minimal inputs, suggesting that much of the advantage lies in the first cross. Similar patterns have been reported for other crossbreeding schemes, where positive heterosis for birth and yearling weight and post-weaning growth was greatest in the initial crossbred generation before diminishing in later backcrosses (Prastowo et al., 2019; Chavala et al., 2023). These results support breeding strategies that prioritize robust F_1 or other limited-generation crosses, combined with improved nutrition and health, rather than indiscriminately increasing the proportion of specialized meat breeds.

5.2 Application of marker-assisted selection (MAS)

Marker-assisted selection (MAS) uses DNA markers associated with growth traits to enrich breeding populations for favorable alleles earlier and more accurately than phenotype-based selection alone. Genome-wide association studies (GWAS) in diverse goat populations have identified numerous single nucleotide polymorphisms (SNPs) linked to body weight, body length, height, chest circumference, and carcass traits, pointing to genes involved in skeletal growth, muscle development, and energy metabolism (Shangguan et al., 2024). In meat and dual-purpose goats, MAS for such loci can complement conventional selection indices built on estimated breeding values for weights and gains, allowing breeders to identify superior kids before full performance records are available (Moaeen-Ud-Din et al., 2022; Ncube et al., 2025).

Selection signature and candidate-gene studies provide further targets for MAS by revealing genomic regions under strong artificial or natural selection for growth. Whole-genome scans in indigenous and improved breeds have pinpointed genes related to body size, muscle accretion, and fat metabolism, including loci with functional variants such as an insertion–deletion polymorphism in PNLIPRP1 associated with enhanced early growth. Copy-number-variation and SNP-based GWAS in cashmere and meat goats have also highlighted growth-related genes involved in cell proliferation, differentiation, and key signaling pathways, suggesting that multi-marker panels could be assembled for routine MAS in breeding nuclei (Liu et al., 2025; Zhang et al., 2025). For smallholder systems, incorporating a limited set of well-validated markers into low-density genotyping tools offers a practical route to integrate genomics into growth-oriented selection programs.

5.3 Mechanisms of genetic improvement on growth performance

Genetic improvement of growth performance operates through both additive and non-additive effects on traits such as birth, weaning, and yearling weight, as well as average daily gain. Heritability estimates for these traits in crossbred and indigenous goats are typically low to moderate, implying that selection can steadily improve early growth and marketing weights when pedigree and performance records are available. Meta-analyses across small ruminants also indicate that efficiency and resilience traits have exploitable genetic variation, supporting selection for animals that maintain growth under variable environments without excessive increases in mature size or health problems (Mucha et al., 2022).

At the molecular level, growth is regulated by complex networks involving endocrine axes, structural proteins, and signaling pathways that govern muscle hypertrophy, bone growth, and nutrient use. Candidate-gene and genomic studies in goats highlight polymorphisms in growth hormone, insulin-like growth factor-1, myostatin, and multiple loci uncovered by GWAS that affect muscle growth, fat deposition, and carcass composition, thereby influencing overall growth efficiency (Shangguan et al., 2024; Ncube et al., 2025). Pathway analyses repeatedly implicate metabolic and MAPK signaling routes, along with genes affecting body size and lipid metabolism, indicating that selection on these genomic regions alters the balance between lean tissue accretion, maintenance requirements, and feed conversion (Guo et al., 2018; Zhang et al., 2025). Integrating this knowledge into breeding schemes—through indices that weigh growth, efficiency, and health, supported by genomic prediction—provides a mechanistic basis for designing goat populations with faster, more efficient growth adapted to specific feeding systems.

6 Health Management and Disease Prevention Measures

6.1 Effects of common diseases on growth performance

Infectious and parasitic diseases are major constraints on growth performance in goats, primarily by depressing feed intake, diverting nutrients to the immune response, and directly damaging target organs. Gastrointestinal