

### 2.3 Health status and immune performance indicators

Health and immune indicators are essential components of goat growth evaluation systems, because rapid gains achieved at the expense of resilience can undermine long-term productivity. Hematological variables such as hemoglobin, packed cell volume, and leukocyte counts, together with rectal temperature and clinical observations, provide a basic assessment of health across management systems. In Beetal kids compared under stall-fed and free-range grazing conditions, stall-fed animals displayed better overall growth and health profiles, while free-range kids often showed higher antioxidant enzyme activities, reflecting differing oxidative challenges and adaptive responses (Bhinder et al., 2024). Comparisons of free-range, semi-intensive and fully barn-kept Thai native goats revealed that continuous confinement led to weight loss, elevated red and white blood cell counts, increased neutrophil-to-lymphocyte ratio, cortisol, and higher gastrointestinal parasite egg counts, highlighting how management and associated feeding patterns can induce physiological stress despite controlled nutrition (So-In, 2023).

At a finer level, immune and oxidative stress biomarkers are widely used in feeding trials to link diet composition to health-related performance. Supplementing goat diets with garlic skin enhanced serum activities of superoxide dismutase, glutathione peroxidase and catalase, reduced malondialdehyde, and elevated IgA and IgG, alongside increased anti-inflammatory cytokines (IL-4, IL-10) and reduced pro-inflammatory cytokines (IL-1 $\beta$ , IL-6, TNF- $\alpha$ ) (Zhou and Shen, 2025). Cecropin supplementation similarly increased antioxidant enzyme activities, improved immunoglobulin levels, and shifted rumen fermentation and microbiota composition, coinciding with better growth and lower feed-to-gain ratio. Meta-analytic evidence for yeast additives also points to higher blood glucose, white blood cell counts and ruminal propionate and total VFA, indicating combined metabolic and immune modulation (Ogbuewu and Mbajorgu, 2023). Together, these findings support incorporating antioxidant status, immunoglobulins, cytokine profiles and selected hematological traits into growth performance evaluation, ensuring that feeding strategies promote both productivity and robust immune function.

## 3 Nutritional Requirements and Diet Formulation for Goats

Nutritional requirements of goats vary with age, physiological stage, and environmental conditions, making precise feeding management essential for optimal growth. During rapid growth, energy and protein demands increase significantly, requiring adjustments in nutrient density and intake. Higher energy and protein levels generally promote better weight gain and feed efficiency, while environmental stress, such as heat, can shift nutrient use toward maintenance rather than growth. Modern feeding standards emphasize stage-specific nutrient supply, considering body weight and growth status. Mineral needs, particularly calcium and phosphorus, rise moderately with body weight, allowing for more accurate and efficient diet formulation in growing goats.

### 3.1 Nutritional characteristics at different growth stages

Nutritional priorities shift markedly from pre-weaning to post-weaning, finishing, and pregnancy, and feeding strategies must track these changes. Early-life goats transition from liquid to solid feeds while the rumen is still developing, so diets must support both tissue growth and rumen maturation. Energy and protein restriction in weaned kids has been shown to impair antioxidant capacity of gastrointestinal tissues, underscoring the sensitivity of this stage to nutritional insults (Abdelsattar et al., 2025). Later, during the main growth period (roughly 4-8 months), goats respond strongly to dietary energy and protein density: increasing ME concentration and CP level enhances average daily gain up to an optimum, beyond which performance may plateau or decline (Lu and Potchoiba, 1990).

Physiological state also modifies nutritional characteristics and efficiency of nutrient use. In hot environments, goats show altered requirements for sodium, potassium and phosphorus relative to widely used feeding systems, likely reflecting adaptive mechanisms to cope with heat stress and associated water and electrolyte challenges (Teixeira et al., 2024). During pregnancy, energy and protein requirements for the conceptus rise, but recent work indicates that the efficiency of ME utilization for pregnancy actually increases as gestation advances, even though absolute mineral accretion requirements grow with fetal size. Under-nutrition at critical gestational windows can compromise offspring gastrointestinal development: feed restriction in early gestation reduced small-intestinal