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SUSTAINABLE BEEF PRODUCTION SYSTEMS IN THE TROPICS: REVIEW

SISTEMA SUSTENTÁVEL DE PRODUÇÃO DE CARNE BOVINA NOS TRÓPICOS: REVISÃO

SISTEMA SOSTENIBLE DE PRODUCCIÓN DE CARNE BOVINA EN LOS TRÓPICOS: REVISIÓN

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ABSTRACT

Beef production in tropical regions plays a fundamental role in global food security and in the economic development of many countries, particularly in Latin America, Africa, and parts of Asia. In these regions, cattle production is predominantly based on grazing systems that utilize extensive areas of natural or cultivated pastures. However, this activity is often associated with significant environmental impacts, such as greenhouse gas emissions, soil degradation, low productive efficiency, and the conversion of natural areas into pastureland. In the face of these challenges, the adoption of sustainable production practices has become essential to reconcile increased productivity with environmental conservation and economic viability. Among the main strategies to promote sustainability in tropical cattle production are proper pasture management, the recovery of degraded areas, sustainable intensification of production systems, and the adoption of technologies such as crop–livestock–forest integration. These practices contribute to improving land-use efficiency, increasing productivity per unit area, and reducing pressure for the expansion of the agricultural frontier. In addition, advances in genetic improvement, animal nutrition, and herd health have enabled significant gains in productive performance and feed efficiency, thereby reducing the intensity of greenhouse gas emissions per unit of product. Another important aspect involves the adoption of practices related to animal welfare, traceability within the production chain, and the efficient management of natural resources, factors that are

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increasingly valued by consumer markets. In this context, sustainable beef production in the tropics depends on the integration of environmental, social, and economic approaches, promoting more resilient and efficient production systems capable of meeting the growing global demand for animal protein in a responsible manner.

Keywords: Beef Cattle. Meat. Consumers. Sustainable Production. Tropics.

RESUMO

A produção de carne bovina nos trópicos desempenha papel fundamental na segurança alimentar mundial e no desenvolvimento econômico de diversos países, especialmente na América Latina, África e partes da Ásia. Nessas regiões, a pecuária bovina é predominantemente baseada em sistemas de pastejo, aproveitando extensas áreas de pastagens naturais ou cultivadas. Contudo, a atividade também é frequentemente associada a impactos ambientais relevantes, como emissões de gases de efeito estufa, degradação do solo, baixa eficiência produtiva e conversão de áreas naturais em pastagens. Diante desses desafios, a adoção de práticas de produção sustentável tem se tornado essencial para conciliar aumento de produtividade, conservação ambiental e viabilidade econômica. Entre as principais estratégias para promover a sustentabilidade da pecuária tropical destacam-se o manejo adequado das pastagens, a recuperação de áreas degradadas, a intensificação sustentável dos sistemas produtivos e a adoção de tecnologias como a integração lavoura-pecuária-floresta. Essas práticas contribuem para melhorar a eficiência do uso da terra, aumentar a produtividade por área e reduzir a pressão por expansão da fronteira agropecuária. Além disso, avanços em melhoramento genético, nutrição animal e sanidade do rebanho têm permitido ganhos significativos em desempenho produtivo e eficiência alimentar, reduzindo a intensidade das emissões de gases de efeito estufa por unidade de produto. Outro aspecto relevante envolve a adoção de práticas voltadas ao bem-estar animal, à rastreabilidade da cadeia produtiva e à gestão eficiente dos recursos naturais, fatores cada vez mais valorizados pelos mercados consumidores. Nesse contexto, a produção sustentável de carne bovina nos trópicos depende da integração de abordagens ambientais, sociais e econômicas, promovendo sistemas produtivos mais resilientes, eficientes e capazes de atender à crescente demanda global por proteína animal de forma responsável.

Palavras-chave: Bovino de Corte. Carne. Consumidores. Produção Sustentável. Trópicos.

RESUMEN

La producción de carne bovina en las regiones tropicales desempeña un papel fundamental en la seguridad alimentaria mundial y en el desarrollo económico de diversos países, especialmente en América Latina, África y partes de Asia. En estas regiones, la ganadería bovina se basa predominantemente en sistemas de pastoreo que aprovechan extensas áreas de pastizales naturales o cultivados. Sin embargo, esta actividad también suele estar asociada a impactos ambientales relevantes, como emisiones de gases de efecto invernadero, degradación del suelo, baja eficiencia productiva y conversión de áreas naturales en pastizales. Frente a estos desafíos, la adopción de prácticas de producción sostenible se ha vuelto esencial para conciliar el aumento de la productividad con la conservación ambiental y la viabilidad económica. Entre las principales estrategias para promover la sostenibilidad de la ganadería tropical se destacan el manejo adecuado de los pastizales, la recuperación de áreas degradadas, la intensificación sostenible de los sistemas productivos y la adopción de tecnologías como la integración agricultura-ganaderíabosque. Estas prácticas contribuyen a mejorar la eficiencia en el uso de la tierra, aumentar la productividad por unidad de área y reducir la presión por la expansión de la frontera agropecuaria. Además, los avances en mejoramiento genético, nutrición animal y sanidad del rebaño han permitido importantes ganancias en desempeño productivo y eficiencia alimentaria, reduciendo la intensidad de las emisiones de gases de efecto invernadero por unidad de producto. Otro aspecto relevante implica la adopción de prácticas relacionadas con el bienestar animal, la trazabilidad de la cadena productiva y la gestión eficiente de los recursos naturales, factores cada vez más valorados por los mercados consumidores. En este contexto, la producción sostenible de carne bovina en los trópicos depende de la integración de enfoques ambientales, sociales y económicos, promoviendo sistemas productivos más resilientes, eficientes y capaces de satisfacer de manera responsable la creciente demanda mundial de proteína animal.

Palabras clave: Bovino de Carne. Carne. Consumidores. Producción Sostenible. Trópicos.

INTRODUCTION

Tropical regions such as Latin America, Sub-Saharan Africa, and Southeast Asia account for a large share of global livestock production (FAPRI, 2025), particularly beef, pork, and poultry, due to favorable climatic conditions, the availability of land for pasture, and the diversity of production systems (Carvalho et al., 2020). Favorable climatic conditions, such as high temperature and humidity, combined with the vast availability of pastureland, make these regions particularly suitable for livestock production (Souza, 2018). However, meat production in tropical regions faces several challenges that require technological innovation, environmental adaptation, and sustainable management of natural resources (Guerrero et al., 2013).

Tropical grasses, such as species of the genera *Brachiaria* (currently *Urochloa*) and *Panicum*, have a high biomass production capacity, enabling animal feeding during most of the year (Moura et al., 2017; Pequeno et al., 2018). However, climatic seasonality, with well-defined dry periods, may compromise forage quality and availability, negatively affecting animal performance (Schio et al., 2011).

Health challenges are also relevant in meat production in tropical regions (Ortunho & Pinheiro, 2018). High temperature and humidity favor the occurrence of parasites, infectious diseases, and heat stress, requiring strict sanitary management, parasite control programs

The use of breeds or crossbreeds adapted to tropical climates. In this context, *Bos indicus* (zebu) breeds and their crosses with *Bos taurus* breeds are particularly important because they combine hardiness, heat tolerance, and good productive performance (Valadares Filho et al., 2016). Another fundamental aspect is the sustainability of meat production in the tropics (Bezerra et al., 2021).

Historically, livestock expansion has been associated with deforestation and environmental degradation, particularly in sensitive biomes (Dias-Filho, 2003). Currently, there is increasing adoption of sustainable practices, such as the recovery of degraded pastures, integrated production systems (crop–livestock and crop–livestock–forest systems), rotational grazing management, and the rational use of natural resources (Zimmer et al., 2012). These strategies contribute to increased productivity per unit area, reduced greenhouse gas emissions, and improved animal welfare (Paula et al., 2019). In addition, meat production in the tropics has advanced technologically, with greater use of feed supplementation, genetic improvement, reproductive management, traceability tools, and meat quality control (Ferracini et al., 2022).

Climatic seasonality in the tropics represents a challenge for meat production because variations in forage availability can directly affect animal weight gain, leading to periods of reduced productivity (Sousa et al., 2011). To mitigate this effect, many producers adopt strategies such as feed supplementation and pasture management through rotational grazing, which improves forage utilization throughout the year (Chaves et al., 2021).

BREEDS AND GENETIC GROUPS FOR BEEF PRODUCTION IN THE TROPICS

Zebu breeds exhibit physiological and anatomical characteristics that confer greater tolerance to heat stress, resistance to ectoparasites, and the ability to maintain productive performance under nutritionally limiting conditions (Carrasco-García et al., 2020). Among these characteristics are a greater number of sweat glands, short and light-colored hair coat, a larger relative body surface area, and greater efficiency in heat dissipation (Burrow, 2010). These adaptations make zebu breeds particularly well suited to pasture-based production systems in tropical regions (Lopes, 2002; Oliveira et al., 2021). In Brazil, the main breed used in beef production is the Nellore, which accounts for the majority of the genetic composition of the national herd (Rosa et al., 2016). It is estimated that more than 80% of the Brazilian cattle herd has genetic influence from this breed, reflecting its high level of adaptation to tropical conditions and its efficiency in extensive production systems (ABIEC, 2025; ANUALPEC, 2025; Barbosa et al., 2014; Lira et al., 2013; Pineda et al., 2000). In addition to the Nellore, other zebu breeds such as the Guzerá, Brahman, Indubrasil, and Tabapuã are also used on a smaller scale, contributing to genetic diversity and to the development of breeding programs focused on beef production (Araújo et al., 2018; Carneiro et al., 2009; Cooke et al., 2009; Rossi et al., 2009). Despite the high adaptability of zebu breeds, they generally exhibit lower finishing precocity, lower meat marbling, and lower weight gain potential when compared with taurine breeds specialized for beef production (Carvalho & Vieira, 2023; Ítavo et al., 2008; Rotta et al, 2009b). Therefore, crossbreeding strategies between *Bos indicus* and *Bos taurus* have been widely adopted with the aim of combining the environmental adaptability of zebu cattle with the high productive potential and meat quality of taurine breeds (Barcellos et al., 2017; Mantovani & Ramos, 2019; Pastor et al., 2017).

In Brazil, the crossbreeding between Nellore cows and Aberdeen Angus bulls represents one of the most widely adopted industrial crossbreeding systems. This system allows the exploitation of hybrid vigor (heterosis), resulting in significant improvements in productive and reproductive traits, such as higher average daily gain, earlier sexual maturity, improved carcass finishing, and greater meat quality (Barcellos et al., 2017). In addition to the Aberdeen Angus, other taurine breeds widely used in crossbreeding programs include the Hereford, Charolais, Limousin, and Simmental (Rotta et al., 2009a; Rotta et al., 2009b).

Another relevant approach involves the development of synthetic or composite breeds adapted to tropical conditions. These breeds are formed by combining different proportions of taurine and zebu genes, aiming to balance environmental adaptation and productive performance. Important examples include the Brangus (Brahman × Aberdeen Angus), Braford (Brahman × Hereford), Santa Gertrudis cattle (Brahman × Shorthorn), and the Canchim (Charolais × Zebu), the latter developed in Brazil by the Embrapa (Mottin et al., 2022; Orellana et al., 2009; Prado et al., 2015; Rotta et al., 2008; Ribeiro, 2009; Rubiano et al., 2009; Santos et al., 2024). These breeds exhibit good adaptation to tropical climates, greater productive efficiency, and superior meat quality when compared with pure zebu breeds (Burrow, 2010).

ANIMAL PERFORMANCE AND FEED EFFICIENCY OF ZEBU AND *BOS INDICUS* × *BOS TAURUS* CROSSBRED CATTLE ON TROPICAL PASTURES

In pasture-based systems in tropical regions, cattle of the *Bos indicus* group exhibit a high level of adaptation to adverse climatic conditions, such as high temperatures, high humidity, and strong parasite pressure, factors that directly influence productive performance and feed efficiency (Burrow, 2010). Comparative studies have shown that physiological and metabolic differences between *Bos indicus* and *Bos taurus* affect feed intake, growth rate, and the efficiency of nutrient utilization (Bell et al., 2017; Prado et al., 2003; Prado et al., 2008).

One of the main adaptive characteristics of zebu cattle (*Bos indicus*) is their greater tolerance to heat stress, which is associated with more efficient physiological thermoregulation mechanisms and a lower basal metabolic rate (Gandra et al., 2011; Skinner & Louw, 1966), his adaptation allows these animals to maintain relatively stable levels of feed intake and productive performance in hot environments with limited nutrient availability. In addition, *Bos indicus* cattle exhibit lower voluntary dry matter intake compared with taurine cattle, which is associated with lower energy requirements for maintenance (Bolormaa et al., 2013; Hansen, 2009; Rogerson et al., 1968).

Despite the lower feed intake, several studies indicate that *Bos indicus* cattle may exhibit feed efficiency similar to that observed in *Bos taurus* cattle when fed diets of moderate to high quality. However, the lower feed intake generally results in lower daily weight gain compared with *Bos taurus* animals. Thus, under intensive production conditions or when nutritional availability is high, taurine cattle tend to show superior performance in terms of growth and weight gain (Gandra et al., 2011; Rotta et al., 2009b; Valadares Filho et al., 2016).

However, in systems based on low- or medium-quality tropical pastures, *Bos indicus* cattle demonstrate important adaptive advantages (Lopes et al., 2004; Quadros et al., 2016). Studies suggest that these animals have a greater capacity to digest and utilize fibrous, low-quality forages, which contributes to greater productive stability in tropical environments (Marcondes et al., 2016; Santos et al., 2014; Valadares Filho et al., 2016).

Several studies conducted in grazing systems demonstrate that crossbreeds such as Nellore × Aberdeen Angus, Brahman × Hereford, and Braford show superior performance compared with pure zebu breeds in terms of weight gain and productivity per unit area (Euclides Filho et al., 2002; Kippert et al., 2008). In addition to growth performance, bioenergetic studies indicate that the efficiency of protein and body fat retention in *Bos indicus* cattle and their crosses with *Bos taurus* may be similar to that observed in taurine cattle, suggesting that productive differences are more closely related to feed intake and growth rate than to metabolic efficiency in energy utilization.

CARCASS YIELD AND CHARACTERISTICS OF ZEBU AND CROSSBRED CATTLE

Carcass yield and characteristics of cattle destined for beef production are strongly influenced by the genetic group, the production system, and environmental conditions (Silva & Cangussu, 2020). In tropical production systems, *Bos indicus* cattle and their crosses with *Bos taurus* predominate due to their greater adaptation to heat, resistance to parasites, and productive efficiency on tropical pastures (Ferraz & Felício, 2010).

Zebu cattle, especially the Nellore breed, which predominates in Brazil, show high carcass yield, generally ranging from 53 to 56%, resulting from a lower proportion of viscera and a higher yield of commercial cuts (Abrahão et al., 2005; Pastor et al., 2017; Pinto et al., 2011). However, these animals tend to show lower marbling and lower intramuscular fat deposition when compared with taurine breeds, a characteristic associated with physiological and metabolic differences between the genetic groups (Ferraz & Felício, 2010; Rotta et al., 2009b; Rubiano et al., 2009). The lower fat deposition may result in leaner meat, although in some cases with reduced tenderness.

In addition to carcass yield, the qualitative characteristics of the carcass are also important for the meatpacking industry and the consumer market. Among the main parameters evaluated are hot carcass weight, ribeye area, subcutaneous fat thickness, and the proportion of commercial cuts (Ferracini et al., 2024; Moletta et al., 2014; Pinto et al., 2011; Rotta et al., 2010). In zebu cattle (*Bos indicus*) raised in extensive pasture-based systems, a larger ribeye area relative to body weight is often observed, indicating good muscle deposition capacity, but with lower fat thickness (Crouse et al., 1989; Rubiano et al., 2009).

Crossbred animals resulting from crosses between zebu and taurine cattle, such as Aberdeen Angus × Nellore or Hereford × Nellore, show advantages derived from heterosis, which are reflected in improved productive performance and carcass quality (Bridi & Constantino, 2009; Lopes et al., 2008; Rocha Júnior et al., 2010; Rotta et al., 2010). These animals often exhibit higher weight gain, greater slaughter weight, and better carcass finishing, resulting in meat with greater marbling and improved tenderness when compared with pure zebu cattle (Ferraz & Felício, 2010; Rubiano et al., 2009).

Studies conducted in Brazil show that crossbred cattle may present carcass yields similar to or slightly higher than those of zebu cattle, generally ranging between 54 and 56%, in addition to greater subcutaneous fat thickness and greater carcass uniformity (Abrahão et al., 2005; Prado et al., 2008). This characteristic is particularly important for meeting the standards required by markets that value the sensory quality of meat, such as tenderness, juiciness, and flavor.

Another relevant aspect concerns the distribution of tissues in the carcass. Zebu cattle (*Bos indicus*) tend to present a higher proportion of muscle and a lower proportion of fat, whereas crossbred animals show a more balanced proportion of muscle, fat, and bone, favoring both industrial yield and meat quality (Ducatti et al., 2009; Prado et al., 2009a; Prado et al., 2009b; Rotta et al., 2009a). In addition, heterosis may contribute to greater feed efficiency and improved muscle tissue deposition in intensive or semi-intensive production systems.

Therefore, although zebu cattle (*Bos indicus*) exhibit high adaptability and good carcass yield under tropical conditions, crossbred animals (*Bos indicus* × *Bos taurus*) often show better carcass finishing and superior meat quality, and are widely used in genetic improvement programs and industrial crossbreeding systems in Brazil. The choice of the ideal genetic group depends on the production system, environmental conditions, and the requirements of the consumer market (Crouse et al., 1989; Ferraz & Felício, 2010).

CHARACTERISTICS OF BEEF FROM PASTURE-RAISED CATTLE IN THE TROPICS

The cattle finished exclusively on pastures often exhibit lower deposition of intramuscular fat compared with animals fed diets rich in concentrates, which is reflected in lower levels of marbling in the meat (Duckett et al., 2013; Realini et al., 2004). Marbling, characterized by the presence of intramuscular fat distributed among muscle fibers, is one of the main determinants of juiciness, tenderness, and flavor in beef (Jackman et al., 2010; Ngapo et al., 2013; Pflanzer & Felício, 2011). In tropical production systems, especially those based on zebu breeds (*Bos indicus*), marbling levels tend to be lower when compared with those observed in taurine breeds (*Bos taurus*) raised in intensive feedlot systems (Crouse et al., 1989; Rubiano et al., 2009). However, this characteristic does not necessarily imply lower nutritional quality of the meat. On the contrary, several studies have shown that meat from pasture-fed animals presents a lipid composition more favorable to human health, including a higher proportion of polyunsaturated fatty acids, greater concentrations of omega-3 fatty acids, and higher levels of conjugated linoleic acid (CLA), compounds associated with beneficial effects on lipid metabolism and inflammatory processes (Daley et al., 2010; Prado et al., 2015; Scollan et al., 2006; Scollan et al., 2014).

In addition to the distinct lipid profile, meat from grazing systems also presents important differences in physicochemical attributes, such as color, ultimate pH, and water-holding capacity. The color of beef is strongly influenced by the concentration of myoglobin in the muscle, a protein responsible for the transport and storage of oxygen in muscle fibers. Animals raised in extensive or semi-intensive grazing systems generally exhibit greater physical activity, which favors the development of oxidative muscle fibers and a higher concentration of myoglobin, resulting in darker-colored meat compared with that of cattle finished in feedlot systems (Muchenje et al., 2009; Vestergaard et al., 2000).

Another important aspect refers to meat tenderness, a sensory attribute highly valued by consumers and influenced by several factors, including slaughter age, growth rate, connective tissue composition, and the activity of the enzymatic system responsible for postmortem proteolysis. In general, animals raised exclusively on pasture may present relatively lower meat tenderness, especially when slaughtered at an older age or with a low degree of fat finishing (Koohmaraie, 1994; Muchenje et al., 2009). The use of energy supplementation in tropical pastures, for example, can increase weight gain rate and promote greater deposition of intramuscular fat, improving the sensory characteristics of the meat (Paulino et al., 2013; Prado et al., 2015)

Animal genetics constitutes another determining factor in the quality of meat produced in tropical environments. In tropical countries, zebu cattle predominate, particularly the Nellore breed, due to their high adaptation to heat, resistance to parasites, and efficiency in extensive production systems (Ferraz & Felício, 2010). However, zebu animals tend to present lower marbling and higher calpastatin activity, a protein that inhibits the enzymes responsible for myofibrillar degradation during the meat aging process, which may result in relatively less tender meat compared with taurine breeds (Crouse et al., 1989; Shackelford et al., 1994).

From a nutritional perspective, beef produced in tropical pastures has high relevance as a source of high biological value protein, vitamins, and essential minerals. In addition to providing all essential amino acids in adequate proportions, beef is an important source of heme iron, zinc, selenium, and B-complex vitamins, particularly vitamin B12 (McAfee et al., 2010). In pasture-based systems, the presence of bioactive compounds derived from forage plants, such as natural antioxidants, may contribute to improving the oxidative stability of the meat and extending its shelf life (Scollan et al., 200

Well-managed pastures can contribute to nutrient cycling, soil conservation, and carbon sequestration, while also reducing dependence on external inputs such as grains and fertilizers (Carvalho & Medeiros, 2010; Herrero et al., 2016). Sustainable pasture intensification, including practices such as crop–livestock integration, strategic fertilization, and rotational grazing management, has been identified as one of the main strategies to increase the productivity of tropical livestock systems without expanding pasture area (Boval & Dixon, 2012).

FATTY ACID COMPOSITION OF BEEF FROM PASTURE-FINISHED CATTLE

The fatty acid composition of beef is strongly influenced by the feeding system of the animals, with diet being one of the main factors responsible for variations observed in the lipid profile of muscle (Almeida et al., 2019; Strada et al., 2019). In production systems based on pastures, which are common in tropical and subtropical regions, the predominant intake of fresh forages results in a fatty acid profile distinct from that observed in cattle finished in intensive systems with concentrate-rich diets (Daley et al., 2010; Scollan et al., 2006; Scollan et al., 2014).

Tropical forages contain high concentrations of polyunsaturated fatty acids (PUFA), particularly α-linolenic acid (C18:3 n-3), which constitutes the main precursor of omega-3 fatty acids present in animal tissues (Scollan et al., 2006; Scollan et al., 2014; Wood et al., 2008). During the digestive process in ruminants, a large portion of these fatty acids undergoes biohydrogenation in the rumen, mediated by ruminal microorganisms, which convert unsaturated fatty acids into more saturated forms (Prado, 2004). However, a fraction of these compounds escapes this process and is absorbed in the intestine, later being incorporated into muscle and adipose tissues (Jenkins et al., 2008). As a result of this metabolic process, meat from pasture-finished cattle generally presents a higher proportion of total polyunsaturated fatty acids and greater concentrations of n-3 fatty acids when compared with meat from animals fed grain-based diets (Daley et al., 2010; Realini et al., 2004). Among the omega-3 fatty acids present in beef, eicosapentaenoic acid (EPA, C20:5 n-3) and docosahexaenoic acid (DHA, C22:6 n-3) stand out, compounds associated with several benefits to human health, including cardioprotective and anti-inflammatory effects (Scollan et al., 2006; Scollan et al., 2014).

Another compound of great relevance in meat from pasture-fed cattle is conjugated linoleic acid (CLA), particularly the cis-9, trans-11 isomer, known as rumenic acid (Albertí et al., 2013; Whigham et al., 2000). This compound is produced in the rumen during the biohydrogenation of linoleic acid and can also be synthesized in animal tissues from vaccenic acid (C18:1 trans-11) through the action of the Δ-9 desaturase enzyme (Daley et al., 2010; Prado, 2004). Studies have shown that meat from pasture-finished cattle presents significantly higher concentrations of CLA compared with meat produced in feedlot systems, which has generated considerable interest from nutritional and functional perspectives (Scollan et al., 2014).

Regarding saturated fatty acids (SFA), beef is predominantly composed of palmitic acid (C16:0) and stearic acid (C18:0). Although saturated fatty acids are often associated with negative effects on cardiovascular health, stearic acid exhibits a distinct metabolic behavior and is considered neutral with respect to plasma cholesterol levels in humans (McAfee et al., 2010). The proportion of these fatty acids may vary according to the feeding system, slaughter age, and degree of carcass fatness. In addition, meat from pasture-finished cattle tends to present a more favorable ratio between omega-6 (n-6) and omega-3 (n-3) fatty acids. Grain-based diets generally increase the proportion of n-6 fatty acids, whereas forage-based diets favor a greater deposition of n-3 fatty acids in tissues (Daley et al., 2010; Wood et al., 2008). The n-6:n-3 ratio is considered an important nutritional indicator of lipid quality in foods, and values below 4:1 in the human diet are recommended for the promotion of cardiovascular health (Simopoulos, 2016). In this sense, beef from pasture-raised cattle often presents an n-6:n-3 ratio closer to this recommended value.

Studies conducted in Brazil have shown that cattle finished on tropical pastures, particularly those raised in systems based on grasses of the *Brachiaria* and *Panicum* genera, produce meat with higher levels of polyunsaturated fatty acids and greater concentrations of CLA compared with animals fed feedlot diets (Prado et al., 2015; Prado et al., 2015; Rotta et al., 2009a). These results reinforce the potential of tropical pasture-based livestock systems to produce beef with a differentiated lipid profile and greater nutritional value.

ANTIOXIDANT COMPOSITION IN BEEF PRODUCED IN PASTURE-BASED SYSTEMS

The antioxidant composition of meat can be influenced by several factors, including genetics, slaughter age, pre-slaughter management, and especially the feeding system of the animals (Descalzo & Sancho, 2008). In this context, cattle raised in pasture-based systems tend to produce meat with higher concentrations of natural antioxidants compared with animals finished on diets predominantly based on concentrates (Daley et al., 2010; Scollan et al., 2014).

Pastures are rich in plant-derived bioactive compounds, including carotenoids, tocopherols (Vitamin E), phenolic compounds, and flavonoids, which possess well-recognized antioxidant activity. During forage consumption, part of these compounds or their metabolites may be absorbed and deposited in the muscle tissues of animals, contributing to increased antioxidant capacity of the meat (Descalzo et al., 2005). As a result, meat from pasture-raised cattle often shows greater resistance to lipid oxidation, an important factor for preserving color, flavor, and nutritional value during storage and commercialization.

Among the main antioxidants present in beef, α-tocopherol (Vitamin E) stands out, being considered one of the most important lipid-soluble antioxidants in animal tissues. α-Tocopherol acts in protecting cellular membranes against lipid peroxidation by interrupting chain reactions mediated by free radicals (Descalzo & Sancho, 2008). Studies have shown that cattle fed exclusively on pastures present significantly higher concentrations of vitamin E in muscle compared with animals fed grain-rich diets, since fresh forage plants constitute an important natural source of this compound (Daley et al., 2010; Scollan et al., 2014).

Another relevant group of antioxidants present in beef from grazing systems is carotenoids, particularly β-carotene. These compounds are natural pigments found in high concentrations in green plant leaves and are partly responsible for the yellowish coloration of fat in pasture-fed cattle (Priolo et al., 2001). In addition to acting as antioxidants, carotenoids also play an important role as precursors of vitamin A in animal metabolism, contributing to the maintenance of essential physiological functions (Descalzo et al., 2005).

The presence of phenolic compounds in the diet may also influence the antioxidant activity of beef. Tropical forages contain different classes of polyphenols, including flavonoids and condensed tannins, which possess high free radical scavenging capacity (Halvorsen et al., 2002). Although the direct transfer of these compounds to muscle tissues is limited, their metabolites may indirectly contribute to reducing lipid oxidation and improving meat stability.

In addition to dietary antioxidants, beef also contains endogenous antioxidants produced by the animal’s own metabolism, such as the enzymes superoxide dismutase, catalase, and glutathione peroxidase. These enzymatic systems play a fundamental role in cellular defense against oxidative stress, acting in the neutralization of reactive oxygen species formed during cellular metabolism (Descalzo & Sancho, 2008). The activity of these systems may be influenced by the nutritional status of the animal and by the presence of trace minerals such as selenium, zinc, and copper, which act as enzymatic cofactors.

In tropical pasture-based production systems, the antioxidant composition of meat may vary according to forage species, plant maturity stage, pasture management, and environmental conditions. Young tropical grasses, for example, generally present higher concentrations of carotenoids and vitamin E compared with plants at more advanced maturity stages (Scollan et al., 2014). Therefore, management strategies that promote the consumption of high-quality forage may contribute to improving the antioxidant content of meat.

In addition to their nutritional importance, the higher concentration of natural antioxidants in meat from pasture-raised animals may improve oxidative stability during storage, reducing the formation of undesirable compounds responsible for changes in color, odor, and flavor (Descalzo & Sancho, 2008). Lipid oxidation represents one of the main causes of meat deterioration, especially in products with higher concentrations of polyunsaturated fatty acids, such as those derived from forage-fed cattle (Scollan et al., 2014).

Thus, beef produced in pasture-based systems presents distinctive characteristics regarding antioxidant composition, particularly the greater presence of natural compounds derived from plant-based diets. These antioxidants contribute not only to product stability and quality but also to its nutritional value, reinforcing the importance of pasture-based production systems for obtaining beef with functional properties and potential benefits to human health.

CONCLUSIONS

Meat production in tropical regions faces several challenges related to environmental conditions, herd health, and sustainability. However, it also presents significant growth opportunities through the adoption of sustainable practices, genetic improvements, and technological advances. The integration of productive systems that respect environmental limits, combined with public policies that encourage sustainable productivity, is essential to ensure that tropical livestock production continues to meet the growing global demand for high-quality meat while contributing to food security and economic development.

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