Research Progress on Energy Metabolism in Fur Animals: Postprint

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Abstract

Dietary energy directly affects the production performance of fur animals, and how to accurately evaluate animals' requirements for dietary energy, its utilization, and energy conversion efficiency is the key focus of energy metabolism research. The maintenance energy of fur animals is influenced by factors such as basal metabolism, ambient temperature, feeding management, breed, and heat increment of nutrient metabolism. This paper reviews the research progress on energy metabolism in fur animals, providing a sufficient theoretical basis for precision feeding and precise feed formulation for fur animals.

Full Text

Research Progress on Energy Metabolism in Fur Animals

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Abstract: Dietary energy directly affects the production performance of fur animals, and accurately evaluating feed energy requirements, utilization, and conversion efficiency represents a central focus of energy metabolism research. Maintenance energy in fur animals is influenced by basal metabolic rate, ambient temperature, feeding management, breed, and the heat increment associated with nutrient metabolism. This review synthesizes research progress on energy metabolism in fur animals to provide a robust theoretical foundation for precision feeding and feed formulation.

Keywords: fur animals; maintenance energy; metabolizable energy

Energy constitutes a vital component of feed nutrients and plays a critical role in animal growth and development, directly impacting production performance [1-4]. The energy value of fur animal feed is typically evaluated using metabolizable energy. However, China' s fur animal nutrition standards primarily reference NRC (1982) [5], NRC (2006) [6], or older literature, which may not accurately reflect domestic conditions due to differences in breeds, feeding practices, and feed composition. These discrepancies introduce substantial errors, underscoring the need for systematic research on energy metabolism tailored to China' s production context to refine national nutrition standards and support industry development.

1. Animal Energy Metabolism Systems

Feed energy comprises gross energy, digestible energy, metabolizable energy, and net energy. Three primary energy systems exist: digestible energy, metabolizable energy, and net energy systems, with significant variation in feed ingredient values across these frameworks [7-8]. Research on pigs and poultry has advanced to net energy evaluation of feed ingredients and requirements, yielding prediction equations and requirement models [9]. In contrast, fur animal research remains limited to the metabolizable energy system, with net energy studies yet to be initiated.

2.1.1 Maintenance Metabolizable Energy (MEm) Requirements

MEm represents the metabolizable energy intake level at which animal tissue deposition is zero, varying across physiological stages and influenced by environmental conditions and management practices. Since Palmer' s pioneering work in 1927 [10], research on mink and fox energy metabolism has concentrated primarily on MEm. International studies on mink MEm requirements are summarized in Table 1 and Table 2 .

Table 1 demonstrates that mink MEm is affected by breed, physiological stage, environmental conditions, and feeding management [11-19]. Table 2 reveals that adult male mink MEm increases gradually from July to November, peaking in summer due to higher heat increment from elevated temperatures and again in autumn as fat deposition begins. MEm declines from December to February as males enter the breeding season and lose weight, then stabilizes from March to June during post-breeding recovery. Female mink exhibit similar patterns despite not participating in reproduction [20].

Domestically, Yang et al. [21] reported fasting metabolic heat production and MEm values of 507.9 and 551.0 kJ/kg $BW^{0.75}$/d, respectively, for mink during early growth (rearing period), and 559.0 and 579.5 kJ/kg $BW^{0.75}$/d during late growth (winter fur period), using indirect calorimetry, energy balance, and comparative slaughter methods. Fink et al. [22] reported lactating kit MEm ranging from 356–448 kJ/kg $BW^{0.75}$. Variations between domestic and international findings likely stem from differences in breeds, feeding environments, and feed composition.

2.1.2 Energy Requirements During Growth

Adequate energy supply is essential for kit growth and pelt development. International studies recommend dietary gross energy levels of 22.26 MJ/kg or 22.68-23.10 MJ/kg for growing mink [23-24]. Dietary analyses from 45 Danish farms (1969-1970) showed metabolizable energy ranging from 14.23-16.32 MJ/kg, while Swedish diets ranged from 14.64-18.83 MJ/kg [25]. NRC (1982) [5] recommended 17.07 MJ/kg for males and 16.44 MJ/kg for females during growth. The relationship between body weight and metabolizable energy requirements for growing mink is detailed in Table 3 .

Domestic research by Li [26] found total energy of 22.04-22.36 MJ/kg during rearing and 21.89 MJ/kg during winter fur period for mink in cold regions. Yang et al. [27] reported total energy of 20.92 MJ/kg during rearing and 20.50 MJ/kg during winter fur period, with corresponding metabolizable energy values of 16.74 and 16.32 MJ/kg. Gu et al. [28] recommended 17.15-17.57 MJ/kg for males and 16.74-17.15 MJ/kg for females. Yang [1] suggested optimal metabolizable energy of 15.0 MJ/kg for males and 16.75 MJ/kg for females during rearing, with males achieving maximum pelt length at 16.19 MJ/kg and optimal pelt quality at 15.0 MJ/kg during winter fur period, while females required 14.41 MJ/kg. Discrepancies between domestic and international results likely reflect differences in breeds, feeding systems, feed composition, experimental conditions, and diet types (dry vs. fresh).

2.1.3 Energy Requirements During Reproduction

Appropriate dietary energy supports breeding performance. Medium-weight females exhibit higher conception rates, while excessive energy intake during early and mid-pregnancy increases obesity, dystocia risk, and embryo absorption while reducing litter rates [29]. High-energy diets during lactation are crucial for kit growth and milk production.

Tauson et al. [30] observed that females nursing six kits nearly doubled metabolizable energy intake from week 1 to week 4 of lactation (900 to 1,600 kJ/kg $BW^{0.75}$), yet milk energy secretion increased from 550 to 1,760 kJ/d, resulting in slight kit weight loss [31]. This demonstrates that increased intake cannot meet lactation demands, necessitating mobilization of body fat reserves, evidenced by significant female weight loss.

Yang et al. [27] recommended total energy levels of 20.50 MJ/kg during pregnancy and 20.92 MJ/kg during lactation. Tauson [32] suggested dietary metabolizable energy of 16.0 MJ/kg during early lactation (birth to initial kit feeding) and 17.3 MJ/kg during late lactation (initial feeding to weaning) to optimize kit growth and female performance. Energy intake should increase from breeding to embryo implantation, decrease throughout pregnancy, and increase again from late pregnancy through lactation to ensure normal production.

2.2 Blue Fox Metabolizable Energy System Research

Koskinen et al. [33] studied female blue fox kits from August (70 days) to December (210 days) using four dietary energy levels: ad libitum, 20-30% restricted, 35-45% restricted, and 50-60% restricted. Kits remained in positive energy balance throughout, with ad libitum intake decreasing from 1,620 to 820 kJ/kg $BW^{0.75}$ and the highest restriction group from 1,460 to 460 kJ/kg $BW^{0.75}$. Daily energy requirements ranged from 330-1,050 kJ/kg $BW^{0.75}$ for ad libitum and 100-990 kJ/kg $BW^{0.75}$ for the restricted group.

Adult foxes showed similar patterns, with ad libitum intake of 100 kJ/kg $BW^{0.75}$ during January-February but exceeding 300 kJ/kg $BW^{0.75}$ in autumn for the restricted group [33]. No significant differences in heat increment were observed among groups, though the highest restriction group remained in positive energy balance from January to May [34]. NRC (1982) [5] recommended 13.5 MJ/kg DM for all physiological stages.

Jin et al. [35] determined blue fox MEm as 467.05 kJ/kg $BW^{0.75}$ during early growth and 494.67 kJ/kg $BW^{0.75}$ during late growth (winter fur period). Other findings indicated daily metabolizable energy requirements of 1.5-2.0 MJ per fox (dietary ME: 14.1-14.3 MJ/kg DM) during early growth (7-16 weeks) and 2.3-2.6 MJ per fox (dietary ME: 12.5-13.0 MJ/kg DM) during late growth (17 weeks to pelt harvest). Koskinen et al. [34] proposed daily requirements of 2.76, 2.34, and 2.05 MJ for foxes weighing 5.00, 5.75, and 6.00 kg, respectively.

Body weight and metabolizable energy requirements for growing and adult blue foxes are presented in Table 4 and Table 5 . Table 5 shows reduced energy expenditure in winter due to pre-breeding weight loss, similar requirements to growing foxes in summer, and elevated requirements in autumn during fat deposition. Fasting heat increment in blue fox kits is shown in Table 6 , demonstrating decreasing fasting heat production per kg metabolic body weight with age, consistent with physiological principles that younger animals exhibit higher per-unit heat production.

3. Factors Affecting Maintenance Energy in Fur Animals

Maintenance energy requirements can be expressed as either MEm (zero deposition level) or maintenance net energy (basal metabolic heat production). Basal metabolic rate, ambient temperature, feeding management, breed, and nutrient metabolism heat increment all influence maintenance energy needs [37].

3.1 Basal Metabolic Rate (BMR)

BMR represents the minimum energy metabolism heat production required for survival in healthy, fasted, quiet animals under thermoneutral conditions. Farrell et al. [11] noted that species-specific characteristics make accurate BMR measurement in mink challenging, requiring measurement during brief sleep periods, with female BMR at 324 kJ/kg $BW^{0.75}$. Iversen [38] reported BMR of

354 kJ/kg $BW^{0.78}$ for mustelids weighing 1.0–15.0 kg.

3.2 Ambient Temperature

Ambient temperature significantly affects energy requirements. In cold conditions, mink require additional energy to compensate for increased heat loss. The temperature at which extra energy is needed to maintain body temperature is termed the lower critical temperature. Korhonen et al. [39-40] found that each 1°C decrease below this threshold required an additional 9.6–15.5 kJ/kg $BW^{0.75}$. Glem-Hansen et al. [41] demonstrated a linear increase of 12.1 kJ/kg $BW^{0.75}$ per 1°C decrease from -3 to 22°C. The lower critical temperature for blue foxes is -6°C [40], though energy requirements below this temperature remain undocumented. Wamberg [15] measured heat increment in adult females at 768 kJ/kg/d at 18°C versus 501 kJ/kg/d at 24°C using direct calorimetry.

3.3 Feeding Management

Feeding management practices affect maintenance energy needs. Cage size influences energy expenditure, with significantly reduced consumption when activity is restricted [42]. Farrell et al. [43] reported that adult females required 1,079.9 kJ/kg digestible energy in large cages compared to 845.5 kJ/kg in small cages at 11°C.

3.4 Breed

Breed differences impact maintenance energy requirements. Colored mink exhibit higher energy needs than standard black mink [44], and imported black mink breeds require more energy than local breeds [45].

3.5 Heat Production from Nutrient Metabolism

Nutrient metabolism generates heat that affects maintenance energy. Energy is released during digestion, absorption, and synergistic digestion, with heat increment accounting for 20% of metabolizable energy from fat and 50% from protein [46]. Heat increment can be calculated using Brouwer’ s [47] formula: Heat increment (kJ) = $3.866 \times O_2$ (L) + $1.200 \times CO_2$ (L) - $0.518 \times CH_4$ (L) - $1.431 \times$ urinary nitrogen (g).

4. Conclusion

Research on mink and fox energy requirements has primarily focused on the metabolizable energy system, yielding varying results across physiological stages due to multiple influencing factors. Modern fur animal production systems, environments, and breeds have evolved substantially, affecting metabolizable energy evaluation. To more accurately determine energy requirements, a more precise system is needed. The net energy system most accurately reflects feed energy value and expresses animal requirements and feed energy on the same basis, yet remains unstudied in fur animals. Future research should address feed ingredient net energy values and net energy requirements across physiological stages to support precision feeding and feed formulation.

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Note: Figure translations are in progress. See original paper for figures.