritability trait.

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Figures, Plates, Tables, and Boxes

- Figure 3.1: Organisation of genetic material from DNA to chromosome Attribution: AI generated. Suggested OER search string: "DNA chromosome organisation nucleosome chromatin histone genetic material hierarchy diagram OER".
- Figure 3.2: Punnett square for a monohybrid cross in livestock (Aa x Aa) Attribution: AI generated. Suggested OER search string: "Punnett square monohybrid cross livestock coat colour Shorthorn cattle Aa genotype phenotype ratio OER diagram".
- Table 3.1: Common inherited defects in farm animals Attribution: AI generated. Suggested OER search string: "inherited defects farm animals BLAD spider lamb Halothane Factor XI livestock genetic table OER".
- Figure 3.3: Contrasting phenotypic distributions of qualitative and quantitative traits in livestock Attribution: AI generated. Suggested OER search string: "qualitative quantitative traits livestock distribution discrete classes normal curve polygenic OER diagram".
- Table 3.2: Heritability estimates for economic traits in livestock and recommended selection methods Attribution: AI generated. Suggested OER search string: "heritability estimates livestock traits cattle sheep pig poultry milk yield litter size carcass table OER".

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- Box 3.1: Important genetic correlations among economic traits in livestock Attribution: AI generated. Suggested OER search string: "genetic correlations livestock economic traits milk yield fat percentage litter size daily gain OER box".

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Course code: AGE 306

Course title: Introduction to Animal Breeding

Course credit load: 2 Units

Series 4: Systems of Breeding, Selection Methods, and Performance Testing

- **Part 4.1: Systems of Breeding**
  - Sub Part 4.1.1: Purebred breeding and its objectives
  - Sub Part 4.1.2: Crossbreeding and heterosis
  - Sub Part 4.1.3: Grading up and breed substitution
- **Part 4.2: Inbreeding and Outbreeding**
  - Sub Part 4.2.1: Inbreeding: definition, measurement, and effects
  - Sub Part 4.2.2: Outbreeding and its applications
  - Sub Part 4.2.3: Managing inbreeding in livestock populations
- **Part 4.3: Methods of Selection**
  - Sub Part 4.3.1: Individual (mass) selection and its efficiency
  - Sub Part 4.3.2: Family selection, within-family selection, and combined selection
  - Sub Part 4.3.3: Index selection and Best Linear Unbiased Prediction (BLUP)
- **Part 4.4: Performance Testing and Progeny Testing**
  - Sub Part 4.4.1: On-farm and central performance testing
  - Sub Part 4.4.2: Progeny testing: principles and procedure
  - Sub Part 4.4.3: Estimated Breeding Values and national cattle evaluation

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Introduction

The choice of breeding system and selection method determines how rapidly a livestock population improves, and what that improvement looks like in practical terms. Purebred programmes, crossbreeding schemes, and grading-up strategies each have distinct advantages and appropriate contexts. Similarly, selecting animals by their own performance, by the performance of their families, or by statistical estimates of their genetic merit each suits different traits, population sizes, and recording infrastructures.

This Series brings together the practical tools that translate genetic principles into management decisions. We begin with the major systems of breeding, from purebred selection through crossbreeding and grading up, examining when each is appropriate in the Nigerian context. We then examine inbreeding and outbreeding as complementary phenomena, and the strategies used to manage them. The Series continues with the main methods of selection, from simple mass selection through BLUP-based genetic evaluation, and concludes with performance testing and progeny testing programmes, including the principles of estimated breeding values and national genetic evaluation.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- SLO 4.1 describe the objectives and application of purebred breeding in livestock improvement (Linked to Part 4.1),
- SLO 4.2 explain crossbreeding systems and the phenomenon of heterosis (Linked to Part 4.1),
- SLO 4.3 describe grading up and breed substitution and evaluate their suitability for Nigerian conditions (Linked to Part 4.1),
- SLO 4.4 define inbreeding, explain how it is measured, and describe its effects on livestock performance (Linked to Part 4.2),

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- SLO 4.5 explain outbreeding and describe management strategies to control inbreeding in livestock populations (Linked to Part 4.2),
- SLO 4.6 describe individual (mass) selection and evaluate its efficiency for different trait types (Linked to Part 4.3),
- SLO 4.7 explain family selection, within-family selection, and combined selection and state when each is preferred (Linked to Part 4.3),
- SLO 4.8 describe index selection and explain the principle of BLUP for estimating breeding values (Linked to Part 4.3),
- SLO 4.9 distinguish between on-farm and central performance testing and explain the advantages of each (Linked to Part 4.4), and
- SLO 4.10 describe progeny testing and explain how Estimated Breeding Values are derived and used in national genetic evaluation (Linked to Part 4.4).

4.1 Systems of Breeding

4.1.1 Purebred breeding and its objectives

Purebred breeding is the mating of animals of the same breed or strain over successive generations, with the objective of fixing desirable traits and maintaining breed identity. The primary goals are to: increase the frequency of favourable alleles for the traits in the breeding objective; maintain the genetic uniformity and predictability that make purebred animals reliable sources of commercial genetics; and produce animals registered in a breed society with documented pedigrees. Purebred programmes are the basis of the **nucleus tier** in the breeding pyramid, from which genetic improvement flows down to multiplier and commercial levels.

In Nigeria, purebred programmes for exotic breeds such as Friesian, Large White, and Landrace are operated primarily by government livestock multiplication centres and a small number of commercial farms. Indigenous breeds such as the White Fulani, Yankasa, and Red Sokoto goat are kept as purelines by smallholder farmers and research institutes. The challenge of purebred

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programmes is that selection within a closed population gradually reduces genetic diversity; over time, the population becomes more uniform but also more vulnerable to inbreeding depression if the effective population size is small.

Fill in the blank: In the breeding pyramid, purebred improvement is carried out at the _____ tier and flows downward to commercial producers.

4.1.2 Crossbreeding and heterosis

Crossbreeding is the mating of animals from two or more different breeds. The primary genetic benefit of crossbreeding is **heterosis** (hybrid vigour), defined as the superiority of the crossbred offspring over the average of its purebred parents. Heterosis is caused by dominance and epistatic interactions between alleles from the two parent breeds that differ in allele frequency, resulting in more heterozygous offspring that express favourable dominant alleles and mask unfavourable recessives. Heterosis is greatest for traits with low heritability and high dominance variance, such as reproduction, survival, and health traits.

Common crossbreeding systems include: **two-breed terminal cross** (F1 offspring from two purebreds are all slaughtered; maximum heterosis in offspring but none retained for breeding); **rotational crossbreeding** (sires of alternating breeds used each generation, maintaining heterosis at 50 to 67 percent of maximum while retaining replacement females); and **three-breed terminal cross** (F1 females are mated to a sire of a third breed, combining breed complementarity in the sire with heterosis in both the dam and offspring). In Nigeria, crossing White Fulani with Friesian is the dominant strategy for dairy improvement, exploiting exotic milk genetics while retaining local disease resistance.

Fill in the blank: The superiority of a crossbred animal over the average of its purebred parents is called _____.

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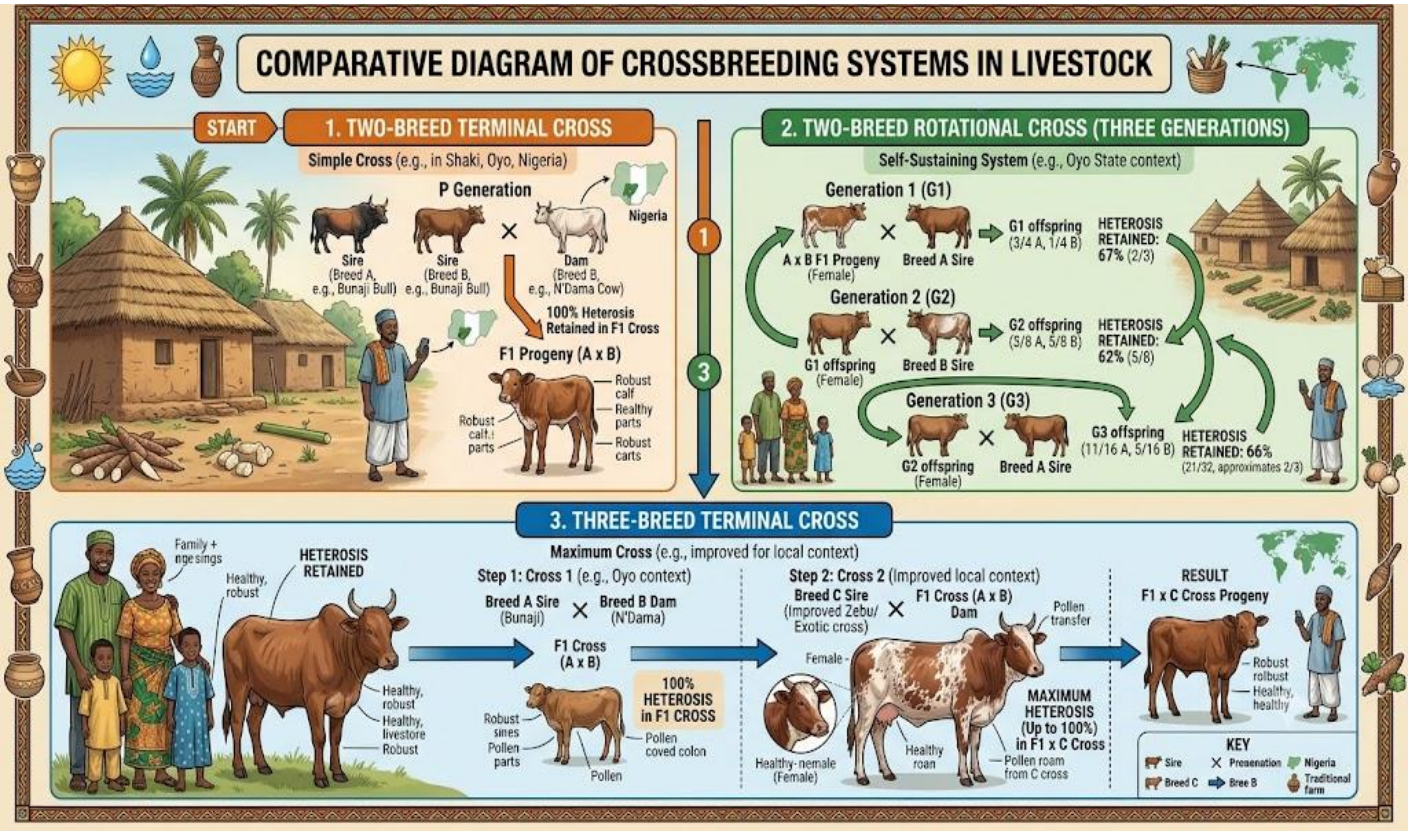

Figure 4.1: Three crossbreeding systems: terminal, rotational, and three-breed terminal cross

4.1.3 Grading up and breed substitution

Grading up is the repeated mating of females of an indigenous or low-merit breed to purebred sires of a superior breed, with the objective of progressively increasing the genetic contribution of the superior breed in successive generations. After one generation of crossing, offspring are 50 percent exotic; after the second, 75 percent; after the third, 87.5 percent; and by the fourth or fifth generation, animals are effectively purebred for the superior breed. Grading up is widely used by smallholder dairy farmers in Nigeria to increase the milk production potential of their White Fulani cows using Friesian AI semen.

The advantage of grading up over direct breed substitution (importing and maintaining a purebred exotic herd) is that it allows gradual adaptation of the animals to local conditions through the retained indigenous genetic background in early generations, and is achievable with AI rather than requiring live animal importation. The risk is that by the fourth or fifth generation, if the grading-up process is not monitored, animals become genetically similar to the exotic

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breed and lose the adaptive traits of the indigenous parent. Choosing the optimal crossbreeding level (typically 50 to 75 percent exotic in Nigeria's humid zones) and then maintaining a stable cross rather than grading up further is often the more practical and productive strategy.

Fill in the blank: After three generations of grading up to a purebred exotic sire, offspring are _____ percent exotic in genetic composition.

Pilot questions 4.1

1. State three objectives of purebred breeding in livestock improvement.
2. Define heterosis and explain the genetic mechanisms that cause it.
3. Distinguish between a two-breed terminal cross and a rotational crossbreeding system.
4. Describe grading up and explain why it is preferred over direct breed substitution in Nigeria.
5. What is the risk of grading up beyond the third or fourth generation in Nigerian dairy cattle?

4.2 Inbreeding and Outbreeding

4.2.1 Inbreeding: definition, measurement, and effects

Inbreeding is the mating of individuals that are more closely related to each other than the average relationship in the population. It increases homozygosity across the genome, meaning the offspring is more likely to receive identical alleles from both parents at each locus. The degree of inbreeding is measured by the **inbreeding coefficient (F)**, which represents the probability that an individual has received identical alleles from the same ancestral source at a given locus. F ranges from 0 (no inbreeding) to 1 (complete homozygosity). Full-sib mating increases F by approximately 0.25 per generation; half-sib mating by approximately 0.125 per generation.

Inbreeding depression is the reduction in performance for fitness-related traits that accompanies increased inbreeding. It is caused by the increased expression of deleterious recessive alleles (which become homozygous in inbred animals) and the loss of heterozygote advantage at loci where the heterozygote is superior. Traits most affected by inbreeding

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depression are those with low heritability and high dominance variance: fertility, survival, immune function, and growth rate. Production traits such as carcass composition and milk fat percentage, which have high heritability and low dominance variance, are less sensitive to inbreeding depression.

Fill in the blank: The probability that an individual has received identical alleles from the same ancestral source is measured by the inbreeding _____.

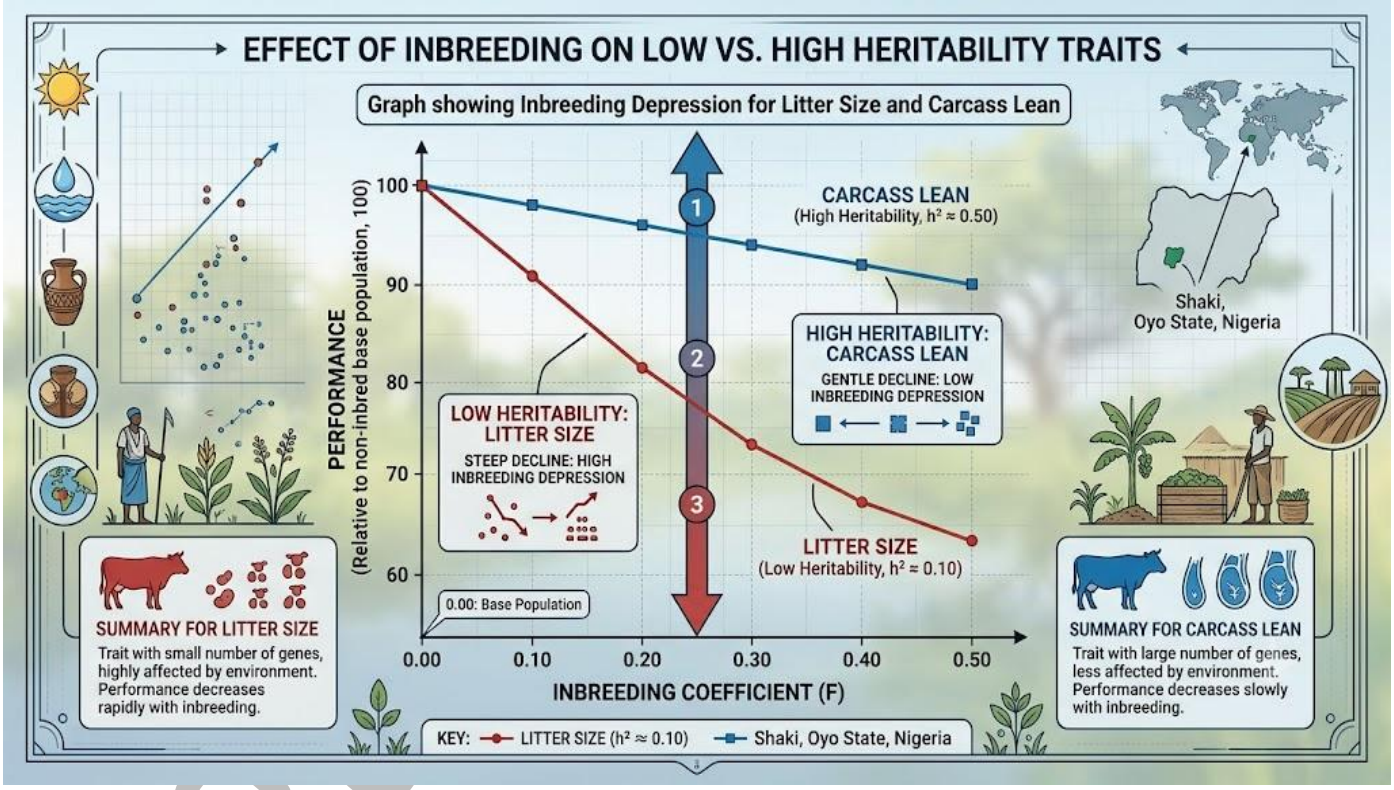

Figure 4.2: Effect of inbreeding coefficient on performance of low and high heritability traits

4.2.2 Outbreeding and its applications

Outbreeding is the mating of individuals that are less closely related than the average of the population, thereby increasing heterozygosity. The extreme form of outbreeding is crossbreeding between breeds, which was covered in Part 4.1. Within a breed, outbreeding is practised by deliberately avoiding matings between close relatives and, in small populations, by using unrelated sires from different lines or introducing unrelated animals from another herd.

Outbreeding reverses the effects of inbreeding depression, restoring heterozygosity and improving fitness-related traits.

Linebreeding is a form of mild inbreeding practised deliberately to concentrate the genetics of a particular superior ancestor while keeping the inbreeding coefficient low. It involves mating descendants of an elite ancestor in combinations that maximise the proportion of the ancestor's genes without pairing the closest relatives. Linebreeding is sometimes used in purebred nucleus herds to perpetuate the influence of an outstanding sire or dam across several generations. It must be practised carefully, as excessive linebreeding eventually crosses the threshold into harmful inbreeding depression.

Fill in the blank: The deliberate mild inbreeding used to concentrate the genes of a superior ancestor while limiting the inbreeding coefficient is called _____.

4.2.3 Managing inbreeding in livestock populations

Managing inbreeding requires monitoring the inbreeding coefficient of the population and implementing mating strategies that prevent it from rising above acceptable thresholds. A maximum inbreeding coefficient of 5 to 6 percent per generation is a common guideline: above this level, inbreeding depression becomes economically significant in fitness traits. Practical management tools include: using pedigree records to identify and avoid close-relative matings; rotating sires from different bloodlines; maintaining a sufficient effective population size (Ne, the size of an ideal random-mating population that would lose genetic diversity at the same rate as the actual population); and introducing unrelated sires from outside the nucleus when inbreeding accumulates.

The effective population size is the key determinant of the rate of inbreeding: the smaller Ne, the faster inbreeding accumulates. For a population using AI with a small number of popular sires, Ne is reduced even when the census population size is large, because genetic diversity is funnelled through few sire lines. This is the reason why breed societies and national AI centres maintain pedigree records and monitor inbreeding trends, and why genomic tools are now used to calculate genomic inbreeding coefficients more accurately than pedigree-based estimates.

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Fill in the blank: The size of an ideal random-mating population that loses genetic diversity at the same rate as the actual population is called the _____ population size.

Pilot questions 4.2

6. Define inbreeding and explain how the inbreeding coefficient F is interpreted.
7. Explain inbreeding depression and state which trait types are most affected.
8. What is linebreeding and how does it differ from uncontrolled inbreeding?
9. State three practical management strategies for controlling inbreeding in a livestock nucleus herd.
10. Explain why using a small number of popular AI sires reduces effective population size even in large herds.

4.3 Methods of Selection

4.3.1 Individual (mass) selection and its efficiency

Individual selection, also called **mass selection**, is the simplest form of selection: animals are ranked by their own phenotypic records for one or more traits, and the highest-ranking individuals are chosen as parents of the next generation. Its efficiency depends entirely on heritability: if h2 is high, the individual's phenotype is a good predictor of its breeding value, and mass selection responds well. For traits with h2 above 0.30 (such as growth rate, carcass composition, egg weight, and milk fat percentage), individual selection is effective and cost-efficient. It requires no relatives' data, no sophisticated analysis, and can be implemented by any farmer with a weighing scale and a record book.

The limitations of mass selection become apparent for traits with low heritability (below 0.15), sex-limited traits (traits expressed only in one sex, such as milk yield in females or sperm quality in males), and traits that can only be measured after slaughter (such as carcass lean percentage). For sex-limited traits, males cannot be evaluated on their own performance and must be assessed through the performance of their female relatives. For post-slaughter traits, living animals can

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only be selected based on correlated indicator traits (such as ultrasound backfat measurement as an indicator of carcass fat) measured on the live animal.

Fill in the blank: Individual selection is most efficient for traits with heritability above _____.

4.3.2 Family selection, within-family selection, and combined selection

Family selection chooses parents based on the average performance of their family (full-sibs or half-sibs) rather than on individual merit. It is most effective when heritability is low (so family means are better predictors of breeding value than individual records) and when family sizes are large (so the family mean is estimated precisely). It is less effective when there is large within-family environmental variation or when families are kept in different environments, as the family mean then confounds genetic and environmental effects. **Within-family selection** selects the best individual within each family, deliberately ignoring between-family differences. It is most effective when families differ in environment (so between-family variation is largely environmental) and when within-family variation is largely genetic.

Combined selection uses a weighted combination of the individual's own deviation from the family mean and the family mean itself, deriving weights from heritability and family size to maximise accuracy. It is always at least as accurate as either family or individual selection alone, and is the theoretical basis for the BLUP mixed model equations used in modern genetic evaluation. In practice, the weight on the family mean increases as heritability decreases, so combined selection approaches family selection for low-heritability traits and approaches individual selection for high-heritability traits.

Fill in the blank: The selection method that combines both the individual's deviation from the family mean and the family mean itself to maximise accuracy is called _____ selection.

Selection Method	Basis of Selection	Best Heritability Range	Family Size Effect	Sex-limited Trait Applicability	Relative Accuracy

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Individual selection	Own performance records	High heritability (>0.4)	Independent of family size	Not applicable to sex-limited traits	Moderate accuracy
Family selection	Average performance of family	Low heritability (<0.2)	Accuracy increases with larger family size	Applicable to sex-limited traits	Moderate–high accuracy
Within-family selection	Comparison among sibs within a family	Moderate heritability (0.2–0.4)	Family size important for reliable comparisons	Limited use for sex-limited traits	Moderate accuracy
Combined selection	Weighted combination of individual and family records	Broad range (low to high heritability)	Family size improves accuracy	Applicable to sex-limited traits	High accuracy

Table 4.1: Comparison of selection methods in livestock breeding

4.3.3 Index selection and Best Linear Unbiased Prediction (BLUP)

A **selection index** combines information from multiple sources (the individual's own records, sire and dam records, collateral relatives) and multiple traits, each weighted by its economic value and its genetic parameters (heritability and genetic correlations), into a single score that ranks animals by total economic merit. The index weights are derived algebraically to maximise the correlation between the index and the true aggregate breeding value of the animal. Tandem selection (selecting on one trait at a time in sequence) and independent culling levels (setting minimum thresholds for each trait) are inferior to index selection for improving overall economic merit.

Best Linear Unbiased Prediction (BLUP) is the statistical methodology used in modern national genetic evaluations to estimate breeding values simultaneously for all animals in a population, accounting for all available pedigree and performance records and correcting for systematic environmental effects (herd, year, season, age at calving, etc.). BLUP produces

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Estimated Breeding Values (EBVs) that are unbiased (not systematically over- or under-estimated), comparable across herds and years, and weighted by the quantity and quality of information available. BLUP is the gold standard for genetic evaluation in cattle, pigs, and sheep worldwide, and is the basis of sire summaries published by national breed societies.

Fill in the blank: The statistical method used in national genetic evaluation that simultaneously estimates breeding values for all animals while correcting for environmental effects is called _____.

Pilot questions 4.3

1. Define individual selection and state the trait heritability range for which it is most effective.
2. Explain why mass selection is ineffective for sex-limited traits and describe an alternative approach.
3. Distinguish between family selection and within-family selection and state when each is preferred.
4. What is a selection index and what are its advantages over selecting on a single trait?
5. Define BLUP and explain the key advantages of EBVs produced by BLUP over simple phenotypic averages.

4.4 Performance Testing and Progeny Testing

4.4.1 On-farm and central performance testing

Performance testing is the systematic measurement of economically important traits on candidate animals under defined and comparable conditions, to provide data for genetic evaluation and selection decisions. **On-farm performance testing** records production data (milk yield, weaning weight, litter size, feed conversion) on animals at the farm where they are kept. It is cost-effective, allows large numbers of animals to be recorded, and captures performance under commercial conditions. Its limitation is that performance comparisons between animals on different farms are confounded by environmental differences unless statistical correction for herd effects is applied.

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Central performance testing brings candidate animals, typically young males, to a single standardised testing station where they are fed identically and managed under uniform conditions for a defined test period (typically 84 to 112 days). All animals experience the same environment, so differences in performance directly reflect genetic differences rather than management variation. Central testing is used extensively for beef bulls, pigs, and sheep in national genetic improvement programmes. Its main disadvantages are cost, the stress of transport and regrouping, and the risk that performance under station conditions may not predict performance under commercial farm conditions.

Fill in the blank: Central performance testing reduces environmental variation by placing all candidate animals in the same _____ conditions for a defined test period.

Testing Method	Location	Environmental Control	Number Tested	Cost	G×E Suitability	Main Limitation
On-farm testing	Conducted on farmers' holdings under local management	Low control; variable feeding and environment	Large numbers possible across farms	Lower cost per animal	High suitability (captures real-world G×E)	Environmental variation reduces accuracy of genetic evaluation
Central testing	Conducted at research stations or test centers	High control; standardized feeding and management	Limited numbers due to facility capacity	Higher cost per animal	Lower suitability (may not reflect farm conditions)	Results may not translate well to diverse farm environments

Table 4.2: Comparison of on-farm and central performance testing

4.4.2 Progeny testing: principles and procedure

Progeny testing evaluates the genetic merit of a parent animal by measuring the performance of its offspring. It is the most accurate method for estimating breeding values for low-heritability traits and for traits that cannot be measured on the candidate (sex-limited or post-slaughter traits). The procedure for progeny testing a dairy bull is: mate the young bull to a random sample

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of cows across multiple herds; wait for daughters to calve (approximately two years); collect milk yield records from daughters over one or more lactations; and estimate the bull's breeding value from the average deviation of daughters from herdmates.

The accuracy of a progeny test increases with the number of daughters and the number of herds they are distributed across. A progeny test based on 100 daughters across 30 or more herds provides high accuracy for dairy bull evaluation. The major disadvantage of classical progeny testing is the long waiting time from birth of the bull to availability of daughter performance data, which extends the generation interval to five to seven years in dairy cattle and reduces the annual rate of genetic gain. This is the fundamental reason why genomic selection, which provides high-accuracy EBVs in young bulls without waiting for progeny data, has largely replaced classical progeny testing in developed-country dairy programmes.

Fill in the blank: The accuracy of a progeny test for a dairy bull increases with the number of _____ and the number of herds they are distributed across.

4.4.3 Estimated Breeding Values and national cattle evaluation

An **Estimated Breeding Value (EBV)** is a numerical estimate of the genetic merit of an individual animal for a specific trait, expressed as a deviation from a genetic base population. A bull with an EBV of +500 litres for milk yield is expected to sire daughters that produce 250 litres more than daughters of a bull with an EBV of zero (because daughters receive only half the sire's genes). EBVs are calculated by BLUP, which simultaneously accounts for all performance records in the database, corrects for fixed environmental effects, and weights each animal's contribution by the accuracy of its own data and that of all its known relatives.

National cattle evaluation systems, operated by breed societies or government livestock agencies, compile EBVs across all participating herds and publish sire summaries ranking bulls by EBV and accuracy for each trait. In Nigeria, the National Animal Production Research Institute (NAPRI) and the Federal Department of Livestock have initiated performance recording schemes for dairy cattle and beef cattle, but a fully operational national genetic evaluation system has not yet been established. The prerequisites for a national evaluation are: a unique animal identification system; a central performance recording database; standardised trait

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definitions; and a sufficient number of connected herds (herds with animals related to animals in other herds through AI sire use) to allow valid cross-herd comparisons.

Fill in the blank: A bull with an EBV of +500 litres for milk yield is expected to sire daughters that produce _____ litres more than daughters of a zero-EBV bull.

Prerequisite	Explanation
Unique ID system	Each animal must have a permanent, unique identification (ear tags, electronic IDs) to track performance and pedigree.
Performance database	Centralized records of production, reproduction, and health traits are needed for accurate genetic evaluation.
Standardised traits	Clear definitions and uniform measurement protocols for traits (e.g., milk yield, growth rate, fertility) ensure comparability across herds.
Connected herds	Genetic links between herds through AI sires or shared pedigrees are essential to allow across-herd evaluations.
BLUP model	Best Linear Unbiased Prediction (BLUP) statistical model is required to estimate breeding values while accounting for fixed effects and herd environment.

Box 4.1: Prerequisites for a national cattle genetic evaluation system in Nigeria

Pilot questions 4.4

1. Define performance testing and distinguish between on-farm and central performance testing.
2. State the advantages and limitations of central performance testing for beef bulls.
3. Describe the procedure for progeny testing a dairy bull and explain how accuracy is increased.
4. Define an EBV and explain how it should be interpreted when comparing two dairy bulls.
5. List four prerequisites for establishing a national cattle genetic evaluation system in Nigeria.

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Series Summary

This Series has equipped you with the practical tools for making informed breeding system and selection decisions in livestock management. We examined the three main breeding systems: purebred programmes that maintain breed identity and genetic uniformity; crossbreeding systems that exploit heterosis for fitness traits; and grading up, which progressively introduces superior exotic genetics while retaining some indigenous adaptation. The choice among these systems depends on the production environment, available resources, and the specific breeding objectives.

We then examined inbreeding and outbreeding as complementary phenomena, explaining how inbreeding accumulates through mating of relatives and how it causes inbreeding depression in fitness traits, while also discussing management strategies including pedigree monitoring, sire rotation, and effective population size management. The selection methods section moved from simple mass selection through family-based methods to BLUP-based index selection, showing how each method suits different traits and data situations. The Series concluded with performance testing and progeny testing, explaining how EBVs are derived from BLUP evaluation and identifying the prerequisites for establishing a national genetic evaluation system in Nigeria.

Glossary of Terms

- **Best Linear Unbiased Prediction (BLUP):** A statistical method that simultaneously estimates breeding values for all animals in a population from pedigree and performance data, correcting for systematic environmental effects.
- **Combined selection:** A selection method that weights the individual's deviation from its family mean and the family mean itself to maximise accuracy of breeding value estimation.
- **Crossbreeding:** The mating of animals from two or more different breeds to produce offspring that benefit from heterosis and breed complementarity.
- **Effective population size (Ne):** The size of an ideal random-mating population that loses genetic diversity (through inbreeding) at the same rate as the actual population.

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- **Estimated Breeding Value (EBV):** A numerical estimate of an individual animal's genetic merit for a specific trait, expressed as a deviation from a genetic base, calculated using BLUP.
- **Grading up:** The repeated mating of females of a local breed to sires of a superior breed, progressively increasing the proportion of superior breed genetics over successive generations.
- **Heterosis:** The superiority of the crossbred offspring over the average performance of its purebred parents, caused by dominance and epistatic interactions between alleles from the two parent breeds.
- **Individual (mass) selection:** Selection of parents based solely on their own phenotypic performance records, most effective for traits with high heritability.
- **Inbreeding:** The mating of individuals more closely related than the population average, increasing homozygosity across the genome.
- **Inbreeding coefficient (F):** The probability that an individual has received identical alleles from the same ancestral source at a given locus; ranges from 0 to 1.
- **Inbreeding depression:** The reduction in performance, especially for fitness-related traits with low heritability, caused by increased homozygosity from inbreeding.
- **Linebreeding:** A form of mild deliberate inbreeding aimed at concentrating the genetics of a superior ancestor in the population while limiting the overall inbreeding coefficient.
- **Progeny testing:** The evaluation of a parent animal's genetic merit by measuring the performance of its offspring, most valuable for low-heritability and sex-limited traits.
- **Purebred breeding:** The mating of animals within the same breed over successive generations to fix desirable traits, maintain breed identity, and produce predictable commercial genetics.
- **Selection index:** A weighted combination of multiple traits and information sources that ranks animals by total economic merit, derived to maximise the correlation with the true aggregate breeding value.

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Concept Check Questions [Series 4]

Objective Questions

1. Define heterosis. (Linked to SLO 4.2)
2. Which crossbreeding system retains approximately 67 percent of maximum heterosis in the offspring generation? a) Two-breed terminal cross b) Two-breed rotational cross c) Three-breed terminal cross d) Purebred selection (Linked to SLO 4.2)
3. Individual (mass) selection is most efficient when trait heritability is: a) Below 0.10 b) Between 0.10 and 0.20 c) Above 0.30 d) Negative (Linked to SLO 4.6)
4. The statistical method used in national genetic evaluation that corrects for environmental effects and estimates breeding values for all animals simultaneously is called _____. (Linked to SLO 4.8)
5. A bull with an EBV of +400 litres for milk yield is expected to sire daughters producing _____ litres more than daughters of a zero-EBV bull. (Linked to SLO 4.10)

Short Answer Questions

1. Distinguish between purebred breeding and crossbreeding and state one advantage of each. (Linked to SLO 4.1, SLO 4.2)
2. Define inbreeding depression and state two trait categories most susceptible to it. (Linked to SLO 4.4)
3. Explain the difference between family selection and within-family selection and state the heritability conditions favouring each. (Linked to SLO 4.7)
4. Describe the procedure for progeny testing a dairy bull and explain why classical progeny testing has been largely replaced by genomic selection. (Linked to SLO 4.10)
5. List three prerequisites for establishing a national cattle genetic evaluation system in Nigeria. (Linked to SLO 4.10)

Long Answer Questions

1. Compare purebred breeding, crossbreeding, and grading up as systems of livestock improvement, evaluating the appropriateness of each for smallholder and commercial producers in Nigeria. (Linked to SLO 4.1, SLO 4.2, SLO 4.3)

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2. Describe the main methods of selection used in livestock breeding (individual, family, within-family, combined, and index selection), explaining the genetic basis for each and the conditions under which each is most appropriate. (Linked to SLO 4.6, SLO 4.7, SLO 4.8)
3. Explain the principles of performance testing and progeny testing, and describe how Estimated Breeding Values derived from BLUP evaluation are used to drive genetic improvement in national livestock programmes, with reference to the Nigerian context. (Linked to SLO 4.9, SLO 4.10)

Answers to Concept Check Questions [Series 4]

Objective Questions

1. Heterosis is the superiority of a crossbred animal over the average performance of its purebred parents, caused by dominance and epistatic interactions between alleles from the two parent breeds.
2. Correct answer: b) Two-breed rotational cross.
3. Correct answer: c) Above 0.30.
4. BLUP (Best Linear Unbiased Prediction).
5. 200 litres (daughters receive half the sire's genes, so EBV effect on daughters is 400/2 = 200 litres above daughters of a zero-EBV bull).

Short Answer Questions

1. Purebred breeding mates animals of the same breed to fix desirable traits and maintain genetic predictability; its main advantage is uniform, predictable offspring suitable as commercial genetics. Crossbreeding mates animals of different breeds to produce heterosis and breed complementarity; its main advantage is improved fitness, survival, and reproduction in the crossbred offspring.
2. Inbreeding depression is the reduction in performance caused by increased homozygosity from mating of relatives, which exposes deleterious recessive alleles and reduces heterozygote advantage. The two trait categories most susceptible are: fitness and reproduction traits (low heritability, high dominance variance) such as litter size, survival, and conception rate; and health and immune function traits.

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3. Family selection ranks animals by their family (full-sib or half-sib) mean and is preferred when heritability is low, so the family mean is a better predictor of genetic value than the individual's own record. Within-family selection selects the best individual within each family and is preferred when families differ in environment (so between-family differences are largely non-genetic) and within-family variation is largely genetic.
4. Procedure: mate a young bull to a random sample of cows in multiple herds; wait for daughters to calve; collect milk yield records from daughters; estimate the bull's EBV from daughter deviations from herdmate averages. Classical progeny testing has been largely replaced by genomic selection because genomic EBVs can be calculated at 12 months of age using DNA markers, avoiding the four to six year wait for daughter data, which shortens generation interval and triples annual genetic gain.
5. Three prerequisites are: a unique animal identification system for every animal; a central performance recording database connecting herds; and a sufficient number of herds linked through common AI sire use to allow valid cross-herd genetic comparisons.

Long Answer Questions

1. Basic response: Purebred breeding fixes desirable traits and maintains breed identity; crossbreeding exploits heterosis for fitness traits; grading up progressively introduces exotic genetics. For smallholders, crossbreeding with AI from proven Friesian bulls onto local cows is most practical. Commercial farms may maintain crossbred populations at a stable 50 to 75 percent exotic level.
2. Value-added response: The optimal system depends on production environment and infrastructure. Purebred programmes require large nucleus herds with thorough recording, which is currently mainly feasible for government multiplication centres in Nigeria. Rotational crossbreeding is practical for smallholders because it maintains a proportion of local adaptation while capturing heterosis in every generation, without requiring a large purebred sire inventory. Grading up risks losing indigenous adaptation traits (trypanotolerance, heat tolerance) if pursued beyond the second or third cross in tsetse-endemic or hot arid zones. The recommendation for humid southern Nigeria differs from the semi-arid north, illustrating how breeding system choice must be tailored to agro-ecology.
3. Basic response: Individual selection uses own phenotype and suits high-heritability traits. Family selection uses family mean and suits low-heritability traits. Within-family selection uses deviation from family mean and suits situations with between-family environmental

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differences. Combined selection weights both and is always at least as accurate as either alone. Index selection combines multiple traits and sources with economic weights for maximum aggregate merit. BLUP applies combined-selection principles across the full pedigree.

4. Value-added response: For Nigerian conditions with limited recording infrastructure, the progression from mass selection to BLUP requires building capacity in stages. The first step is reliable individual identification and weighing at weaning and yearling stages, which allows EBV estimation for growth rate using BLUP even with limited pedigree depth. Adding milk recording to dairy herds enables EBV for milk yield. The key insight is that connected herds (sharing AI sires) are required for cross-herd comparisons; a single herd's records, however thorough, can only rank animals within that herd, not across the industry.
5. Basic response: Performance testing measures production traits under defined conditions; on-farm testing is cost-effective but confounded by herd environment; central testing eliminates environmental differences but is costly. Progeny testing evaluates parents through offspring records; it is highly accurate for low-heritability traits but slow. BLUP EBVs combine all data sources and correct for environmental effects; they enable cross-herd comparisons and are the standard for sire summaries.
6. Value-added response: The Nigerian cattle genetic evaluation context faces specific challenges: sparse and disconnected herd records, limited AI sire pedigree depth, and no national identification system. The most cost-effective entry point is to establish a recording cooperative in which a group of smallholder dairy farmers weigh calves and record milk at AI centres, using a common set of AI bulls. After three to five years, enough daughter records across enough herds accumulate to run BLUP for growth and milk EBVs. Publishing these EBVs for the participating AI bulls, even in a limited area, creates the economic incentive for more farmers to join, eventually scaling to a national evaluation.

Answers to Pilot Questions [Series 4]

Part 4.1: Systems of Breeding

1. Three objectives are: to fix and increase the frequency of favourable alleles for traits in the breeding objective; to maintain genetic uniformity and predictability in the breed so offspring

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performance can be predicted reliably; and to produce pedigree-registered animals that form the genetic base for commercial crossbreeding programmes.

2. Heterosis is the superiority of the crossbred offspring over the average of its purebred parents. It is caused by two mechanisms: dominance, where favourable dominant alleles from one breed mask unfavourable recessive alleles contributed by the other, increasing the proportion of dominant genotypes in the crossbred; and epistasis, where favourable gene interactions between the two breeds produce superior phenotypes not present in either purebred.
3. In a two-breed terminal cross, F1 offspring from two purebred breeds are all used for commercial production (e.g., slaughter) and none is retained for breeding, capturing maximum heterosis in the F1 but requiring continuous supply of purebred parent stock. In a rotational crossbreeding system, sires of alternating breeds are used in successive generations, retaining replacement females and maintaining heterosis at 50 to 67 percent of maximum across generations without requiring a continuous supply of purebred females.
4. Grading up involves repeated mating of local cows to purebred exotic sires (typically through AI) over several generations, progressively increasing the exotic genetic contribution. It is preferred over direct breed substitution in Nigeria because it allows incremental adaptation of animals to local conditions through the retained indigenous genetics in early generations, is achievable through AI without costly live animal importation, and allows farmers to manage the transition to higher productivity gradually with their existing herd.
5. The risk of grading up beyond the third or fourth generation is that animals become genetically similar to the exotic purebred and lose the indigenous traits of heat tolerance, trypanotolerance, and disease resistance that made the local breed viable under Nigerian conditions. High-grade exotic animals require intensive management and inputs that may not be feasible for smallholders, and suffer high mortality if these inputs are unavailable.

Part 4.2: Inbreeding and Outbreeding

1. Inbreeding is the mating of individuals more closely related than the population average. The inbreeding coefficient F represents the probability that both alleles at any locus in an individual are identical by descent from the same ancestral source. F = 0 means no inbreeding (no increase in homozygosity above the population base); F = 0.25 means the individual has a 25 percent probability of having identical-by-descent alleles at any locus, equivalent to the offspring of a full-sib mating.

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2. Inbreeding depression is the reduction in mean performance of inbred animals compared to non-inbred animals. It is caused by increased homozygosity, which exposes deleterious recessive alleles and reduces heterozygote advantage. Traits most affected are those with low heritability and high dominance variance: fertility and reproduction traits (litter size, conception rate, calving interval), neonatal survival, immune function, and general fitness.
3. Linebreeding is a deliberate, mild form of inbreeding designed to concentrate the genes of a specific superior ancestor in the population. It differs from uncontrolled inbreeding in that it is managed carefully to keep the overall inbreeding coefficient low, typically by selecting matings that maximise the proportion of the ancestor's genes without pairing the closest relatives. Uncontrolled inbreeding, such as repeated full-sib or parent-offspring mating, drives F rapidly to high levels and causes severe inbreeding depression.
4. Three strategies are: maintain pedigree records and use mating software to avoid pairing closely related animals; rotate sires from different bloodlines across breeding seasons to prevent the dominance of any single sire line; and introduce unrelated sires from outside the nucleus periodically to inject new genetic diversity when inbreeding trends upward.
5. When a small number of popular AI sires is used intensively, a large proportion of animals in the population are half-siblings (sharing the same sire). Although the census population may be large, the genetic diversity is bottlenecked through few sire lines. The effective population size reflects the number of independent genetic lineages, not the total number of animals, so heavy use of a few sires reduces Ne and accelerates inbreeding accumulation even in herds of thousands of cows.

Part 4.3: Methods of Selection

1. Individual (mass) selection ranks animals based solely on their own measured phenotypic performance and selects the highest-ranking individuals as parents. It is most effective for traits with heritability above 0.30, because high heritability means the individual's own record is a reliable predictor of its underlying breeding value.
2. For sex-limited traits such as milk yield, males cannot express the trait and therefore cannot be ranked by their own record. An alternative approach is to evaluate males through the performance of their female relatives, either by progeny testing (using daughters' milk records) or by BLUP that incorporates dam and sister records into the sire's EBV estimation.
3. Family selection ranks and selects animals based on the average performance of their family group (full-sibs or half-sibs). It is preferred when heritability is low (below 0.15) because the

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family mean averages out environmental noise and is a better predictor of breeding value than any single record. Within-family selection selects the best individual within each family without regard to between-family differences. It is preferred when families differ markedly in management or environment (so between-family variation is mostly environmental) and within-family variation is largely genetic.

4. A selection index combines performance records from multiple traits and multiple relatives, each weighted by its economic value and genetic parameters (heritability, genetic correlations), into a single score ranking animals by total economic merit. Its advantages over single-trait selection are that it simultaneously improves all economically important traits, prevents inadvertent deterioration of correlated traits, and maximises the aggregate genetic gain per generation.
5. BLUP (Best Linear Unbiased Prediction) is a statistical procedure that estimates breeding values for all animals in a population simultaneously from all available pedigree and performance data, correcting for all known systematic environmental effects. EBVs from BLUP are superior to simple phenotypic averages because they are unbiased (adjusted for environment), comparable across herds and years, weighted by the accuracy and quantity of the data used, and exploit all available information from relatives.

Part 4.4: Performance Testing and Progeny Testing

1. Performance testing is the systematic measurement of economically important traits on candidate animals under defined conditions to provide data for genetic evaluation. On-farm testing records production data on animals at their home farm under commercial conditions; it is low-cost and captures performance in a realistic environment but is subject to between-herd environmental confounding. Central testing brings candidates to a single standardised testing station under uniform conditions; it removes environmental confounding between animals but is costly and may not reflect commercial farm performance.
2. Advantages: all bulls experience identical nutrition and management, so differences in growth rate and feed efficiency reflect genetic differences directly; results are directly comparable across bulls from different herds; large-scale testing allows high selection intensity. Limitations: cost of transporting, housing, and feeding bulls at the station; stress from transport and regrouping may depress performance, especially in the early weeks; station performance may not predict commercial farm performance due to GxE interactions.

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3. Procedure: mate the candidate bull to a random sample of cows across multiple herds; allow daughters to calve; collect milk yield records over one or more lactations; calculate the bull's EBV as the average deviation of daughters from their herdmate contemporaries. Accuracy increases with more daughters (typically 100 or more) and more herds (30 or more), which reduces the influence of any single herd's environment on the estimate.
4. An EBV is a numerical estimate of an animal's genetic merit for a specific trait, expressed as a deviation from a genetic base. When comparing two dairy bulls, a bull with an EBV of +600 litres is expected to sire daughters that produce 300 litres more than daughters of a zero-EBV bull (because daughters receive half the sire's genes). The difference between the two bulls' EBVs divided by two gives the expected difference in daughter performance.
5. Four prerequisites are: a unique national animal identification system for every recorded animal; a central performance recording database that collects and stores standardised production records from all participating herds; a sufficient number of herds linked by common AI sire use to allow valid across-herd genetic comparisons (connectedness); and a BLUP statistical evaluation model with appropriate fixed effects to correct for herd, year, season, and management differences.

References and Attributions [Series 4]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Figure 4.1: Three crossbreeding systems: terminal, rotational, and three-breed terminal cross Attribution: AI generated. Suggested OER search string: "crossbreeding systems terminal rotational three-breed heterosis livestock diagram OER".
- Figure 4.2: Effect of inbreeding coefficient on performance of low and high heritability traits Attribution: AI generated. Suggested OER search string: "inbreeding depression inbreeding coefficient livestock litter size carcass performance graph OER".
- Table 4.1: Comparison of selection methods in livestock breeding Attribution: AI generated. Suggested OER search string: "selection methods individual family within-family combined livestock breeding comparison table OER".
- Table 4.2: Comparison of on-farm and central performance testing Attribution: AI generated. Suggested OER search string: "on-farm central performance testing livestock comparison location environmental cost GxE table OER".
- Box 4.1: Prerequisites for a national cattle genetic evaluation system in Nigeria Attribution: AI generated. Suggested OER search string: "national cattle genetic evaluation Nigeria prerequisites BLUP performance recording AI connected herds OER box".

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Course code: AGE 306

Course title: Introduction to Animal Breeding

Course credit load: 2 Units

Series 5: Distribution of Nigerian and Foreign Breeds of Livestock

- **Part 5.1: Nigerian Indigenous Cattle Breeds**
  - Sub Part 5.1.1: Zebu (Bos indicus) breeds of Nigeria
  - Sub Part 5.1.2: Taurine (Bos taurus) and sanga breeds of Nigeria
  - Sub Part 5.1.3: Geographic distribution and production systems of Nigerian cattle
- **Part 5.2: Nigerian Indigenous Small Ruminant and Pig Breeds**
  - Sub Part 5.2.1: Indigenous sheep breeds of Nigeria
  - Sub Part 5.2.2: Indigenous goat breeds of Nigeria
  - Sub Part 5.2.3: Indigenous pig breeds and the Nigerian ecotype pig
- **Part 5.3: Foreign Beef and Dairy Cattle Breeds**
  - Sub Part 5.3.1: Exotic beef cattle breeds used in Nigeria
  - Sub Part 5.3.2: Exotic dairy cattle breeds used in Nigeria
  - Sub Part 5.3.3: Crossbreeding of exotic and indigenous cattle in Nigeria
- **Part 5.4: Foreign Small Ruminant, Pig, and Poultry Breeds**
  - Sub Part 5.4.1: Exotic sheep and goat breeds used in Nigeria
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  - Sub Part 5.4.3: Commercial poultry breeds and their global distribution

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Introduction

Nigeria is endowed with a rich diversity of indigenous livestock breeds shaped by centuries of adaptation to the country's varied agro-ecological zones, disease environments, and cultural management practices. These breeds, while often lower in individual productivity than their exotic counterparts, possess invaluable adaptive traits, including trypanotolerance, heat tolerance, and disease resistance, that make them resilient in low-input production systems. Understanding their distribution and characteristics is as important for the animal breeding student as knowledge of the high-yielding foreign breeds that have been introduced to improve productivity.

This Series provides a systematic survey of the major indigenous and exotic livestock breeds relevant to Nigeria. We begin with indigenous cattle breeds, covering the dominant Zebu types, the taurine N'dama, and the intermediate Sanga breeds, together with their geographic distribution. We then describe the indigenous small ruminant and pig breeds before turning to the exotic beef, dairy, sheep, goat, pig, and poultry breeds used in Nigerian improvement programmes. For each breed, the key characteristics, geographic origin, and role in Nigerian livestock production are described.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- SLO 5.1 identify the major Zebu (Bos indicus) cattle breeds of Nigeria and describe their characteristics and distribution (Linked to Part 5.1),
- SLO 5.2 describe the taurine and Sanga cattle breeds of Nigeria and their adaptive significance (Linked to Part 5.1),
- SLO 5.3 describe the geographic distribution and production systems associated with Nigerian cattle breeds (Linked to Part 5.1),

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- SLO 5.4 identify the major indigenous sheep and goat breeds of Nigeria and describe their characteristics and uses (Linked to Part 5.2),
- SLO 5.5 describe Nigerian indigenous pig breeds and the ecotype pig (Linked to Part 5.2),
- SLO 5.6 identify the major exotic beef and dairy cattle breeds used in Nigeria and describe their characteristics (Linked to Part 5.3),
- SLO 5.7 describe the crossbreeding strategies used to combine exotic and indigenous cattle genetics in Nigeria (Linked to Part 5.3),
- SLO 5.8 identify the major exotic sheep, goat, and pig breeds used in Nigeria and describe their roles in improvement programmes (Linked to Part 5.4),
- SLO 5.9 describe the major commercial poultry breeds and their global distribution (Linked to Part 5.4), and
- SLO 5.10 evaluate the relative merits of indigenous and exotic breeds for different production contexts in Nigeria (Linked to Part 5.1, 5.2, 5.3, 5.4).

5.1 Nigerian Indigenous Cattle Breeds

5.1.1 Zebu (Bos indicus) breeds of Nigeria

The majority of cattle in Nigeria belong to the **Bos indicus** (Zebu) subspecies, characterised by a prominent cervicothoracic hump, pendulous ears, large dewlap, heat-tolerant skin with numerous sweat glands, and relative resistance to tick infestation and tick-borne diseases. The most numerous and widely distributed Nigerian Zebu breed is the **White Fulani (Bunaji)**, a large, white-coated, lyre-horned breed kept predominantly by Fulani pastoralists across the northern states and the Middle Belt. It is valued for beef, draught power, and limited milk production. The **Sokoto Gudali (Gobra)** is a heavy, well-muscled Zebu breed of the northwest, characterised by a large hump and dark pigmentation around the muzzle and hooves, and prized for its beef quality.

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The **Adamawa Gudali** is a taller variant of the Gudali found in the northeast, adapted to the sub-humid Guinea savanna. The **Rahaji (Bodoji)** is a small Zebu breed of the Lake Chad Basin, highly drought-tolerant and important for communities in the arid extreme north. The **Azawak** is a refined, long-legged Zebu adapted to arid Sahelian conditions and found along the northern border with Niger, valued for both beef and milk. The **Keteku** is a natural Zebu-taurine intermediate found in the Middle Belt, not a deliberate cross but a result of long-standing sympatry between Zebu and taurine populations.

Fill in the blank: The most widely distributed indigenous cattle breed in Nigeria, kept by Fulani pastoralists, is the _____ Fulani.

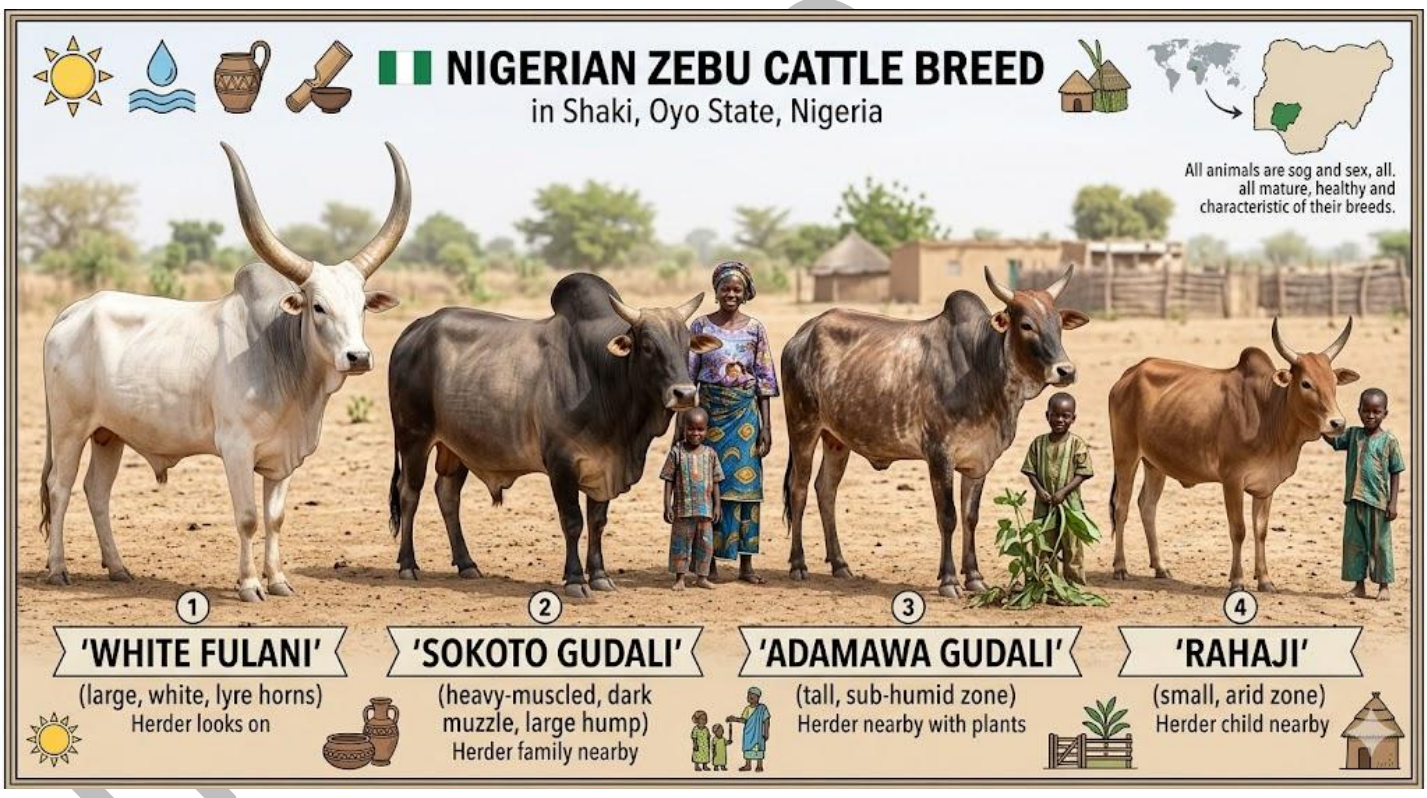

Plate 5.1: Nigerian Zebu (Bos indicus) cattle breeds: White Fulani, Sokoto Gudali, Adamawa Gudali, and Rahaji

5.1.2 Taurine (Bos taurus) and Sanga breeds of Nigeria

The **N'dama** is Nigeria's most important **Bos taurus** (taurine) cattle breed, found in the humid southwest and parts of the Middle Belt where tsetse fly challenge is severe. N'dama are small,

compact, and without a hump, with short lyre-shaped horns and a tawny to dark brown coat. Their most valuable characteristic is **trypanotolerance**: the ability to survive, maintain body condition, and reproduce in areas with high trypanosome challenge without routine trypanocidal drug treatment. This makes N'dama indispensable for communities in the tsetse belt where keeping Zebu breeds would require frequent and costly drug interventions.

The **Muturu (Dwarf Shorthorn)** is another West African taurine breed found in pockets of humid forest and derived savanna zones of southwestern Nigeria. It is even smaller than the N'dama and also trypanotolerant. **Sanga cattle** are intermediate between Zebu and taurine in origin, shaped by millennia of interbreeding between the two subspecies in the contact zone of Central and West Africa. In Nigeria, the Sanga type is represented by the **Keteku** of the Middle Belt and certain ecotypes of the White Fulani that show varying degrees of taurine introgression. Sanga cattle generally combine reasonable beef productivity with partial adaptation to the humid environment.

Fill in the blank: The N'dama is valued above all for its _____, which allows it to survive and produce in tsetse-infested zones without drug treatment.

5.1.3 Geographic distribution and production systems of Nigerian cattle

Nigerian cattle breeds are distributed along a gradient from north to south that broadly follows the agro-ecological zones. Sahelian Zebu breeds (Azawak, Rahaji) are found in the dry extreme north (Sudan and Sahel savanna zones). The White Fulani dominates the northern Guinea savanna, Sudan savanna, and the Middle Belt, kept under nomadic or semi-nomadic extensive systems by Fulani herders. The Gudali breeds are concentrated in the northwest (Sokoto-Kebbi) and northeast (Adamawa-Borno) states under semi-extensive management. The N'dama and Muturu occupy the humid forest zone and derived savanna of the southwest and parts of the south-south, kept by sedentary farmers under extensive or semi-intensive conditions.

The predominant production system for Nigerian cattle is extensive, relying on communal grazing on natural pastures and rangeland. Transhumance (seasonal migration following rainfall and pasture) is practised by Fulani herders who move cattle southward in the dry season and northward in the wet season. Government livestock multiplication centres and a small number of

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commercial ranches operate semi-intensive systems with planted pastures and concentrate supplementation. Peri-urban intensive dairy systems using Friesian-Bunaji crosses and exotic breeds are found near major cities such as Kaduna, Kano, Jos, and Lagos.

Fill in the blank: The seasonal migration of Fulani herders and their cattle following rainfall and pasture availability is called _____.

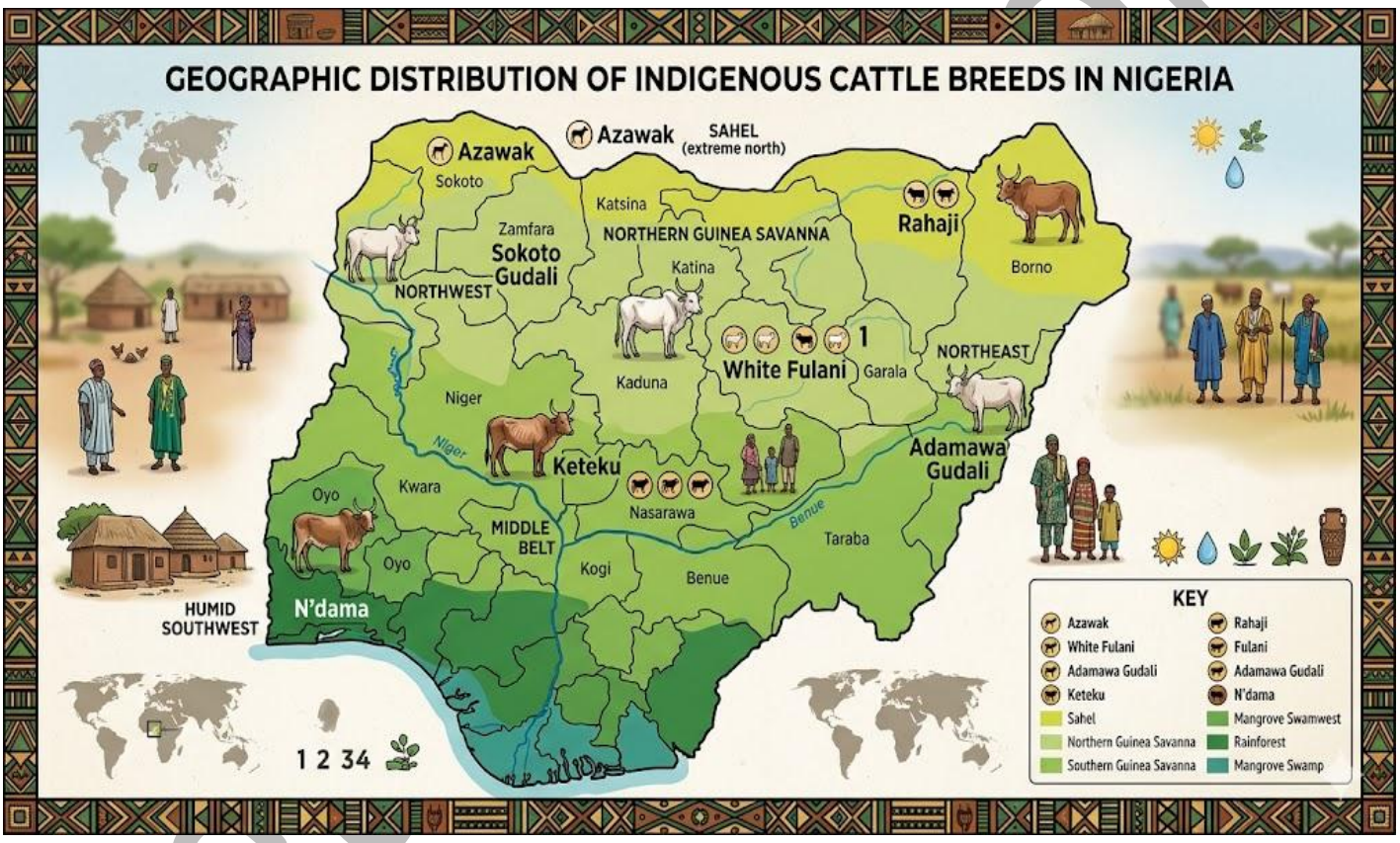

Figure 5.1: Geographic distribution of indigenous cattle breeds across Nigerian agro-ecological zones

Pilot questions 5.1

1. Name four Nigerian Zebu cattle breeds and state one distinguishing characteristic of each.
2. Describe the N'dama cattle breed and explain why it is important in the Nigerian humid zone.
3. What are Sanga cattle and how did they originate in West Africa?
4. Describe the geographic distribution of the White Fulani in Nigeria.
5. What is transhumance and why is it practised by Fulani herders?

5.2 Nigerian Indigenous Small Ruminant and Pig Breeds

5.2.1 Indigenous sheep breeds of Nigeria

Nigeria's indigenous sheep are predominantly hair sheep (not wool-bearing), adapted to tropical conditions where heavy fleece would cause heat stress. The **Yankasa** is the most widely distributed sheep breed in Nigeria, found across the northern states from Sokoto to Borno. It has a white coat with distinctive dark patches around the eyes, nose, and feet, a moderate body size, and good meat conformation. The **Uda** is a taller, long-legged breed with a bicoloured coat (black or brown foreparts and white hindquarters) adapted to the Sahelian zone. It is valued for its large body size and meat quality at festivals.

The **Balami** is the largest of Nigeria's indigenous sheep breeds, pure white with a convex nasal profile (Roman nose), found mainly in Borno and Yobe states. It is highly prized for sacrificial use at Eid-el-Kabir and commands premium market prices. The **West African Dwarf (WAD) sheep**, also called the Djallonke or Forest sheep, is found across the humid and sub-humid southern zone. It is small, dark-coated, prolific, and distinctively **trypanotolerant**, making it the dominant sheep type in the tsetse-infested south where larger breeds do not survive without drug treatment. Its small size is compensated by high litter rates and rapid turnover.

Fill in the blank: The largest indigenous sheep breed in Nigeria, pure white with a convex nasal profile and found in the northeast, is the _____.

5.2.2 Indigenous goat breeds of Nigeria

The **Red Sokoto (Maradi) goat** is the most commercially important goat breed in Nigeria, found in Sokoto, Kebbi, Zamfara, and adjacent states in the northwest. It is characterised by a reddish-brown coat, short hair, moderate body size, and, most importantly, a fine skin that produces the internationally renowned **Moroccan leather** used in premium footwear, handbags, and bookbinding. The **Sahel (Bornu) goat** is a tall, slender, long-legged goat of the extreme north,

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kept for meat and milk under harsh arid conditions and adapted to browse on thorny savanna vegetation.

The **Kano Brown (Sokoto Brown)** goat is a medium-sized, brown-coated breed found in northern Nigeria, valued for meat and skin. The **West African Dwarf (WAD) goat** is the dominant goat breed in the humid southern zone, characterised by small size, varied coat colours, high prolificacy (often twinning), and trypanotolerance. It is the most important goat for smallholder farmers in the south, who keep it for household meat supply, savings, and social ceremonies. The **Bornu White goat** is a large, white, long-legged breed of the northeast adapted to arid conditions and kept primarily for meat production.

Fill in the blank: The Red Sokoto goat is internationally valued for its fine skin, which is processed into high-quality _____ leather.

Breed Name	Species	Region of Distribution	Coat Colour & Markings	Main Production Use	Distinctive Characteristic
Yankasa	Sheep	Northern Nigeria (savanna belt)	White coat with black patches around eyes, ears, and legs	Meat and skin	Large body size, popular in northern markets
Uda	Sheep	Northern Nigeria (semi-arid zones)	White body with black or brown head and neck	Meat	Long legs, adapted to arid conditions
Balami	Sheep	Northeastern Nigeria (Sahel)	Entirely white coat	Meat and skin	Very large frame, high carcass yield
West African Dwarf (WAD) Sheep	Sheep	Southern Nigeria (humid forest)	Variable colours, often white or brown	Meat	Small size, high disease resistance

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Red Sokoto (Maradi)	Goat	Northern Nigeria (Sokoto region)	Uniform dark red coat	Skin (leather), meat	Famous for high-quality "Morocco leather"
Sahel Goat	Goat	Northern Nigeria (Sahel belt)	White or light coat, short hair	Meat	Tall, long-legged, adapted to dry climates
West African Dwarf (WAD) Goat	Goat	Southern Nigeria (humid forest)	Variable colours, often black, brown, or white	Meat	Small size, trypanotolerant, hardy in humid zones
Kano Brown Goat	Goat	Northern Nigeria (Kano region)	Brown coat	Meat and skin	Medium size, well adapted to local feeding systems

Table 5.1: Major indigenous sheep and goat breeds of Nigeria

5.2.3 Indigenous pig breeds and the Nigerian ecotype pig

Nigeria does not have formally recognised indigenous pig breeds in the conventional sense, but a diverse group of small, hardy pigs known collectively as the **Nigerian ecotype pig** (or West African Dwarf pig) is found across the Middle Belt and southern states, particularly among non-Muslim communities in Plateau, Benue, Kogi, Cross River, Anambra, and Imo states. These pigs are small (adult weight 30 to 50 kilograms), have a varied coat colour (black, brown, spotted), are prolific (litter sizes of 6 to 10 piglets), and are highly adapted to scavenging under free-range village conditions, subsisting on crop residues, kitchen waste, and foraging.

The Nigerian ecotype pig is disease-resistant and heat-tolerant but produces very lean, often tough meat in small carcasses. Its economic importance lies primarily in its role as a savings asset and a source of low-cost protein for rural households. Formal improvement of the Nigerian ecotype pig has been limited; most commercial pig production in Nigeria uses exotic Large White and Landrace breeds or their crosses, which are managed intensively and produce far more pork per animal. Research efforts have explored crossbreeding the ecotype with exotics to improve productivity while retaining local adaptation.

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Fill in the blank: The small, hardy, free-range pigs found in southern and Middle Belt Nigeria are collectively called the Nigerian _____ pig.

Pilot questions 5.2

1. Name four indigenous sheep breeds of Nigeria and state one feature of each.
2. Describe the Red Sokoto goat and explain why its skin is commercially important.
3. Why is the West African Dwarf goat the dominant goat breed in southern Nigeria?
4. Describe the Nigerian ecotype pig and explain its importance to rural households.
5. Compare the WAD sheep and WAD goat in terms of distribution, size, and production use.

5.3 Foreign Beef and Dairy Cattle Breeds

5.3.1 Exotic beef cattle breeds used in Nigeria

Several exotic beef breeds have been introduced into Nigeria through government importation and crossbreeding programmes. The **Hereford** is a British beef breed with a white face and red body, known for early maturity, good temperament, and efficient grazing. The **Charolais** is a large, white-coated French breed with exceptional growth rate and lean carcass yield, used in terminal crossbreeding to improve beef output in commercial herds. The **Simmental** is a Swiss dual-purpose breed with good growth rate and moderate milk production, valued for crossbreeding programmes seeking improvement in both beef and milk.

The **Brahman** is an American Zebu breed (**Bos indicus**) derived from Indian Zebu imports, characterised by a large hump, pendulous ears, loose skin, and strong heat and tick tolerance. It is particularly relevant to Nigeria because it shares the Zebu adaptive traits of the local breeds while having been improved for beef production. The **Boran** is an East African Zebu breed with demonstrated adaptation to tropical conditions and good growth rates under range conditions. Crossbreeding with these breeds has been explored at government livestock stations, though limited infrastructure and cold chain have restricted widespread dissemination.

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Fill in the blank: The large French beef breed with exceptional growth rate and lean carcass yield used in terminal crossbreeding is the _____.

Breed Name	Origin	Coat Colour	Body Size	Key Production Trait	Suitability for Nigerian Conditions
Hereford	United Kingdom	Red body with white face and underline	Medium–large	Good beef quality, early maturity	Moderately suitable; needs adaptation to heat and parasites
Charolais	France	White or cream	Large, heavy muscled	High growth rate, excellent carcass yield	Limited suitability; sensitive to heat stress
Simmental	Switzerland	Red and white patches	Large, dual-purpose	Good beef yield, also milk potential	Moderately suitable; requires improved management
Brahman	India (developed in USA)	Grey, red, or white	Medium–large, humped	Heat tolerance, disease resistance, beef production	Highly suitable; thrives in tropical climates
Boran	East Africa (Kenya/Ethiopia)	White to grey	Medium–large	Hardy, efficient beef production	Very suitable; adapted to African drylands

Table 5.2: Exotic beef cattle breeds used in Nigerian improvement programmes

5.3.2 Exotic dairy cattle breeds used in Nigeria

The **Friesian (Holstein-Friesian)** is the world's highest-yielding dairy breed, originating in the Netherlands and North Germany. It is large-framed, predominantly black and white, and produces 6,000 to 10,000 litres of milk per lactation under optimal conditions. In Nigeria, Friesians are kept at government dairy multiplication centres and commercial peri-urban farms,

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where they require intensive management, high-quality feed, veterinary support, and cooling facilities to perform adequately in the tropical heat. The **Brown Swiss** is a Swiss dual-purpose breed with good milk yield and higher heat tolerance than the Holstein, making it better suited to tropical conditions.

The **Jersey** is a small, fawn-coloured dairy breed from the Channel Islands, known for the highest butterfat content of any major dairy breed (4.5 to 5.5 percent), heat tolerance relative to Holstein, and efficiency of milk production per unit of body weight. The **Guernsey** produces milk with high fat and protein and distinctive golden colour from elevated beta-carotene content. Both Jersey and Guernsey have been used in crossbreeding programmes with local Nigerian cattle to improve milk fat yield while maintaining animal health in tropical conditions. The Friesian-Bunaji cross remains the most widely used dairy crossbred in Nigeria.

Fill in the blank: The Jersey breed is valued for its milk, which has the highest _____ content of any major dairy breed.

5.3.3 Crossbreeding of exotic and indigenous cattle in Nigeria

The dominant crossbreeding strategy for dairy improvement in Nigeria is the Friesian x White Fulani (Bunaji) cross, producing F1 animals that are 50 percent Friesian and 50 percent Bunaji. F1 cows typically yield 1,500 to 2,500 litres per lactation under semi-intensive management, compared to 300 to 600 litres for the purebred Bunaji. The F1 retains the Bunaji's heat tolerance and disease resistance while gaining the Friesian's superior milk secretory capacity. Grading up beyond 75 percent Friesian is generally discouraged in most Nigerian environments due to the declining adaptive traits and increasing management requirements.

For beef improvement, government programmes have used Charolais, Simmental, and Brahman sires in terminal crosses with White Fulani cows to produce F1 steers with improved growth rates and carcass quality for the urban beef market. The Brown Swiss has also been used as a sire breed for dual-purpose improvement in smallholder systems where both milk and beef income are important. The choice of exotic sire breed depends on the production objective, available management inputs, and the agro-ecological zone, with Zebu-type exotics (Brahman, Boran) better suited to extensive low-input systems in the north.

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Fill in the blank: In Nigeria, the most widely used dairy crossbred is the F1 from crossing _____ with White Fulani (Bunaji) cows.

Pilot questions 5.3

1. Name three exotic beef cattle breeds used in Nigeria and state one production characteristic of each.
2. Why is the Brahman considered more suitable than Charolais for extensive beef production in northern Nigeria?
3. Describe the Friesian breed and explain why it requires intensive management in Nigeria.
4. Why is the Jersey breed considered an attractive option for crossbreeding in Nigerian dairy systems?
5. Describe the typical milk yield of a Friesian-Bunaji F1 cow compared to a purebred Bunaji.

5.4 Foreign Small Ruminant, Pig, and Poultry Breeds

5.4.1 Exotic sheep and goat breeds used in Nigeria

Several exotic sheep and goat breeds have been introduced into Nigeria for crossbreeding and research purposes. The **Dorper** is a South African composite meat sheep breed (Dorset Horn x Blackhead Persian) that has attracted attention in Nigeria for its exceptional growth rate, meat quality, and adaptation to hot, semi-arid conditions. Its white body with black head is distinctive, and it sheds its light fleece naturally, avoiding the need for shearing. The **Merino** is a fine-wool breed of Spanish origin kept worldwide for wool production; it has been evaluated in northern Nigeria at government stations but has not become commercially significant due to limited demand for wool.

For goats, the **Saanen** is a Swiss dairy goat breed producing 800 to 1,200 litres of milk per lactation, white-coated, large-framed, and one of the highest-yielding dairy goat breeds globally. It has been introduced to Nigerian government research stations for dairy goat development. The **Boer goat** is a South African meat goat breed characterised by a white body with a red or brown head, large frame, and rapid growth rate; it is valued in terminal crossbreeding onto WAD or Red

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Sokoto does to improve kid growth rate and carcass weight for the commercial meat market. The **Anglo-Nubian** is a dual-purpose dairy and meat goat with long pendulous ears, Roman nose, and high milk butterfat content, kept at some Nigerian research stations.

Fill in the blank: The South African meat goat breed used in terminal crossbreeding to improve kid growth rate in Nigeria is the _____ goat.

Breed Name	Species	Origin	Coat Colour	Production Type	Status in Nigeria
Dorper	Sheep	South Africa	White body with black head (or all white)	Meat	Introduced for crossbreeding; limited but growing use
Merino	Sheep	Spain (developed in Australia)	Fine white wool	Wool	Rare; experimental use, not widely adopted
Saanen	Goat	Switzerland	White or cream	Dairy	Introduced for milk improvement; small populations
Boer Goat	Goat	South Africa	White body with red/brown head	Meat	Widely used for crossbreeding; popular for meat production
Anglo-Nubian	Goat	United Kingdom (mixed Middle Eastern ancestry)	Variable colours, often brown or black with markings	Dual-purpose (milk and meat)	Present in small numbers; valued for adaptability

Table 5.3: Exotic sheep and goat breeds used in Nigerian improvement programmes

5.4.2 Exotic pig breeds used in Nigerian commercial production

Commercial pig production in Nigeria relies almost exclusively on two European improved breeds and their crosses. The **Large White (Yorkshire)** is a large, white, erect-eared breed from northern England, one of the most widely distributed pig breeds in the world. It is known for

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large litter sizes (10 to 14 piglets born alive), good maternal ability, excellent growth rate, and lean carcass. It is used as the dam line in most commercial pig production systems, providing the reproductive performance and maternal traits essential for profitability. The **Landrace** is a long-bodied, white, droopy-eared breed of Danish origin, known for exceptional length and high loin lean yield. It is widely used as the sire line in commercial pig production and in combination with Large White in F1 hybrid production.

The Large White x Landrace F1 hybrid is the standard commercial dam line in intensive Nigerian pig farms, combining the reproductive performance of the Large White with the carcass length and lean yield of the Landrace. Terminal sires of the Duroc, Pietrain, or Hampshire breeds are sometimes used on F1 dams to produce market pigs with improved growth rate and lean meat percentage. The Duroc, an American red-coated breed, is valued for its growth rate and meat quality (intramuscular fat giving good flavour). The Pietrain, a Belgian breed with distinctive black-and-white spotted coat, provides extreme lean carcass yield but carries the Halothane gene (porcine stress syndrome) in some lines, which must be screened out.

Fill in the blank: The Large White breed is used as the _____ line in commercial pig production because of its large litter size and good maternal ability.

Tier	Genetic Base	Notes
Nucleus	Pure breeds (Large White, Landrace)	Maintains elite genetic lines; selection for growth, reproduction, and carcass traits; foundation of pyramid
Multiplier	F1 hybrid gilts (crosses of nucleus breeds)	Expands genetic material; produces replacement breeding stock; ensures wider distribution of improved genetics
Commercial Tier	Terminal sire cross (e.g., Duroc × F1 gilts)	Produces pigs for slaughter; maximizes heterosis (hybrid vigor) for growth rate, feed efficiency, and carcass quality

Box 5.1: The commercial pig breeding pyramid in Nigeria

5.4.3 Commercial poultry breeds and their global distribution

Commercial poultry production worldwide is based on highly specialised breeds developed by a small number of multinational breeding companies. For **broiler (meat) production**, the

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dominant lines are produced by Cobb-Vantress, Aviagen (Ross), and Hubbard. These broiler lines are composites of White Plymouth Rock, White Cornish, and New Hampshire breeds, selected for rapid growth (reaching market weight of 2.5 to 3 kilograms in 35 to 42 days), high breast meat yield, and superior feed conversion ratio. Broiler breeders supply parent stock (P) to multiplier farms, which produce the commercial F1 broiler chicks distributed to grow-out farms.

For **layer (egg) production**, dominant commercial lines are produced by Hy-Line, Lohmann, Novogen, and ISA (Institut de Selection Animale). White egg-laying strains are based on White Leghorn genetics, while brown egg-laying strains derive from Rhode Island Red, New Hampshire, and Plymouth Rock crosses. Commercial layers produce 300 to 320 eggs per hen per year in modern production systems. In Nigeria, both broiler and layer production are supplied by day-old chicks from local hatcheries that import parent stock from the multinational breeding companies. Indigenous Nigerian poultry ecotypes (local chickens, Muscovy ducks, guinea fowl, and turkeys) remain important for subsistence and village-level production but are being studied for conservation and improvement potential.

Fill in the blank: Commercial white egg-laying strains of poultry are based on genetics derived from the _____ Leghorn breed.

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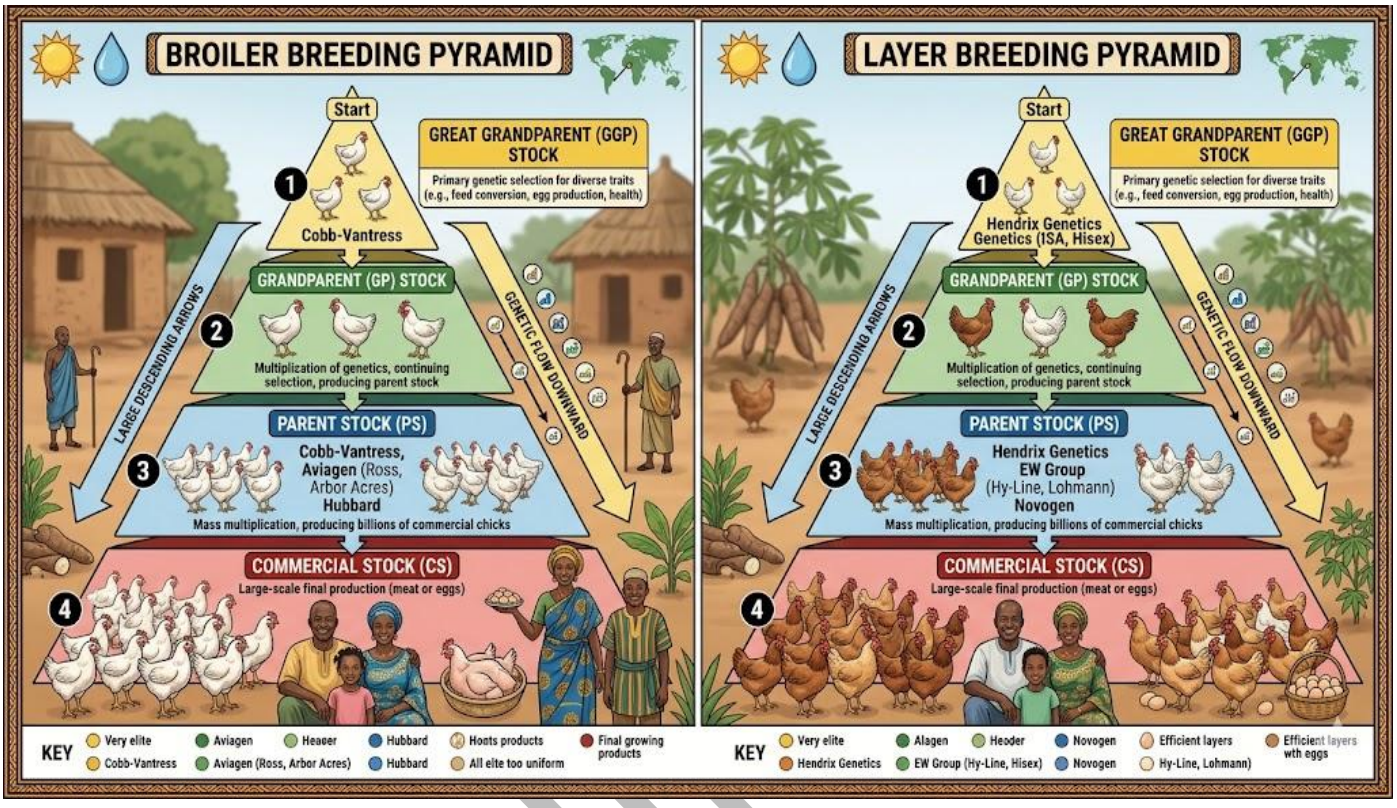

Figure 5.2: The global commercial poultry breeding pyramid for broilers and layers

Pilot questions 5.4

1. Describe the Dorper sheep breed and explain its potential for crossbreeding in Nigeria.
2. Compare the Saanen and Boer goat breeds in terms of production purpose and role in Nigerian improvement.
3. Describe the Large White pig breed and explain why it is used as the dam line in commercial production.
4. What is the role of the Landrace breed in commercial pig production and how does it complement the Large White?
5. Describe the pyramid structure of commercial poultry production from great-grandparent to commercial tier.

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Series Summary

This final Series has provided a comprehensive survey of the indigenous and exotic livestock breeds that are distributed in and used within Nigeria. We began with the indigenous cattle breeds, examining the dominant Zebu types (White Fulani, Sokoto Gudali, Adamawa Gudali, Rahaji, Azawak), the trypanotolerant taurine N'dama and Muturu, and the intermediate Sanga Keteku, together with their geographic distribution across Nigeria's agro-ecological zones and the production systems associated with each. We then described the indigenous sheep breeds (Yankasa, Uda, Balami, WAD), goat breeds (Red Sokoto, Sahel, WAD, Kano Brown), and the Nigerian ecotype pig.

Moving to foreign breeds, we examined the exotic beef breeds (Hereford, Charolais, Simmental, Brahman, Boran) and dairy breeds (Friesian, Brown Swiss, Jersey, Guernsey) used in Nigerian improvement programmes, and described the Friesian-Bunaji crossbreeding strategy that underpins commercial dairy development in Nigeria. The Series concluded by describing exotic small ruminant breeds (Dorper, Merino, Saanen, Boer, Anglo-Nubian), commercial pig breeds (Large White, Landrace, Duroc, Pietrain) and their pyramid breeding structure, and the global commercial poultry industry based on highly specialised broiler and layer lines from multinational breeding companies. Together, this knowledge of breed characteristics and distribution enables informed decisions about breed selection, crossbreeding, and conservation in Nigerian livestock production.

Glossary of Terms

- **Adamawa Gudali:** A large Zebu beef cattle breed of northeastern Nigeria, adapted to the sub-humid Guinea savanna zone.
- **Balami:** The largest indigenous sheep breed of Nigeria, pure white with a Roman nose, found mainly in Borno and Yobe states and highly valued for ceremonial use.
- **Boer goat:** A large South African meat goat breed with a white body and red or brown head, used in terminal crossbreeding to improve kid growth rate and carcass weight.

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- **Bos indicus:** The Zebu subspecies of domestic cattle, characterised by a thoracic hump, large dewlap, pendulous ears, and adaptation to tropical heat and tick challenge.
- **Bos taurus:** The taurine subspecies of domestic cattle, without a hump, originating in Europe and the Middle East; includes the N'dama in West Africa.
- **Dorper:** A South African meat sheep breed (Dorset Horn x Blackhead Persian cross) with exceptional growth rate, meat quality, and heat tolerance; sheds its light fleece naturally.
- **Friesian (Holstein-Friesian):** The world's highest-yielding dairy cattle breed, originating in the Netherlands and North Germany, black and white in colour, requiring intensive management in tropical conditions.
- **Jersey:** A small, fawn-coloured dairy breed from the Channel Islands, known for the highest butterfat content among major dairy breeds and relative heat tolerance.
- **Landrace:** A long-bodied, droopy-eared Danish pig breed with high carcass lean yield, widely used as the sire line in commercial pig production.
- **Large White (Yorkshire):** A large, erect-eared English pig breed valued for large litter size and good maternal ability, widely used as the dam line in commercial pig production.
- **N'dama:** A West African taurine (Bos taurus) cattle breed of the humid zone, characterised by small size, tawny coat, and trypanotolerance.
- **Red Sokoto (Maradi) goat:** An indigenous Nigerian goat breed from the northwest, with a distinctive reddish coat and fine skin that produces high-quality Moroccan leather.
- **Sanga cattle:** Cattle of intermediate Zebu-taurine genetic origin, shaped by millennia of interbreeding between Bos indicus and Bos taurus populations in Central and West Africa.
- **Transhumance:** The seasonal migration of livestock herders and their animals between wet-season northern pastures and dry-season southern pastures, practised by Fulani herders in Nigeria.
- **West African Dwarf (WAD):** A group of small, prolific, trypanotolerant sheep and goat breeds found in the humid zones of West Africa, important for smallholder farmers in southern Nigeria.

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Concept Check Questions [Series 5]

Objective Questions

1. Define Bos indicus. (Linked to SLO 5.1)
2. The N'dama cattle breed is valued primarily for its: a) High milk yield b) Large body size c) Trypanotolerance d) Wool production (Linked to SLO 5.2)
3. The Red Sokoto goat is commercially important because its skin produces: a) Wool b) High-quality Moroccan leather c) Cashmere fibre d) Coarse leather for sole use (Linked to SLO 5.4)
4. The world's highest-yielding dairy cattle breed, widely used in Nigerian crossbreeding programmes, is the _____. (Linked to SLO 5.6)
5. The most common dam line in commercial pig production combines Large White and _____ genetics to produce F1 hybrid gilts. (Linked to SLO 5.8)

Short Answer Questions

1. Name four Nigerian Zebu cattle breeds and state one adaptive characteristic shared by all of them. (Linked to SLO 5.1)
2. Explain why the West African Dwarf goat is the dominant goat breed in southern Nigeria despite its small size. (Linked to SLO 5.4)
3. Describe the Friesian-Bunaji crossbreeding strategy and explain the production advantage of the F1 cow over the purebred Bunaji. (Linked to SLO 5.7)
4. Compare the Large White and Landrace pig breeds and explain their complementary roles in commercial pig production. (Linked to SLO 5.8)
5. Describe the structure of the global commercial poultry breeding pyramid from great-grandparent to commercial tier. (Linked to SLO 5.9)

Long Answer Questions

1. Describe the major indigenous cattle, sheep, and goat breeds of Nigeria, explaining their geographic distribution, adaptive traits, and production uses, and evaluate their importance for food security and livelihoods. (Linked to SLO 5.1, SLO 5.2, SLO 5.3, SLO 5.4)

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2. Describe the exotic beef and dairy cattle breeds used in Nigeria and evaluate the crossbreeding strategies employed to improve Nigerian cattle productivity, with specific reference to the Friesian-Bunaji programme. (Linked to SLO 5.6, SLO 5.7)
3. Describe the foreign small ruminant, pig, and poultry breeds used in Nigeria and evaluate the contribution of these exotic genetics to commercial livestock production in the country. (Linked to SLO 5.8, SLO 5.9, SLO 5.10)

Answers to Concept Check Questions [Series 5]

Objective Questions

1. Bos indicus is the Zebu subspecies of domestic cattle, characterised by a cervicothoracic hump, pendulous ears, large dewlap, and adaptation to tropical heat and tick challenge.
2. Correct answer: c) Trypanotolerance.
3. Correct answer: b) High-quality Moroccan leather.
4. Friesian (Holstein-Friesian).
5. Landrace.

Short Answer Questions

1. Four Nigerian Zebu breeds are: White Fulani, Sokoto Gudali, Adamawa Gudali, and Rahaji. The adaptive characteristic shared by all Zebu breeds is adaptation to tropical heat through numerous skin sweat glands, large body surface area relative to mass, heat-tolerant skin pigmentation, and relative resistance to tick infestation.
2. The WAD goat thrives in southern Nigeria because it is trypanotolerant, surviving and producing in tsetse-infested areas where larger Zebu-type breeds require continuous trypanocidal drug treatment. Its high prolificacy (frequent twinning) compensates for low individual carcass weight with rapid herd turnover, and its adaptability to humid conditions and low-quality feed makes it ideal for resource-poor smallholder farming.
3. Friesian bulls are used through AI to mate White Fulani (Bunaji) cows, producing F1 offspring that are 50 percent Friesian and 50 percent Bunaji. F1 cows typically yield 1,500 to 2,500 litres per lactation under semi-intensive management, compared to 300 to 600 litres for

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the purebred Bunaji. The F1 retains the Bunaji's heat tolerance and disease resistance while gaining the Friesian's superior milk secretory capacity.

4. The Large White is a large, erect-eared breed with excellent reproductive performance (10 to 14 piglets born alive) and good maternal ability; it is used as the dam line. The Landrace is a long-bodied, droopy-eared breed with superior carcass length and lean meat yield; it is used as the sire line. Crossing the two produces F1 hybrid gilts that combine large litter size with lean carcass, maximising both reproductive and market efficiency.
5. The breeding pyramid has four tiers: the great-grandparent (GGP) tier, maintained by multinational breeding companies as closed nucleus flocks with the highest genetic merit; the grandparent (GP) tier, which multiplies GGP genetics to produce parent stock; the parent (P) tier, where parent males and females are crossed to produce commercial F1 chicks; and the commercial tier, where F1 broilers are grown to market weight or F1 layers produce eggs for consumption.

Long Answer Questions

1. Basic response: Nigerian Zebu breeds (White Fulani, Sokoto Gudali, Adamawa Gudali, Rahaji, Azawak) are distributed across the northern agro-ecological zones and are valued for beef, draught, and milk. The N'dama taurine breed occupies the humid southwest and is valued for trypanotolerance. WAD sheep and goats dominate the south due to trypanotolerance, while Yankasa, Uda, and Balami sheep and Red Sokoto and Sahel goats are important in the north.
2. Value-added response: The adaptive traits of indigenous breeds are the product of centuries of natural and human selection under Nigerian conditions. Trypanotolerance in N'dama and WAD breeds is a heritable trait controlled by multiple genes, representing a genetic resource of global significance. Systematic characterisation and conservation of these breeds is essential both for sustaining smallholder livelihoods in low-input systems and as a genetic reservoir for future breeding programmes. The risk of genetic erosion through indiscriminate crossbreeding with exotics, without retaining pure indigenous populations, is a real concern for Nigerian animal genetic resource conservation.
3. Basic response: Exotic beef breeds used in Nigeria include Charolais (high growth rate, lean carcass), Simmental (dual-purpose), Brahman (Zebu-type, heat-tolerant), and Boran (East African adapted). Dairy breeds include Friesian (highest milk yield), Brown Swiss (better heat tolerance), and Jersey (high butterfat). The Friesian-Bunaji F1 cross is the dominant

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dairy improvement strategy, yielding 1,500 to 2,500 litres per lactation versus 300 to 600 for purebred Bunaji.

4. Value-added response: The choice of exotic sire breed must match the production environment and management capacity. Friesian sires are appropriate for peri-urban intensive dairy with access to quality feed and veterinary services. In sub-humid and semi-arid zones with limited inputs, Brahman or Boran sires on local dams produce more viable crossbreds than European dairy breeds. The optimal exotic genetic level (typically 50 to 75 percent in humid zones, lower in arid zones) should be determined by local performance trials rather than assumed from temperate data, because GxE interactions mean that EBVs from European evaluations overestimate performance under Nigerian conditions.
5. Basic response: Exotic sheep include Dorper (meat, adapted to heat), Merino (wool, limited commercial role), and Saanen (dairy goat, research stations). Pigs rely on Large White (dam line, large litters) and Landrace (sire line, lean carcass) with Duroc and Pietrain terminal sires. Poultry use specialised broiler (Cobb, Ross) and layer (Hy-Line, Lohmann) lines from multinational companies, distributed through parent stock and hatchery networks.
6. Value-added response: The contribution of exotic genetics to Nigerian commercial production is greatest in intensive peri-urban systems (dairy, pig, poultry) where management and inputs can support their requirements. In extensive smallholder systems, the contribution is more limited because exotic breeds require inputs that are unavailable or unaffordable. The most sustainable model for Nigeria is a differentiated strategy: intensive peri-urban systems using high-exotic-content crossbreds or pure exotics for dairy, pig, and poultry; and extensive rural systems using indigenous breeds or low-exotic-content crossbreds with superior adaptation. Conservation of indigenous breeds as a genetic resource is an integral part of this strategy, not an afterthought.

Answers to Pilot Questions [Series 5]

Part 5.1: Nigerian Indigenous Cattle Breeds

1. White Fulani: large, white, lyre-horned, most widely distributed. Sokoto Gudali: heavy-muscled, large hump, dark muzzle, northwest Nigeria. Adamawa Gudali: tall, sub-humid Guinea savanna, northeast. Rahaji: small, drought-tolerant, Lake Chad Basin arid north.

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2. The N'dama is a small, compact, humpless taurine (Bos taurus) breed with a tawny to dark brown coat and short lyre-shaped horns, found in the humid southwest. Its most important characteristic is trypanotolerance, enabling it to survive, maintain condition, and reproduce in areas of high tsetse fly challenge without the continuous trypanocidal drug treatment required by Zebu breeds, making it essential for cattle keeping in the Nigerian tsetse belt.
3. Sanga cattle are an intermediate genetic type between Zebu (Bos indicus) and taurine (Bos taurus) cattle, formed by millennia of natural interbreeding between the two subspecies in the contact zones of Central and West Africa. They were not deliberately created by breeders but arose from the coexistence and intermixing of Zebu and taurine herds in the same geographical areas over thousands of years.
4. The White Fulani is distributed across the northern Guinea savanna, Sudan savanna, and Middle Belt of Nigeria, from Sokoto and Zamfara states in the northwest through Kaduna, Niger, Kwara, and Benue states in the Middle Belt. It is kept predominantly by Fulani pastoralists under nomadic or semi-nomadic extensive management systems, moving seasonally to follow rainfall and pasture.
5. Transhumance is the practice of moving livestock herds seasonally between complementary pasture areas, typically moving northward during the wet season when northern pastures are green and moving southward during the dry season when southern areas retain moisture and pasture quality. Fulani herders practise it to maintain herd nutrition year-round in an environment where no single location provides adequate pasture throughout the year.

Part 5.2: Nigerian Indigenous Small Ruminant and Pig Breeds

1. Yankasa: white coat with dark patches on face and feet, most widely distributed sheep breed, good meat conformation. Uda: tall, bicoloured (black or brown front, white hindquarters), Sahelian zone, large body size. Balami: pure white, Roman nose, largest indigenous sheep, Borno and Yobe states. WAD sheep: small, dark-coated, trypanotolerant, humid south, high prolificacy.
2. The Red Sokoto goat is a medium-sized, reddish-brown short-haired goat from the northwest of Nigeria. Its skin is commercially important because it produces the fine, tightly-grained leather known as Moroccan or Sokoto leather, which commands high prices in international markets for use in premium footwear, handbags, and bookbinding.
3. The WAD goat is dominant in southern Nigeria because it is trypanotolerant, enabling it to survive in the tsetse-infested humid zone where non-tolerant breeds require frequent drug

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treatment. It is also well adapted to humid conditions and low-quality tropical feed, prolific with frequent twinning, and capable of maintaining productivity on the low-cost scavenging systems typical of southern Nigerian smallholder farms.

4. The Nigerian ecotype pig is a group of small (30 to 50 kilograms), varied-coloured, free-range pigs found in the Middle Belt and southern states. They are highly adapted to scavenging on crop residues and kitchen waste without formal feeding, are heat-tolerant and disease-resistant, and are prolific with litter sizes of 6 to 10. They serve as savings assets and a low-cost protein source for rural households that cannot afford or access exotic pig breeds.
5. Both WAD sheep and WAD goats are small, dark-coated, prolific, and trypanotolerant, found in the humid southern zone of Nigeria. WAD sheep are slightly larger than WAD goats and are primarily kept for meat; they are found in both humid and sub-humid zones. WAD goats are more widespread in the deep humid south and serve multiple purposes including meat, cash income, and social obligations, and are more commonly kept in village scavenging systems than WAD sheep.

Part 5.3: Foreign Beef and Dairy Cattle Breeds

1. Hereford: white face, red body, good temperament and early maturity. Charolais: large, white, exceptional growth rate and lean carcass yield. Simmental: dual-purpose, good growth rate and moderate milk production.
2. The Brahman is itself a Zebu (Bos indicus) breed, sharing the heat-tolerant physiology, tick resistance, and drought adaptability of the local Nigerian Zebu breeds. Under extensive northern conditions with limited water, poor dry-season forage, and high tick challenge, the Brahman maintains body condition and continues growing where European taurine breeds such as Charolais would suffer severe heat stress, tick load, and disease susceptibility.
3. The Friesian is the world's highest-yielding dairy breed, a large black and white breed producing 6,000 to 10,000 litres per lactation under optimal conditions. It requires intensive management in Nigeria because its high milk production capacity demands high-quality feed in large quantities, cool housing (fans or shade), reliable veterinary care, and regular parasite control, all of which are costly and infrastructure-dependent. Without these inputs, production drops sharply and disease rates increase.
4. The Jersey is an attractive crossbreeding option because it is smaller and more heat-tolerant than the Holstein, produces milk with the highest butterfat content of any major dairy breed (4.5 to 5.5 percent), and is efficient per unit of body weight. Jersey-Bunaji crossbreds

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therefore produce high-value whole milk and butter in a smaller, more manageable animal that is less demanding of feed and housing than Holstein-Bunaji crosses.

5. A Friesian-Bunaji F1 cow typically yields 1,500 to 2,500 litres of milk per lactation under semi-intensive management in Nigeria. In contrast, a purebred Bunaji cow produces only 300 to 600 litres per lactation under similar conditions. The F1 therefore produces three to five times more milk, substantially improving household dairy income while retaining the Bunaji's heat tolerance and disease resistance.

Part 5.4: Foreign Small Ruminant, Pig, and Poultry Breeds

1. The Dorper is a South African composite meat sheep (Dorset Horn x Blackhead Persian) with a white body and black head, which sheds its light fleece naturally. For crossbreeding in Nigeria, it offers exceptional growth rate and meat quality in terminal crosses on Yankasa or WAD ewes, producing heavier market lambs in a shorter time, and its heat tolerance and adaptability to semi-arid conditions make it more suitable than most European breeds.
2. The Saanen is a Swiss dairy goat, large-framed and white, producing 800 to 1,200 litres of milk per lactation; it is used in Nigeria at research stations for dairy goat development and crossbreeding to improve milk yield. The Boer goat is a South African meat goat with a white body and brown or red head, used in terminal crossbreeding onto local does to improve kid growth rate and carcass weight for commercial meat markets. The Saanen is a dairy type, while the Boer is a meat type.
3. The Large White is a large, erect-eared, white pig breed from England with large litter sizes (10 to 14 born alive), good milk production, and calm temperament. It is used as the dam line because reproductive efficiency (litter size and weaning weight) is the primary driver of commercial pig farm profitability, and the Large White excels in these maternal traits.
4. The Landrace is a long-bodied, droopy-eared, white Danish breed with superior carcass length and lean meat yield compared to the Large White. As the sire line, it contributes carcass quality to the F1 market pig. Together with the Large White, it produces F1 hybrid gilts that combine reproductive performance (from Large White) with lean carcass (from Landrace), outperforming either purebred as a commercial dam.
5. The four tiers are: great-grandparent (GGP) tier, maintained by multinational breeding companies in closed nucleus flocks with the highest genetic merit for production traits; grandparent (GP) tier, which multiplies GGP stock and sells GP birds to parent farms; parent (P) tier, where parent males and females are mated to produce commercial F1 chicks or

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hatching eggs; and commercial tier, where F1 broilers are grown to market weight or F1 layers produce consumption eggs. Genetic improvement flows downward from GGP to commercial; the GGP company captures the value of genetic progress at every level.

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Figures, Plates, Tables, and Boxes

- Plate 5.1: Nigerian Zebu (Bos indicus) cattle breeds: White Fulani, Sokoto Gudali, Adamawa Gudali, and Rahaji Attribution: AI generated. Suggested OER search string: "Nigerian Zebu cattle breeds White Fulani Sokoto Gudali Adamawa Gudali Rahaji photos OER".
- Figure 5.1: Geographic distribution of indigenous cattle breeds across Nigerian agro-ecological zones Attribution: AI generated. Suggested OER search string: "Nigeria map indigenous cattle breeds distribution agro-ecological zones White Fulani N'dama Gudali OER".
- Table 5.1: Major indigenous sheep and goat breeds of Nigeria Attribution: AI generated. Suggested OER search string: "Nigerian indigenous sheep goat breeds Yankasa Uda Balami WAD Red Sokoto Sahel table OER".
- Table 5.2: Exotic beef cattle breeds used in Nigerian improvement programmes Attribution: AI generated. Suggested OER search string: "exotic beef cattle breeds Nigeria Hereford Charolais Simmental Brahman Boran table OER".

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- Table 5.3: Exotic sheep and goat breeds used in Nigerian improvement programmes Attribution: AI generated. Suggested OER search string: "exotic sheep goat breeds Nigeria Dorper Merino Saanen Boer Anglo-Nubian table OER".
- Box 5.1: The commercial pig breeding pyramid in Nigeria Attribution: AI generated. Suggested OER search string: "commercial pig breeding pyramid Nigeria Large White Landrace F1 hybrid terminal sire Duroc OER box".
- Figure 5.2: The global commercial poultry breeding pyramid for broilers and layers Attribution: AI generated. Suggested OER search string: "commercial poultry breeding pyramid broiler layer GGP GP parent commercial tiers Cobb Ross Hy-Line OER diagram".

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