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Brazilian beef produced on pastures: Sustainable and healthy

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ABSTRACT

With a herd of 209 million cattle, Brazilian beef production estimate for 2023 is 10,935 million tons, representing an increase of 28.9% and accounting for 20% of the world trade. Beef cattle production is constantly evolving; however, there are extremes, ranging from simple existing farm ranges to intensive forage systems, strategic supplementation, updated health and genetic improvement programs for the production of quality beef. This modern production is based on scientific research carried out at universities and other research institutions. A new generation of professionals with multidisciplinary knowledge and a holistic vision of the productive chainproposed management practices to reduce greenhouse gas emissions in the production of grass-fed beef cattle, whose meat has high omega-3 and CLA contents. Age at slaughter of steers and of heifers at first mating, significant increases in the ratio calves/100 cows, adequate traceability for pastoral systems with hundreds or thousands of animals per farm and a more intense transference of technology are required.

1. Introduction

1.1. Brazilian beef cattle production situation

Brazil has a cattle herd of approximately 209 million head, distributed in 20% of an estimated total pasture area of 174 million ha of land. Brazilian meat exports in 2013 amounted to 1,846,000 tons, representing an increase of 20% compared to the previous year (2012), reaching the value of US$ 6.6 billion, equivalent to 16.5% of total meat production. Economic estimates for the year 2014 indicate a total income of US$ 8 billion. Average annual consumption per capita meat was 43 kg, corresponding to 83.5% of total production in MAPA (2013). Furthermore, approximately 401,000 live animals were sold to other countries. Most of beef cattle production in tropical conditions is developed on a large diversity of soils, including transition areas among different soil types. In addition, there is wide regional and seasonal climatic variability in the southern subtropical areas, such as the State of Rio Grande do Sul, at the border with Uruguay and Argentine, which constitute the Pampa Biome. In addition, five other biomes occur in Brazil: Amazonia, Caatinga, Pantanal, Atlantic Forest and Cerrado.

Such wide environment diversity supports different beef cattle production activity levels, as also previously reported by Ferraz and Felicio (2010). Consequently, production and productivity levels present also a wide variation. On one hand, there are extremes of extractive/extensive beef cattle production, with minimum use of technology and human interference, consequently have very low productivity indexes, with 21% average cattle offtake (number of head slaughtered relative to total national herd). On the other hand, intensive farming uses genetic improvement programs that select thousands of cows and their progenies for better performance in those environments, intensive forage management, health control and modern managerial practices (Rosado Júnior & Lobato, 2010).

In many operations, *Bos taurus* heifers and zebu crosses are first bred at 13–15 months of age and Nelore heifers (*Bos indicus*), which is the predominant breed in Brazil, at 18 months of age. According to Ribeiro (2009), in the State of Rio Grande do Sul, such operations are usually managed as modern companies, and use integrated beef–crop systems, applying new technologies that make them references to other farmers. According to that author, there is a second level of operations that use some technology, such as artificial insemination and internal parasite control. However, this technology is not systematically applied, and many of their productivity indexes need to be improved.

In the lower end, there are traditional operations that practice the so-called "extractive" beef production, characterized by low use of technology. In these operations, heifers are first bred at 36 months of age, and pregnancy and weaning rates of primiparous cows are low. These heifers, with poor body conditions that do not allow their earlier breeding, are a huge obstacle to beef cattle production. However, they have the potential to achieve higher productivity, as reported by Potter, Lobato, and Mielitz Netto (1998), and Beretta, Lobato, and

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Mielitz Netto (2001). For instance, the cow/calf ratio in Rio Grande do Sul State is low, with 56 calves/100 cows (SEAPA, 2013), and it is not different from the Brazilian average.

Foreign and domestic markets demand better production, productivity and meat quality. However, several packing plants operate below their full capacity during some months, as observed in the last few years. Many of these packing plants were built in 1950–1970, when beef cattle slaughter was seasonal, extending from late spring to late autumn. Fig. 1 shows slaughter percentage in the most important Brazilian beef-cattle producing states, representing more than 70% of the national beef production (MAPA, 2013).

There are technologies available to improve production and productivity. However, the current low cow/calf ratio precludes higher production levels and the advance in genetic animal improvement. Evidently, no selection pressure is possible with ratios of 50–60 calves per 100 cows and only 28–30 replacement heifers. Also, there are thousands of heifers that do not present the minimum conditions required to produce a good steer.

The knowledge produced by Brazilian Federal Universities through their graduate programs that started in 1965, and by EMBRAPA (Brazilian Research Agency) and the other governmental research institutions have shown that production and productivity may be increased if the published technologies are massively applied. Farmers that apply these technologies have become leaders in the beef cattle industry and have increased national productivity index. However, it is still a huge challenge to make these technologies available to farmers (Andreatta, 2009; Ribeiro, 2009). There is still a lot of room to increase production and productivity and to create conditions to obtain differentiated products, both for the domestic and foreign markets.

2. Results of the adoption of technology

For a long period of time (1950–1970), Brazilian beef production was primarily based on the expansion of extensive pastures. However Martha, Alves, and Contini (2012) recently showed that, especially during the period of 1996–2006, the productivity increased at an impressive rate of 6.64% per year. Table 1 shows the Brazilian beef production characteristics between 1950 and 2006. For instance, carcass equivalent increased from 17.61 kg/head to 40.13 kg/head between 1975 and 2006, which was achieved by increasing the stocking rate (35%) and better animal performance (65%). During the period of 1950–2006, productivity improvements explained 79% of the growth in beef production and supported a land-saving effect of 525 million ha. A long-term run program of pasture fertilization or carry-over fertilizer effects applied on crops (integrated crop–livestock systems), together with the use of modern cattle management, is recommended to obtain high productivity in the next years.

Universities and researchers increasingly publish new results and propose new practices to be adopted by the farmers. However, new technologies are only adopted when they prove to be competitive relative to the existing alternatives, already in use, and when relative prices are favorable (Martha Júnior, Alves, & Contini, 2011).

An important issue is that the adoption of the technologies needs to be considered under a multidisciplinary approach in grazing systems (Wade & Carvalho, 2000) and relative to costs. The costs of fertilization, soil preparation, seeds, etc., to recover pastures and improve soil fertility can be compensated using Crop and Livestock Integrated Systems (CLIS). Many studies on the application of CLIS to mitigate deforestation and/or pasture degradation in the Cerrado of Brazil demonstrated that it improves animal and crop production, as shown by higher stocking

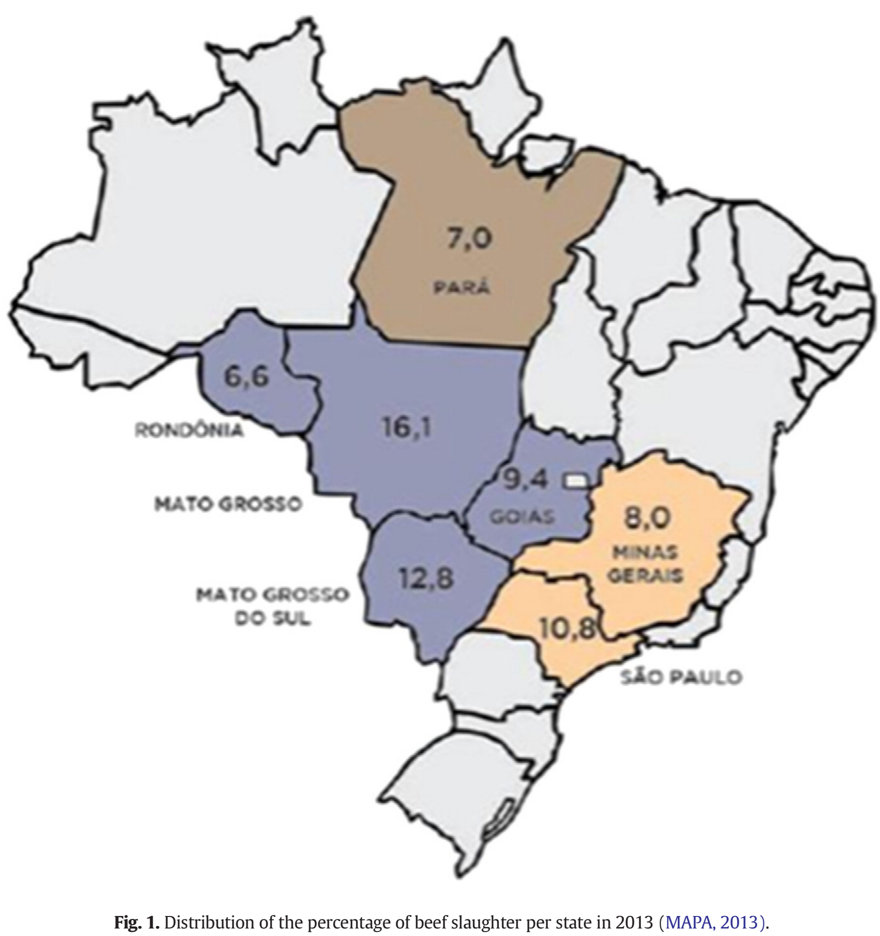

Fig. 1. Distribution of the percentage of beef slaughter per state in 2013 (MAPA, 2013).

Table 1
Brazilian beef production characteristics, 1950–2006.
Source: Martha Jr. et al. (2012) calculations.

	Unit	1950	1960	1970	1975	1980	1985	1996	2006
Bovine population	Head	46.891.208	56.041.307	78.562.250	101.673.753	118.085.872	128.041.757	153.058.275	171.613.337
Pasture area	ha	107.633.043	122.335.386	154.138.529	165.652.250	174.499.641	179.188.431	177.700.472	158.753.866
Production	1.000 ton c.e.	1083.67	1359.22	1845.18	1790.25	2083.77	222.65	4053.18	6886.58
Stocking rate	Head/ha	0.44	0.46	0.51	0.61	0.68	0.71	0.86	1.08
Animal performance	kg c.e.[a]/head	23.11	24,25	23.49	17.61	17.65	17.36	26.48	40.13
Productivity	kg c.e.[a]/ha	10.07	11.11	11.97	10.81	11.84	12.40	22.81	43.38

[a] c.e. is carcass equivalent.

rates, live weight gain, and grain yield, reaching towards new thresholds of production and environment protection, and consequently, better sustainability. Higher profits, higher employment rates, use of byproducts and efficient use of machinery and labor, are also other advantages of CLIS (Euclides et al., 2010). More recently, trees have been introduced in the system and included in studies, as reviewed by Almeida and Medeiros (2013), to improve beef production and to reduce greenhouse gas emissions.

Poor soil fertility and no fertilization caused pasture degradation in the Cerrado region. However, based on research results, in the beginning of 2014, the Brazilian Government launched a program called "More Beef" aiming at significantly improving beef productivity and sustainability, increasing the stocking rate of 1.3 head to 2.6 head/ha, with a consequent production of 13.6 million tons of beef in an area of 113.6 million ha, allowing the release of 46.2 million ha for other agricultural activities. Other Brazilian data estimate a 22.5% increase in beef production, of 8930 million tons, between 2013 and 2023.

These goals, probably supported by results obtained by Euclides and Montagner (2013) (Table 2), on medium soil fertility with increasing doses of nitrogen, indicate that it is possible to obtain higher tropical pasture production, thereby reducing the interval between grazing periods, in order to achieve at least 70 cm pasture height in the next grazing period and an additional grazing cycle. This would allow higher stocking rates, live weight gain per head and per hectare, and productivity. The increase of N fertilization from 150 kg to 300 kg/ha produces 2.4 kg/ha more of live weight for each kilogram of N applied. Researchers, acknowledging the difficulties private farmers have to estimate pasture availability on dry matter basis in order to use pastures more efficiently, recommend the use of pasture height to obtain satisfactory results. As shown in Fig. 2, pasture height is related to live weight gain per head and per hectare. Optimal stocking rate is the range that allows a balance between gain per animal and per hectare.

As mentioned above, research has shown that it is possible to increase beef production per hectare with steers, and most management practices have been also applied by the farmers with this animal class, with significant reductions in slaughter age. This has allowed the establishment of meat quality programs, as those of the Angus, Hereford, Nelore and other breeders associations in partnership with packing plants and supermarkets to supply special markets.

Nevertheless, in Brazil as a whole, little research has been conducted on pasture systems to improve the current reproductive indexes. However, leading operations have obtained high reproduction rates in multiparous cows, with heifers getting pregnant at two years of age. A few have developed a strong program based on pasture management and on intensive genetic selection to get Nelore (*B. indicus*) heifers pregnant at 18 months of age, such as Jacarezinho and CFM Farms, in the State of São Paulo.

Table 2
Mean stocking rate (AU/ha), averaged daily gain (kg/animal/day), and gain per area (kg/ha) from animals grazing Tanzânia grass (*Panicum maximum*), under two levels of nitrogen fertilization, 150 (N-150) and 300 kg/ha (N-300) during the water season.
Source: Euclides and Montagner (2013).

	N-150	N-300
Stocking rate (AU/ha)	4.4	6.3
Average daily gain (kg)	0.790	0.830
Gain per area (kg/ha)	850	1215
Rest period (days)	30	26
Grazing cicles (number)	6.1	7

In subtropical regions, specifically in the State of Rio Grande do Sul, research on natural pasture grazing systems has obtained significant pregnancy rates in primiparous cows of more than 80% and up to 90%, when pasture availability of 2500 and 3000 kg dry matter/ha (Pötter & Lobato, 2004; Simeone & Lobato, 1998; Tanure, Pötter, & Lobato, 2011), or stocking rates per hectare of 320 (0.71 A.U./ha) and 240 kg (0.53 A.U./ha), respectively. Grazing on annual ryegrass pre- and/or post-calving also allows adequate body condition and high pregnancy rates in primiparous cows (Lobato, Menegaz, & Pereira, 2010; Tanure et al., 2011).

Using winter–spring pastures, such as annual ryegrass (*Lolium multiflorum*), white clover (*Trifolium repens*), *Trifolium vesiculosum* cv. Yuchi, and birdsfoot trefoil (*Lotus corniculatus* cv. São Gabriel), which are the cool season species most commonly used in the State of Rio Grande do Sul, studies have shown that high pregnancy rates can be easily obtained in 2-year-old heifers maintained exclusively on pasture (Pereira Neto & Lobato, 1998; Pio de Almeida & Lobato, 2004). Farmers that obtained success with this practice have gradually advanced to get heifers pregnant at 13–15 months of age. Research shows that, in order to get heifers pregnant at this age, the heaviest and those with the best traits of their breed need to be identified at weaning, and then receive high nutrition levels, including supplementation when grazing on natural pastures in autumn/early winter before grazing on winter forage species, as previously mentioned (Azambuja, Pilau, & Lobato, 2008; Rocha & Lobato, 2002; Rosa, Vaz, & Lobato, 2012). Similarly, pregnancy rates can be obtained with two-year-old primiparous cows grazing on those same winter species in late winter and practically during all spring, before returning to natural pastures, provided that live weight and body condition goals are achieved (Rocha & Lobato, 2002).

These data constitute only a small sample of the most recent research results published in the last 50 years, as well as how they can be used by beef cattle operations, and well as the many possibilities to increase production and productivity per animal and per hectare.

3. Greenhouse gas (GHG) emissions by Brazilian livestock

Brazil is an important player in the global beef industry, but its cattle production system contributes with approximately 22% to the anthropogenic gas emission effect — GHG (Almeida & Medeiros, 2013). Therefore, the Brazilian Government announced voluntary goals in 2009, during the 15th Conference of the United Nations, in Copenhagen, to reduce GHG emissions until 2020. These goals are: to reduce GHG emissions in 83–104 Mt CO_2 eq by recovering 15 million ha of degraded pastures, in 18–22 Mt CO_2 eq with integrated livestock–crop–forest systems, in 16–20 Mt CO_2 eq with no-tillage, and in 16–20 Mt CO_2 eq with biological nitrogen fixation (Brasil, 2010b), in spite of the costs of establishment and persistence of legumes

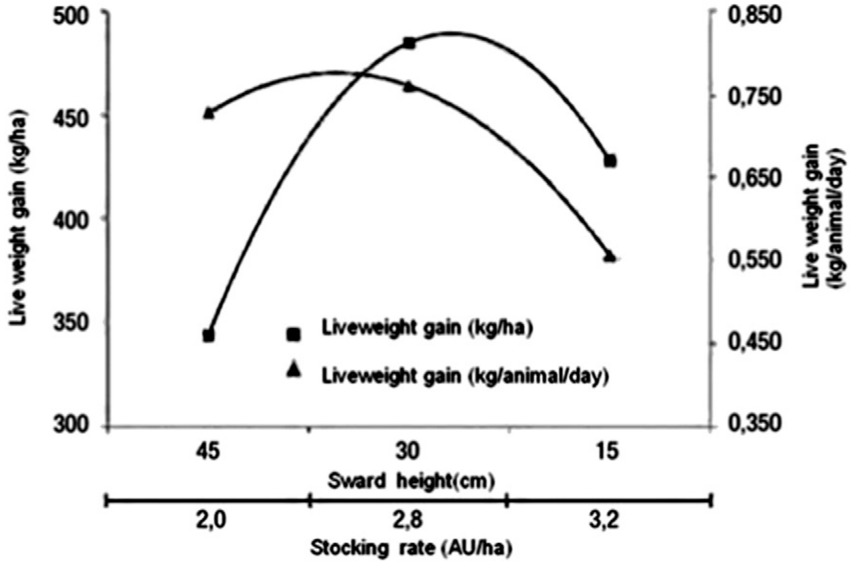

Fig. 2. Relationship between sward height and live weight gain per animal and per hectare on Marandu grass (*Panicum maximum* cv. Marandu) pasture.
Source: Euclides and Montagner (2013).

associated with grasses in Brazil and Australia (Berndt & Tomkins, 2013), as it was known since 1970s. In order to reach these goals, the Brazilian Government put on practice the Agriculture Low Carbon Program or "ABC program" (Brasil, 2010a; MAPA, 2012). The aim is to reduce GHG emissions in 38.9% (Berndt & Tomkins, 2013).

However, GHG emissions present uncertainties due to the wide complexity of the production systems, especially livestock production. Almeida and Medeiros (2013) reported that, in spite of the few studies with animals, average results differ from the reference values of the Intergovernmental Panel on Climate Change — IPCC (2006), contributing to more realistic and promising estimates of Brazilian animal production. The reference value of IPCC (2006) for enteric methane emission in beef cattle in South America is 56 kg/animal/year, whereas the average presented by those authors is 48.8 kg/animal/year, with a daily average gain of 0.366 kg, resulting in 67.5 kg live weight/ha, compared with the Brazilian average of 45 kg live weight/ha. It is concluded that further studies are required to evaluate the different Brazilian beef cattle production systems, particularly relative to breeding herds and their reproductive efficiency. Fisher et al. (2007), in an extensive review involving studies on Savannah regions of Brazil and Colombia carried out between 1998 and 2004, observed that the rates of manure deposition were underestimated and, consequently, GHS production was overestimated and mitigation was underestimated.

The research developed in Brazil typically target modifying diet digestibility to promote food intake, weight gain and dilution of emissions per unit of product. A recent study of Ruviaro, de Léis, Lampert, Barcellos, and Dewes (2014) evaluated the carbon footprint of seven rearing and finishing systems of Angus steers: natural grass; improved natural grass; natural grass plus ryegrass; improved natural grass plus sorghum; cultivated ryegrass and sorghum; natural grass supplemented with protein mineral salt; and natural grass supplemented with protein–energy mineral salt. The carbon footprint ranged from 18.3 kg CO_2 eq/kg live weight for ryegrass and sorghum pasture systems to 42.6 kg CO_2 eq/kg live weight for the natural grass system, including the contributions of cows, calves and steers. Among all grassland-based cattle farms, production systems with digestible dry matter intake from 52 to 59% achieved the lowest CO_2 emissions and the highest feed conversion rate, thereby generating lower CH_4 and N_2O emissions per production system. On the other hand, the direct interference in rumen to reduce the production of H_2, to provide alternative sinks for the H_2 already produced and to reduce populations of methanogenic microorganisms, generated an average emission factor of 37.7 kg CH_4/head/year, which is 33.8% lower than the average of animals grazing on improved pastures and supplemented (57 kg CH_4/head/year). More strategies include the use of synthetic chemicals, halogens, nitrates, and natural compounds, but with variable results (Berndt & Tomkins, 2013). Seeking opportunities to mitigate GHG emissions, Almeida and Medeiros (2013) also reported alternatives to reduce GHG emission by grazing on corn, sorghum and rice stubbles, with the use of protein supplements, and use of short-time feedlot during the finishing period.

In addition to different feeding regimes (different pastures), the effects of grazing management on GHG emissions have been studied in Brazil. Savian et al. (2014) analyzed the effect of grazing intensity and stocking methods on the production of lambs and ewes and methane emissions, and concluded that stocking method was more important than grazing intensity for methane production. Continuous stocking was the most efficient grazing management method for reducing methane emissions per unit animal production.

Monteiro (2009) simulated the progressive intensification of a herd production system based on 800 ha, considering: (1) extensive grazing system; (2) intensive grazing system; (3) intensive grazing system with finishing in feedlots. When considering all the inputs of these three systems, the estimated emissions in CO_2 eq/carcass eq were 19.88, 14.11 and 12.3, respectively, indicating that a strategic feedlot period, equivalent to 90 days, could significantly reduce slaughter age and associated emissions in up to 38% or 13%.

Cardoso (2012) simulated the effect of GHG emissions of different levels of intensification of beef production systems in Brazil by applying appropriate emission factors. Four scenarios were established with 100 cows, considering all inputs: (1) animals spending the entire cycle in areas of degraded pastures in an extensive system; (2) animals spending the entire cycle on improved pastures, but under an extensive system; (3) animals raised on extensive improved pastures and supplemented under growing and fattening systems; (4) animals reared on pastures with intensive finishing on high grain diets. The GHG emission estimates were based on national studies on the characteristics and husbandry in each scenario. Using the IPCC methodology, the annual amount of CO_2-e/carcass-e produced in scenario 2 was 35.47% lower compared with scenario 1, 18.85% lower in scenario 3 compared with scenario 2, and 19.6% lower in scenario 4 compared with scenario 3. Hunter and Neithe (2009) also calculated the effects of weaning rate, growth rate of the slaughter generation, and finishing strategy for beef cattle typical of northern Australia. Their results indicate that CH_4

emissions from a breeding cow/steer unit could be reduced by as much as 30% if weaning rate or growth rate were increased in 20% or 0.3 kg/day, respectively. But, the greatest reduction in CH_4 emissions, of 55%, was obtained if steers with 400 kg live weight were moved from pasture and finished on high-grain diets in a feedlot, although methane emissions associated with the growing, harvesting, transporting and processing of energy-dense feedstuffs were not included.

Based on a long-term experiment of Maraschin et al. (1997), who studied four pastures availabilities (4%, 8%, 12%, or 16% DM/kg head) and obtained significant increase in live weight gain per head and per hectare on natural pastures with 12–13% allowance, Conceição, Bayer, Castilhos, Mielniczuk, and Guterres (2007) performed an experiment for three years in another region of the same Bioma Pampa, in the State of Rio Grande do Sul, with these same pasture allowances. They showed that, at higher pasture availability per kg live weight, organic C content increased, especially at the superficial soil layers. Organic C reserves (0–40 cm) ranged from 103 ton/ha (4%) to an average of 140 ton/ha. Tornquist and Bayer (2009), based in these results, estimated linear annual organic C conservation rates of 2.4% ton/ha (8.8 ton CO_2/ha), under an availability of 4%, and of 3.7% ton/ha (13.6 ton CO_2/ha) at higher allowances (8%, 12% and 16%).

As mentioned by Almeida and Medeiros (2013) in their extensive review, the problem in Brazilian beef production is the methane produced by cattle with low live weight gains, or even weight loss during the dry season; cows with low weaning rate; and higher age at first mating of heifers, with no corresponding milk and meat production. In the study of Charmley, Stephens, and Kennedy (2008), cows were either not supplemented or provided with a molasses-based supplement to prevent bodyweight loss during the dry season. Over a 6-year period, it was found that supplementation increased the number of calves born from 2 to 4, reduced predicted CH_4 emissions by the cow per live output by 45%, but increased total emissions from the system by 11%. Barioni, Lima, Zen, Guimarães Júnior, and Ferreira (2007) estimated and concluded that, between 2008 and 2025, under Brazilian conditions, increasing calving rate from 55% to 68%, reducing slaughter age from 48 or more to 28 months, and reducing mortality of calves up to one year of age in 2025, could effectively reduce emission intensity by as much 18% c.e. In a long review on the perspectives of mitigating methane emissions from beef cattle in tropical grazing systems of Brazil and Australia, Berndt and Tomkins (2013), in addition of corroborating with the authors mentioned above that emissions are a result of the utilization of pastures with low nutritional value, emphasized that emissions are also due to low live weight gain and to breeding herds with long and inefficient calving intervals and late age at first calving. However, leading operations in Brazil have obtained better results than those estimated by Barioni et al. (2007) and have applied the proposals of Berndt and Tomkins (2013). They have better weaning rates, heifers getting pregnant and steers slaughtered at two years of age or even younger. Their outcome rate is around 28–30% in grazing systems, as identified by Potter et al. (1998) and Beretta et al. (2001). In the article of FAO (2009), “Grasslands: enabling their potential to contribute to greenhouse gas mitigation”, the authors suggest that there is a higher GHG mitigation potential from pastures than the methane emissions of the ruminants and their manure. They state that grasslands (including grazing land management plus a share of restoration of degraded lands, plus a share of cropland management) present a high potential to build up carbon if appropriate management practices are adopted. These practices are based on the introduction of new species and varieties, restoration of organic soils and degraded lands, extending the use of perennial crops, increasing tree cover in silvopastoral systems, managing grazing intensity and periodicity, and improving pasture quality.

Therefore, the reduction of GHG emission effects requires the use of more appropriate measuring methodologies in Brazilian grazing systems by applying the technologies published by universities and research institutions by Brazilian farmers. The intensification of beef cattle production systems, as shown by the gradual reduction of age at slaughter of steers that supports meat quality programs, must also be applied in breeding herds and in heifer development. According to Cerri et al. (2010), these goals can be achieved by the use of the available technologies. The previously mentioned ABC program (Brasil, 2010a; MAPA, 2012) is a government's stimulus to transfer new technologies to a large number of farmers. For example, Carvalho (2013) described the successful Brazilian case study of PISA (Produção Integrada de Sistemas Agropecuários), with 575 farmer families, showing that grazing behavior research can reach farmers and change their lives by the use of simple management strategies supported by reductionist approaches applied in holistic frameworks.

4. Influence of Brazilian production systems on beef quality parameters

4.1. Lipid profile

Brazil beef cattle production systems can be considered as “grass-fed based”, since all breeding and rearing are made on pastures, and only 7.5% (Brazilian Association of Feedlot Producers), or even less, of the slaughtered cattle are finished on feedlots, and for a short period of time. This may be an important appeal to consumers because of the very favorable image of “green beef”. In associating with the Brazilian climate, grazing systems provide animal welfare, eliminate risks of Bovine Spongiform Encephalopathy (BSE), produce a healthier product when compared with beef produced exclusively in feedlots, and have low production costs.

Brazilian researchers have recently worked with the analysis and identification of the composition of beef (Fernandes et al., 2009; Freitas et al., 2014; Ladeira et al., 2014; Menezes et al., 2013; Metz et al., 2009; Rossato et al., 2010). Padre et al. (2007) analyzed the effects of genetic groups on the fatty acid profile of the *Longissimus dorsi* muscle (LM) of steers slaughtered with 480 kg and 25 months of age, finished for 90 days on *Brachiaria brizantha* cv. Marandu pastures and reported that Nelore steers presented lower fat deposition and lower proportion of saturated fatty acids (SFA) than Santa Gertrudes × Nelore crossbred steers. Small differences were observed in the concentration of conjugated linolenic acid (CLA), which was higher in Santa Gertrudes × Nelore crossbreds compared with Simmental × Nelore crossbreds and Nelore purebreds. Rossato et al. (2010) analyzed the meat of Angus and Nelore steers reared exclusively on *Brachiaria* and *Panicum* pastures and slaughtered at 36 months of age, producing 250 kg carcasses. The authors reported that Nelore beef was less tender, but nutritionally healthier than Angus beef due to its lower cholesterol levels and higher $n-3$ fatty acids and CLA contents. However, the omega-6 to omega-3 ratio ($n-6/n-3$) did not differ, and was below the average (1.73).

Faria et al. (2007) reared and finished Nelore steers on *B. brizanta* cv. Marandu pasture according to three treatments: a) without supplementation in the dry season; b) with bean protein bank area consisting of guandu (*Cajanus cajan* cv. Super N); and c) supplementation with concentrate at 5% body weight, but did not find any differences in LM fatty acid profile. Moreira, Souza, Matsushita, Prado, and Nascimento (2003) evaluated three finishing systems on pastures: a) millet (*Pennisetum americanum* L.); b) star grass (*Cynodon plectostachyus* Pilger), both with mineral salt supplementation — and c) star grass + protein mineral salt supplementation. The authors also did not find any differences in meat composition, but higher lipid content in *B. indicus* compared with *B. indicus* × *B. taurus* (1.86 vs. 1.37%, respectively). On the other hand, Menezes et al. (2013) concluded that supplementation with concentrate, at 1% body weight, increased the meat content of the fatty acid docosahexaenoic (DHA) (C22:6$n-3$) and, therefore of the $n-6/n-3$ ratio (3.1) in the meat of Devon steers grazing on pearl millet pasture (*Pennisetum americanum* L. Leeke) compared with pearl millet pasture plus 0.5% supplementation (2.1).

Padre et al. (2006) evaluated castrated and intact Nelore × Angus steers, with an average age of 20 months and 480 kg grazing on *Panicum maximum* Jacq. cv. Mombaça pasture, and reported higher total $n-3$ content in the meat of uncastrated relative to castrated steers, which beef presented higher myristic (C14:0), palmitic (C16:0) fatty acid and CLA contents than that of uncastrated, as justified by the higher lipid content in LM.

Feedlots are mainly concentrated in the State of São Paulo, and are managed by packing plants and their associated farmers. They are commercially strategic for the industry and for production systems that confine steers during the dry season in the tropics (June–September), allowing reducing age at slaughter to two years or even less. Feedlots have also been recommended to reduce greenhouse gas effects, despite the CO_2 emissions caused by grain production (Cardoso, 2012; Monteiro, 2009). Brazilian feedlots were characterized by Millen, Pacheco, Arrigoni, Galyean, and Vasconcelos (2009) as follows: animals are Zebu males and crosses, castrated or not, fed for short periods of 57 to 83 days, and slaughtered up to 500 kg live weight. Due to limitations of grain processing, the utilization of starch is not optimal and, in addition, the grain levels fed are much lower than those used in the North-American feedlots. There is an important participation of forage and byproducts (roughage: fresh chopped sugarcane, corn silage, sorghum silage, sugarcane bagasse, grass silage and sugarcane silage; byproducts: whole cottonseed, citrus pulp pellets and soybean residues) in Brazilian feedlot diets. According to a risk-analysis study (Pacheco et al., 2014), a slaughter weight of 467 kg presents the lowest risk for finishing cattle in feedlots when compared with 425 and 510 kg. The most important variables influencing the Net Present Value are the prices of feeder and finished steers, initial and final weights, concentrate and roughage costs, and minimum rate of attractiveness, demonstrating the importance that should be given to these variables when deciding on feedlot finishing to obtain economic success.

Freitas (2006), working with castrated or uncastrated Nelore steers reared on *B. brizantha* cv. Marandu pasture and finished in feedlots (corn silage, soybean meal, corn and cottonseed) for 100 days, and slaughtered at 22 months of age, reported that meat of uncastrated steers was leaner and contained more poly-unsaturated fatty acid (PUFA), $n-6$ and $n-3$, but presented similar $n-6/n-3$ ratio (4.1 in average) relative to castrated steers. Fernandes et al. (2009), evaluating uncastrated Nelore and Canchim animals with 22 and 19 months of age, respectively, also reported better fatty acid composition in Nelore beef, i.e., higher unsaturated fatty acid levels. However, fatty acid composition was different when levels of 40 and 60% of concentrates in dry matter were used. Sugarcane was used as roughage and the concentrate consisted of sunflower, corn, soybean meal and sugarcane dry yeast.

Kuss et al. (2007) observed that, when the body weight of Charolais and Nelore crossbred cows at culling increased, the intramuscular fat fatty acid profile in LM was beneficial to human health, with lower hypercholesterolemic and higher hypocholesterolemic fatty acid contents. Metz et al. (2009), when reducing the slaughter age of steers from 24 to 14 months, reported that beef of steers with more Charolais blood presented a less unsaturated profile compared to that of steers with more Nelore. On the other hand, Menezes et al. (2009) observed healthier meat, due higher PUFA content in the meat of 3/4 Charolais × 1/4 Nelore steers compared to 3/4 Nelore × 1/4 Charolais steers. Rodrigues, Bressan, Cardoso, and Freitas (2004), evaluating steers in a feedlot for 112 days fed a diet consisting of elephant grass, brewers' grain and cassava scrapings, demonstrated that LM of Nelore steers contained more fat, more SFA, less PUFA and $n-6$, but lower ratio $n-6/n-3$ than Nelore × Sindi crosses (6.08), which, however, was very high according to recommendations of the Brazilian Ministry of Health (Department of Health, USA, 1994).

Mello (2007) found that the meat of uncastrated Blonde D'Aquitaine × Nelore crossbred steers finished in feedlot and fed a low-lipid diet (43% sugarcane [*Saccharum officinarum* L.] and 57% concentrate of citric pulp and cotton meal), was richer in CLA, with higher content of MUFA and lower $n-6/n-3$ ratio, than that Angus x Nelore crossbreds. The meat of the lighter steers (480 kg) presented higher redness, higher $n-3$ and CLA contents, and lower $n-6/n-3$ ratio than the heavier animals (560 kg). Costa et al. (2002), evaluating the effect of different slaughter weights of Red Angus steers (340–433 kg), did not find any significant differences, with average lipid contents of 2.35% and 43 mg/100 g LM of cholesterol.

The use of monensin in diets, at levels up to 200 mg/head/day, had virtually no effect on the fatty acid profile of the LM (Ladeira et al., 2014; Menezes et al., 2006). Furthermore, according to Ladeira et al. (2014), the inclusion of ground soybean grain in the diet increased PUFA, CLA, and linoleic acid (C18:2) content in LM, compared with the animals fed rumen-protected fat, which presented higher linolenic acid (α-C18:3).

Medeiros (2008) evaluated the LM of Angus steers fed an energy supplement based on corn compared with grazing on *Avena strigosa* Schreb. and *L. multiflorum* Lam. pastures and a feedlot diet, and obtained higher levels of $n-3$ fatty acids and better $n-6/n-3$ ratios in the meat of grazing steers compared with those in feedlot. The author also observed that supplementation levels linearly reduced $n-3$ and CLA contents and linearly increased the $n-6/n-3$ ratio. On the other hand, Menezes (2008), comparing the fatty acid profile in the carcass of Devon steers in feedlots (corn silage + concentrate) or grazing on pearl millet pasture or annual ryegrass pastures, reported that annual ryegrass pasture promoted higher CLA and $n-3$ fatty acid contents than the feedlot feed. The $n-6/n-3$ ratio was better in the pasture-fed than in the feedlot steers. According to French et al. (2000), reducing concentrate and increasing forage allowance do not affect $n-6$ fatty acid content in the intramuscular fat of cattle but, increases $n-3$ content and linearly decreases the $n-6/n-3$ ratio. Cattle grazing has a high PUFA $n-3$ intake due to the higher C18:3 content of grasses, which is approximately 30 times higher (in the case of temperate grasses) than that in concentrates.

In southern Brazil, the Pampa Biome is characterized by native pasture areas in ecosystem with a wide diversity of plant species (Boldrini, 1997). This Brazilian subtropic region presents cold winters, with the occurrence of frosts, hindering the growth of spring and summer pastures. The introduction of species with cold season cycle helps to reduce forage deficit, significantly improving the supply of nutrients to the herd. Freitas (2010) determined the fatty acid composition of the most important forage species consumed by Angus steers and its crosses with Nelore on a farm of the Pampa Biome and their effect on meat composition. The vegetative period of natural species in spring and the introduction of *L. multiflorum* increases linolenic (C18:3$n-3$) and linoleic (C18:2$n-6$) PUFA levels, improving the lipid profile of the diet (more PUFA) and, as a consequence, reduced the $n-6/n-3$ ratio in LM (lower than 3.0). In addition, that author found that the LM of Nelore × Angus crossbreds contained higher levels of linoleic (C18:2$n-6$c), α-linolenic (C18:3$n-3$) fatty acids and of the sum of $n-3$ than that of Angus steers, when grazing on fertilized natural pastures or fertilized and improved pasture by the introduction of cool season species. Such results have allowed the delimitation of areas for Denomination of Origin (IP) meat quality programs such as Meat of the Pampa Gaúcho of the Meridional Region. Devincenzi et al. (2012), evaluating the composition of the meat of steers under that program and finished on natural or improved pastures with over seeding of *L. multiflorum* Lam. and *L. corniculatus*, did not report any effect of feeding on most of the fatty acids analyzed. However, they demonstrated the excellent nutritional quality of their meat, as shown by the high ration of unsaturated to saturated fatty acids and the very low $n-6/n-3$ ratios (average of 1.25). This average is well below that found in the diet of Western countries ($n-6/n-3$ ratios of 10:1 to 20:1(Simopoulos, 2004)), while health agencies of different countries recommend a daily intake of 4:1 (Department of Health, USA, 1994) to 5:1 of $n-6$ e $n-3$ fatty acid ratios.

Freitas et al. (2014) evaluated the lipid content of LM of steers finished on pastures or in feedlots and reported an average of 3.7 g of fat and 48 mg of cholesterol per 100 g of meat. This cholesterol content is half the value that the FDA (2009) considers as lean meat. According to the authors, feeding steers for a short period of time (68 days) and a low energy diet in feedlot (diet consisting of 37% whole plant corn silage and 63% concentrate with sorghum grain and soybean meal) virtually did not change meat lipid composition. Carcasses of 2-year-old Hereford and Braford steers ranged between 220 and 240 kg, with the finishing of 3 to 4 mm of subcutaneous fat. The observed difference was a higher percentage of $n-3$ in the meat of steers reared only on natural pastures of Pampa Biome and finished on *L. multiflorum* Lam., *T. repens* L. cv. Yi and *L. corniculatus* L. cv. São Gabriel pasture (Freitas et al., 2014). Evaluating the meat of Hereford steers, finished in feedlot or on perennial ryegrass (*Lolium perenne*), birdsfoot trefoil, white clover, and tall fescue (*Festuca arundinacea*) pasture in the Pampa Biome in Uruguay, Realini, Duckett, Brito, Dalla Rizza, and De Mattos (2004) identified twice as much intramuscular fat (3.18 vs. 1.68%, in 100 and 130 days of finishing, respectively) in steers finished in feedlot with a high corn diet (50% of corn silage + 18% of corn grain in the concentrate). According to Perry (2005), beef cattle finished with grains present more intramuscular fat than those grazing on pastures. For each additional 10 kg of carcass weight, intramuscular fat increased 0.31% in feedlot cattle compared with 0.19% in pasture-grazing cattle.

4.2. Sensorial parameters

In addition of being extremely healthy, beef must present the sensorial attribute expected by the consumers. These characteristics were recently studied by Brazilian researchers. Color is one of the most important attribute of meat purchase decision (Mancini & Hunt, 2005). Pre-slaughter handling affects meat color. The Brazilian herd is predominantly composed of *B. indicus* and *B. indicus* × *B. taurus* crosses, which have reactive temperaments and are difficult to handle during transport and pre-slaughter procedures (Braga et al., 2011). Therefore, these animals spend their muscle glycogen stores, causing their meat to be darker. Investments have been made in personnel training and facilities to allow for more gentle handling, according to the welfare practices of the Brazilian Animal Welfare and Humanitarian Slaughter code (MAPA, 2000). Immune suppression of sex hormones (immunocastration) have shown to be an efficient method to reduce meat color faults in *B. indicus* and *B. indicus* × *B. taurus* crossbreds (Miguel et al., 2014). According to Muchenje et al. (2009), normal values of luminosity (L^*) in beef range between 33.2 and 41.0, redness (a^*) ranges between 11.1 and 23.6, and yellowness ranges between 6.1 and 11.3. Recent Brazilian studies conducted on grazing systems show L^* values ranging from 32.3 to 39.1, a^* values ranging from 19 to 23.7 and b^* values from 4 to 9.3 (Amatayakul-Chantler et al., 2013; Devincenzi et al., 2012; Rossato et al., 2010).

Tenderness is the most important beef quality attribute. Ferraz and Felicio (2010) mentioned the relationship between breeds reared in Brazil and meat tenderness. Zebu genes decrease meat tenderness through several mechanisms: muscle structure, physiology, and enzymatic activity (Lawrie, 2005).

Using Nelore and Angus bulls reared on *Brachiaria* pastures and slaughtered at 36 months of age, Rossato et al. (2010), obtained shear force of grilled steak of the *Longissimus thoracicis* of Nelore bulls of about 91.3 Newtons (N), while 78.6 N was obtained in Angus bulls. Pflanzer and Felicio (2009), evaluating the effects of age and carcass fatness on carcass quality traits of Nelore steers, concluded that fat cover was more important to improve meat tenderness than age. After 14 days of aging, the authors obtained mean shear force values of 70 N in the meat of animals with 1–3 mm of fat cover and 59 N when animals presented 4–6 mm of fat cover.

Progress also has been achieved by Brazilian researchers with the identification of proteins associated with shear force (Carvalho et al., 2014) and molecular markers for beef tenderness in Zebu cattle (Tizioto et al., 2012). These results are relevant for the application of marker-assisted selection, which is an important tool to define selection criteria to improve the meat quality of the Brazilian herd.

In packing plants, practices such as electric carcass stimulation are commonly employed. Vacuum aging (wet aging) of meat also is a current practice in Brazilian exported beef. Export beef cuts are aged by vacuum packing at temperatures of 0–1 °C for an average period of 15 days. Aging is globally used in the meat industry as it increases meat tenderness and enhances flavor. This method is very effective in reducing meat toughness of the meat of crossbreed young bulls (3/4 *B. taurus*, 1/4 *B. indicus*) (Ribeiro et al., 2002), who found a reduction of 52.6% (7.87 to 4.17 kgf/cm^2) in shear force of the LM after 14 days of wet aging. Although some foreign consumers dislike this product (Stenstrom, Li, Hunt, & Lundstrom, 2014), this method is still the most indicated to preserve the quality of meat products.

Cooked meat from grass-fed animals is said to have a characteristic "pastoral" or "grassy" flavor, which may not be appreciated by some markets. The acceptability of meat is largely influenced by cultural aspects and consumption habits. In the USA, consumers prefer the flavor of grain-finished beef (Van Elswyk & McNeill, 2014). On the other hand, Realini et al. (2013) found that, for European consumers, sensory scores were numerically higher for overall acceptability of beef from grass-based production systems than concentrates from grain-fed cattle.

In Southern Brazil, a pioneer study was conducted to evaluate meat quality traits of cattle finished in production systems based on the natural rangeland of Pampa Biome. One of the main results of the study is that trained panelists were able to find odor and flavor differences among beef produced in three different production systems in the Pampa Biome: (i) natural grassland, (ii) improved natural grassland and (iii) summer annual forage crop (Devincenzi, Nabinger, Cardoso et al., 2012). These results can lead to further investigation about specific compounds present in forage and which are responsible for particular odors and flavors of southern Brazilian beef.

5. Brazilian beef, a component of a healthy diet

Recent and extensive analyses have demonstrated that the consumption of red meat is not a predictor of coronary disease and diabetes (Vieira et al., 2012), which are, however, attributed to industrial processed meats (Micha, Wallace, & Mozaffarian, 2010).

Beef produced in two finishing systems (Freitas et al., 2014) was consumed by a previously-selected panel, and considered healthy, to study the effect of lean meats on the lipid profile of individuals (Vieira et al., 2012). Voluntary consumers, employees of the Institute of Cardiology of the State of Rio Grande do Sul, Cardiology University Foundation, were divided in two groups. The individual ate at the cafeteria once a day, at lunch time, 120 g of beef from feedlot steers or from steers reared and finished on pastures (LM; only lean meat, with all external fat removed). After six weeks of consumption, a wash out period was applied, followed by a second period of beef consumption, but changing the groups. Based on measurements and biochemical exams from the beginning to the end of the consumption periods, Vieira et al. (2012) concluded that there were no changes in the lipid profile with the constant intake of lean red meat during the observation period. Moreover, there were no statistically significant differences between the intake of beef from grazing or feedlot cattle. However, systolic and diastolic blood pressure and serum sodium levels were significantly reduced with time. According to the authors, these findings can aid health professionals, who may advise their patients to consume unprocessed lean beef, without visible fat, and in small amounts. However, they caution that further studies are needed to evaluate lean beef consumption for a long period to determine its long-term effects, exerting the precaution of choosing beef cuts with no fat and consuming it in limited amounts.

6. Traceability

The first Brazilian system of bovine identification (SISBOV) was implemented on January 9, 2002 by Normative Instruction (IN) n. 1, to meet the requirements of the European Union which was the main importer of Brazilian meat at that time, representing 45% of total imports. Thereafter, new IN were issued (n. 1 of January 21, 2005 and July 13, 2006), which established the category of Approved Rural Property in SISBOV (ERAS farm) to meet the necessary requirements and adjust them to the conditions of Brazilian beef cattle production. On March 20, 2014, IN n.6 of the Brazilian Ministry of Agriculture (MAPA, 2014) issued a set of rules and procedures for an individual traceability system, with voluntary membership of the cattle and buffalo meat production chain. These rules comply with the requirements of the European Union Rural Property (ERUE), ensuring, for instance, that cattle were at least 90 days in states authorized by the European Union and at least 40 days prior to slaughter on an authorized farm, are individually identified, and comply with other certification requirements. The individual traceability of cattle reared exclusively on pastures, and a small percentage of cattle finished in feedlots, free of hormones according to federal legislation, is made using ear tags and chips. The loss of this equipment, the ensuing difficulties, deadlines for consequent re-identification, animal stocking rate paddock and number of animals per farm — one of the advantages of Brazilian beef cattle production and of its scale of production — are strong barriers for the increase in boneless beef exports to the European Union of boneless meat. Alternatives for the current traceability model applied in the Brazilian beef industry could be the use of analytical methodologies, such as plant biomarkers and spectroscopy (Oliveira et al., 2013); however, more studies must be developed on this domain.

7. Conclusions

Brazilian beef production in 2023 is estimated in 10,935 million tons of meat in 2023, representing an increase of almost 29% relative to 2013, and 20% of the global market share. This target can be achieved if the scientific knowledge produced in universities and other research institutions during the last fifty years are gradually and systematically adopted by beef cattle producers. Leading cattle operations that apply these technologies and modern administration methods are responsible for the increase in production and productivity indexes. New generations of professionals, with extensive technological knowledge, have entered the labor market, supplying and disseminating modern techniques, and have started a new phase in the Brazilian agribusiness. These professionals are aware of the need to conciliate these necessary increases in productivity with the preservation and sustainability of the production areas, even at the most distant corners of the nation. TV networks, with specific programs directed to the rural sector, strongly collaborate to disseminate technologies. The aim of these technologies is to supply more quality beef not only to Brazilians and to the increasing world population, but also to consumers that want to know how this beef is produced, as well as its respective nutritional composition. When part of a balanced diet, beef from pasture-fed cattle is healthy, and does not affect the lipid profile of consumers. Reducing age at slaughter improves the sensorial qualities of Brazilian "grass-fed" beef and research results have shown its better lipid composition. The reduction of age at slaughter of steer has been achieved by a better forage management, and has been the basis of meat-quality programs of some breed associations, in partnerships with packing plants and supermarket chains. However, progress still has to be made for the reduction of age at first mating in heifers and in the weaning rate in breeding herds. The ratio of the number of calves/100 cows needs to be urgently improved to reduce the costs of greenhouse gas emission effects per kg of beef produced. The Brazilian Government has put in place programs to stimulate the recovery of degraded pasture areas, to increase the production and the productivity of beef cattle production, and to reduce environmental effects. It is also important to emphasize that Brazil has important natural pastoral ecosystems, and that beef cattle is essential for their preservation and sustainability (Pampa Biome, Campos de Cima da Serra and Pantanal). In those ecosystems, animal products could be valued not only for supplying food, but also by providing environmental services.

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