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Rumen-Protected Amino Acids: Their Importance and Effects on Performance, Heat Stress and Immunity in Cattle

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ABSTRACT

Balanced nutrition is crucial for optimum dairy cow production, with protein quality being particularly important for productivity and reproductive performance. Ruminal microorganisms utilize diet components to synthesize microbial protein (MCP), which is then digested in the small intestine (SI). The protein and amino acids produced by microbial processes are inadequate for optimal daily production, leading to the current practice of supplementing ruminant diets with additional amino acids.Bacteria in the rumen can break down free amino acids, necessitating the supplementation of amino acids in a protected form to ensure their stability in the rumen and absorption post-ruminally for metabolic purposes. The small intestine (SI) is the primary site of amino acid absorption, so it is crucial to protect amino acids from ruminal degradation and direct them to the absorption sites. Beyond their role in milk production, amino acids are important for immune function in animals and have been shown to alleviate oxidative stress. Low-protein diets supplemented with rumen-protected amino acids (RPAA) can replace high-protein diets in summer, as increased protein metabolism can result in higher heat production and subsequent stress.

KEYWORDS: Limiting amino acids, Milk production, Oxidative stress, Rumen-protected amino acids, Ruminants

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INTRODUCTION

Protein is a major macromolecule composed of amino acids (AAs).Amino acids, the building blocks of proteins, are classified based on their structure, the electrical charge of side chains, and their essentiality in nutrition.The essential amino acids (EAAs) which cannot be synthesized in the body and are required by ruminants and non-ruminants in diet include lysine (Lys), methionine (Met), histidine (His), isoleucine (Ile), leucine (Leu), phenylalanine (Phn), threonine (Thr), tryptophan (Trp), Arginine (Arg) and valine (Val). Among these essential amino acids, some of them including lysine, methionine etc are low in practical diets termed as critical amino acids. High-producing animals often require more dietary essential amino acids than those supplied by microbial and escaped protein pools, making the supplementation of rumen-protected protein (RPP) and amino acids crucial to meet their physiological and productive needs (Ali et al., 2009). This has led to the trend of supplementing ruminant diets with amino acids (Schwab and Broderick, 2017). However, supplementing free amino acids in ruminants is ineffective because rumen microorganisms utilize them before they reach the small intestine for absorption (Chen et al., 2020). Since the small intestine (SI) is the main site of amino acid absorption, amino acids need to be supplemented in a protected form to ensure stability in the rumen and post-ruminal absorption for metabolic purposes. Shielding amino acids from degradation in the rumen allows for the supplementation of diets with specific amino acids that can be absorbed in the intestine (NRC, 2001).Rumen-protected protein (RPP) supplementation is vital for productive ruminants relying on high crude protein (CP) diets, as inefficiency arises when highly degradable concentrates like groundnut or mustard cake are used, converting amino acids into non-protein compounds (Ali et al., 2009). Encapsulated nutrients are particularly beneficial for dairy animals during transition and peak lactation, meeting higher nutrient demands.

Thus, supplementing nutrients in protected forms is an effective strategy for improving dairy production under stressful conditions like transition, peak lactation, and heat stress.Understanding the use of rumen-protected amino acids (RPAA) and their benefits is crucial. Additionally, the benefits of using different amino acids and RPAA in animal growth and production are emphasized.

Principles of rumen protection and mechanism of action:

Physical or Chemical Protection

Techniques like heat treatment, tannin inclusion, or chemical additives (e.g., sodium hydroxide, formaldehyde, alcohols etc) are used to modify proteins, making them resistant to microbial breakdown (Mazinani et al., 2022).Non-enzymatic browning (Maillard reaction) increases protein resistance to ruminal enzymes.

Selective Degradation

Encapsulation is defined as the "entrapment of a component (the core) within a secondary material (encapsulant matrix). Encapsulation methods ensure specific amino acids, like methionine and lysine, bypass the rumen while being available for absorption in the intestine(Ji et al*.,* 2016).

Optimized Utilization

Protection mechanisms ensure the availability of essential nutrients like lysine and methionine for absorption in the small intestine, promoting tissue protein synthesis and enhancing overall feed efficiency.

The process of rumen-protected amino acids, such as lysine and methionine, being safeguarded by a protective coating to prevent rumen degradation. The coating dissolves in the intestine, allowing amino acids to be absorbed for tissue protein synthesis.

Importance of rumen-protected amino acids

Rumen-protected amino acids are vital nutrients that improve the biology of cattle and optimize the use of other dietary components. This enables the fulfilment of health, production and reproductive demands of cows across all stages of lactation and production levels. They supply essential nutrients, such as lysine and methionine, more efficiently and reliably than conventional feed sources like blood meal and soybean meal, while avoiding the oversupply of nutrients that the cow may not need. Rumen-protected amino acids offer several advantages for livestock nutrition. By incorporating these amino acids into the feed, farmers can reduce total ration costs, as they provide essential nutrients more efficiently than traditional feedstuffs. This efficiency helps mitigate the impact of rising raw material prices. Additionally, rumen-protected amino acids optimize ration space, allowing for the inclusion of other vital nutrients like energy and fiber (Amrutkar et al., 2014;Mazinani et al.,2022). This results in a more balanced and nutrient-dense diet that supports optimal cattle growth and health. Another benefit is the consistent nutrient flow they provide, reducing variability in nutrient supply often caused by traditional feed ingredients. This consistency helps maintain steady milk production and overall herd health. Compared to heat-treated ingredients like blood meal and soybean meal, rumen-protected amino acids offer a more reliable nutrient supply because they are designed to withstand the rumen environment, leading to better nutrient absorption. Furthermore, their inclusion in diets promotes environmental and health benefits by improving nitrogen use efficiency, reducing nitrogen excretion, and lowering environmental pollution, while also supporting better animal health and preventing metabolic disorders.

Effects of Rumen-Protected Amino Acids on Cattle Performance

A. Milk Production and composition

Milk production in dairy cows is closely tied to their ability to meet nutritional needs, particularly in terms of essential amino acids like lysine (Lys) and methionine (Met), which play a pivotal role in protein synthesis and metabolism. During early lactation, cows experience increased demand for these amino acids, making their supplementation crucial to achieving optimal milk yield and composition. Rumen-protected amino acids (RPAA), especially RP-Lys and RP-Met, have been widely studied for their ability to bypass degradation in the rumen and improve amino acid availability in the small intestine, directly influencing milk production.

Research consistently shows that supplementing diets with RPAA can enhance milk yield and improve the concentrations of milk fat and protein, particularly in high-producing cows. Studies like Liu et al. (2016) demonstrated that the inclusion of RP-Lys in lactating cows' diets increased milk yield and fat-corrected milk (FCM), especially when the cows were fed rapeseed meal. This finding is consistent with Pas et al.(2014), who observed enhanced milk fat and protein concentrations in Holstein Friesian cows producing more than 36 kg of milk per day. These studies highlight a critical insight: the efficacy of RPAA is often influenced by the cow's milk production level. In cows with lower milk yields, the response to RPAA supplementation may be less pronounced, possibly due to a reduced metabolic demand for these amino acids or a balanced amino acid profile in the basal diet.Additionally, studies on individual supplementation of the metabolizable protein deficit (MPD) diet with RP-Met, RP-Lys, and RP-histidine found no significant impact on milk yield, echoing similar observations regarding Lys (Robinson et al., 2000).

Amrutkar et al. (2015) took this a step further by investigating the effects of combined supplementation of RP-Lys and RP-Met in periparturient dairy cows. Their findings illustrated a significant increase in milk yield by 14.21% compared to the control group, along with improvements in milk fat, protein, and lactose concentrations. The increased milk production in response to RPAA is largely attributed to the role of Lys and Met in enhancing protein synthesis, which is particularly critical during the early lactation period when cows experience negative energy balance (NEB).Recent studies have shown that the addition of a combination of three RPAA to the metabolizable protein deficit (MPD) diet numerically increased milk yield, albeit still below that of the metabolizable protein adequate (MPA) diet. This result can be attributed to the trend for increased dry matter intake (DMI) due to RP-histidine, along with the positive independent and additive effects of the three RPAA on milk production (Lemosquet et al., 2009). Positive responses in milk yield have also been reported with similar combinations of essential amino acids (Kim et al., 2000; Lee et al., 2012).

Contrasting findings, such as those from Awawdeh (2016), who found no significant impact of RPAA on milk yield and composition except for milk protein, suggest that the response to RPAA supplementation may depend on multiple factors, including the cow's lactation stage, the overall protein content of the diet, and the adequacy of other nutrients such as energy. In contrast, Mohsen et al. (2011) found that RP-choline (RPC) supplementation had a notable impact on nutrient digestibility, milk yield, and composition, pointing to the diverse roles different rumen-protected compounds can play in enhancing milk performance.

The combination of RP-Lys, RP-Met, and other essential amino acids such as histidine has shown synergistic effects, particularly in diets deficient in metabolizable protein (Lee et al., 2015). These amino acids not only promote milk protein synthesis but also improve nitrogen utilization efficiency, reducing nitrogen excretion into the environment. This finding has been supported by multiple studies (Giallongo et al., 2016 and Wang et al.,2022), emphasizing the environmental benefits of RPAA in minimizing nitrogen pollution while maintaining milk production. Such findings are particularly significant in modern dairy production systems, where sustainability and environmental impacts are of increasing concern.

Beyond amino acids, rumen-protected choline (RPC) has also gained attention for its role in supporting milk yield, particularly by improving liver function and fat metabolism. Huang et al. (2023) consistently demonstrated that the supplementation of rumen-protected amino acids positively influences both milk yield and milk protein synthesis in dairy cows.However, the effectiveness of RPC supplementation appears to vary, as demonstrated by studies like Hartwel (2000), Piepenbrink and Overton (2003) and Leiva et al. (2015), who found mixed results regarding its ability to enhance milk yield and composition. These studies suggest that while RPC may offer metabolic benefits, its effects on milk production are more context-dependent, requiring careful consideration of diet composition and physiological state.

B. Growth performance

In addition to lactation, the supplementation of RPAA has been shown to positively impact growth performance in cattle, particularly during the critical stages of development, including the growing and finishing phases. Growth performance is highly influenced by the availability of essential amino acids in the diet, which are required for muscle accretion and tissue development. Rumen-protected forms of Lys and Met have proven effective in increasing the efficiency of amino acid absorption, leading to improved body weight gain and feed efficiency.

Several studies have demonstrated that RPAA supplementation enhances dry matter intake (DMI) and average daily gain (ADG) in growing cattle. Amrutkar et al. (2015) showed marked increases in nutrient intake and body condition in lactating cows receiving RP-Lys and RP-Met. These improvements are likely linked to enhanced protein metabolism and nitrogen utilization, allowing the animals to convert dietary protein into muscle tissue more efficiently.

Similarly, studies on buffaloes and crossbred bulls (Gami et al., 2015; Xue et al., 2011) further support the role of RPAA in promoting growth. The incorporation of RP-Lys and RP-Met into the total mixed ration (TMR) improved average daily gain and body condition, demonstrating that RPAA is effective across different cattle breeds and production systems. Sai et al. (2014) reported a 16.1% higher average daily gain in female calves fed a basal diet supplemented with 2 g rumen-protected methionine (RPM) and 17 g rumen-protected lysine (RPL) per calf daily for 90 days. Singh et al.(2015) found improved average daily gain in heifers supplemented with RPM and RPL at varying levels, highlighting better growth performance compared to a control group. However, the benefits of RPAA supplementation are not universally observed. Heiderscheit and Hansen (2020) reported a negative effect of RP-Lys supplementation on ADG in Angus crossbred steers, suggesting that over-supplementation of Lys, particularly in the finishing phase, may disrupt the balance of amino acids and hinder growth. This underscores the importance of carefully balancing amino acid levels in cattle diets to avoid overconsumption and ensure optimal growth performance.Cabezas et al. (2023) studied two groups of 40 Montbéliard steers fed either a control diet or a diet with rumen-protected lysine and methionine. No significant differences were observed in body weight, or average daily gain (ADG) during the first 112 days or overall (0–202 days). However, from days 112 to 202, steers on the reduced protein diet had a higher ADG than those on the control diet.

Recent research, like that of Almallah et al. (2021), has further elucidated the mechanisms through which RPAA improves growth performance, particularly by enhancing nitrogen retention and reducing the energy cost of nitrogen excretion. By promoting more efficient nitrogen utilization, RPAA allows animals to allocate more energy towards growth, reducing the waste associated with excess nitrogen excretion. This is particularly beneficial in high-growth phases when nutrient efficiency is critical for achieving target body weights.

The role of rumen-protected amino acids in heat stress amelioration

Heat stress is a major concern in dairy and beef cattle production, especially in tropical and subtropical climates where high temperatures and humidity can severely impact animal performance. Heat stress reduces feed intake, lowers milk yield, impairs reproductive performance, and can lead to increased susceptibility to diseases. One of the emerging strategies to mitigate the adverse effects of heat stress is the use of RPAA, which can improve nutrient utilization and reduce the energetic cost of nitrogen metabolism.

Research has shown that feeding excess protein during heat stress can exacerbate the energy deficit by increasing heat production during nitrogen excretion. Studies like Abdi-Benemar et al. (2015) have demonstrated that low-protein diets supplemented with RP-Lys and RP-Met can alleviate some of these effects by improving nitrogen efficiency and reducing urinary nitrogen excretion, thereby conserving energy for milk production. This is crucial in hot climates, where energy conservation is key to maintaining productive performance.

Cheng et al. (2014) also explored the role of rumen-protected γ-aminobutyric acid (GABA) in alleviating heat stress. Their findings indicated that GABA supplementation reduced rectal temperatures in heat-stressed dairy cows, suggesting that certain amino acids can play a thermoregulatory role. Likewise, Izquierdo et al. (2024) found that RP-Met supplementation lowered internal body temperatures in Nellore cows, highlighting the potential of RPAA to reduce heat stress and improve animal welfare during hot conditions. These findings are significant for improving cattle resilience in regions prone to extreme weather, pointing to the broader benefits of RPAA beyond production and growth.

Effect of rumen-protected amino acids on immune function

The transition period, particularly the weeks surrounding calving, is a critical time for dairy cows, marked by metabolic and physiological challenges that can compromise immune function. During this period, cows experience a drop in dry matter intake (DMI) and enter a negative energy balance (NEB), leading to increased susceptibility to metabolic disorders and infections. Recent research has explored the role of RPAA, particularly RP-Met, in enhancing immune function during this critical time.

Methionine, as a precursor to key metabolites like glutathione, taurine, and polyamines, plays a crucial role in maintaining antioxidant capacity and supporting immune responses. Studies like Sun et al.(2016) demonstrated that RP-Met and RP-choline supplementation improved antioxidant status in transition cows by increasing blood vitamin E concentrations, glutathione peroxidase (GSH-Px) activity, and total antioxidant capacity (T-AOC). These improvements in antioxidant markers contribute to better immune defense mechanisms, reducing the risk of infections during the peripartum period.

Other research, such as Batistel et al.(2018), further confirmed the role of RP-Met in supporting liver function and immune response. Cows supplemented with RP-Met showed higher plasma levels of cholesterol, albumin, and IL-6, along with reduced haptoglobin, indicating a more robust immune status. Additionally, Zhou et al. (2016) highlighted the beneficial effects of RP-Met on phagocytic capacity and oxidative burst, both of which are critical components of the immune response in dairy cows.

However, not all studies have reported positive effects. Abdelmegeid et al. (2017) studied neonatal calves and found that methionine supplementation reduced the expression of interleukin-10 (IL-10) and IL-6 genes in Toll-like receptors (TLR-4) and NFêâ pathways. This suggests that methionine attenuated the inflammatory response in PMN leukocytes.

Cost efficacy of rumen-protected amino acids

Studies on the cost efficacy of rumen-protected amino acids (RPAA) highlight their dual benefits of reducing feed costs and maintaining livestock production. RPAA supplementation allows a reduction in dietary crude protein levels while preserving performance, leading to significant savings in feed costs (Mazinani et al., 2022) . RPAA also improved nitrogen utilization efficiency, minimizing nitrogen excretion and enhancing environmental sustainability alongside economic gain (Kamalak et al., 2005)Additionally, Amrutkar et al.(2014)concluded that supplementing rumen-protected methionine (RPM) and lysine (RPL) in the diet of high-yielding lactating cows during early lactation improved net returns by 12.3% compared to a standard diet, with similar feed costs and cost-benefit ratios, enhancing the profitability of dairy operations by reducing input costs while optimizing production .

CONCLUSION

Rumen-protected amino acids (RPAAs) are vital for optimizing dairy cow nutrition by ensuring essential amino acids like lysine and methionine are absorbed in the small intestine. They enhance milk production and quality, improving yield and composition. RPAAs also boost growth and feed efficiency, positively affecting body weight and condition. They help mitigate heat stress by reducing metabolic heat production and nitrogen excretion. Additionally, RPAAs support immune function and reduce oxidative stress, aiding overall animal health. Their use represents an effective strategy for improving high-yielding dairy cows.

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