UNIVERSIDADE DE BRASÍLIA

FACULDADE DE AGRONOMIA E MEDICINA VETERINÁRIA

CARCASS AND MEAT QUALITY IN CURRALEIRO-PÉ-DURO, PANTANEIRO AND NELORE CATTLE

MAÍRA DE CARVALHO PORTO BARBOSA

TESE DE DOUTORADO EM CIÊNCIAS ANIMAIS

BRASÍLIA / DF

SETEMBRO DE 2021

UNIVERSIDADE DE BRASÍLIA
FACULDADE DE AGRONOMIA E MEDICINA VETERINÁRIA

QUALIDADE DE CARCAÇA E DA CARNE EM BOVINOS CURRALEIRO-PÉ-DURO, PANTANEIRO E NELORE

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PUBLICAÇÃO:245D/21

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TESE DE DOUTORADO SUBMETIDA AO PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS ANIMAIS, COMO PARTE DOS REQUISITOS NECESSÁRIOS À OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS ANIMAIS.

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BRASÍLIA, 23 de setembro de 2021.

REFERÊNCIA BIBLIOGRÁFICA E CATALOGAÇÃO

BARBOSA, M. C. P. **Carcass and meat quality in Curraleiro-Pé-Duro, Pantaneiro and Nelore cattle.** Brasília: Faculdade de Agronomia e Medicina Veterinária, Universidade de Brasília, 2021, 138 p. Tese de Doutorado.

FICHA CATALOGRÁFICA

Barbosa, Maíra de Carvalho Porto
BM228c Carcass and meat quality in Curraleiro-Pé-Duro, Pantaneiro and Nelore cattle / Maíra de Carvalho Porto Barbosa; orientador Concepta Margaret Pimentel Mcmanus . -- Brasília, 2021.
138 p.

Tese (Doutorado - Doutorado em Ciências Animais) -- Universidade de Brasília, 2021.

1. raças localmente adaptadas. 2. Bos taurus ibericus. 3. eficiência. 4. características de carcaça. 5. qualidade da carne. I. Mcmanus , Concepta Margaret Pimentel, orient. II. Título.

AGRADECIMENTOS

A Deus que tudo permitiu e ao meu esposo e filhos pelo apoio em todos os momentos. Ao meu pai e minha mãe (*in memoriam*) pelo incentivo. À minha orientadora por toda ajuda, ensinamentos e compreensão. À CAPES pelas bolsas, ao CNPq e à FAPEG pelo financiamento dos projetos.

INDEX

Summary

ABSTRACT

CARCASS AND MEAT QUALITY IN CURRALEIRO-PÉ-DURO, PANTANEIRO AND NELORE CATTLE

Maíra de Carvalho Porto Barbosa**,** Concepta Margaret McManus Pimentel
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Curraleiro Pé-Duro and Pantaneiro breeds, locally adapted, were introduced in Brazil since the colonization period being subjected to natural selection processes and are currently animals adapted to the local conditions of the Brazilian climate. Despite this, the commercial herd is mainly formed by *Bos taurus indicus* breeds that have undergone several genetic improvements, such as the Nelore. The preference for improved animals with high productivity associated with little knowledge about the quality of carcass and meat of local breeds meant that many naturalized animals were no longer used in production, leading to the risk of extinction. The preference for improved animals with high productivity caused many naturalized animals to stop being used in production, leading to the risk of extinction. With the objective of comparing the meat and carcass traits of two local breeds with a commercial one, raised in similar management systems, observing the quantitative and qualitative characteristics of the cuts and carcass finishing, 15 steers of the Curraleiro Pé-Duro, Pantaneiro and Nelore breeds were analyzed, after a 112-day confinement. Pre-slaughter weighing and ultrasound measurements were carried during feedlot and after slaughter the carcasses were typified in terms of conformation, physiological maturity, marbling and texture. pH, CieLab colour, percentage of bone, muscle and fat, fatty acid profile, shear force, water retention capacity and meat quality analyzed by a sensory panel were determined. There was no difference in daily weight gain and slaughter weight between breeds. Nelore and Curraleiro deposited more fat than Pantaneiro, while Curraleiro and Pantaneiro had more muscle than Nelore, which also had more bone and a higher percentage of second quality cuts. Nelore had less succulence than Pantaneiro and more shear force than other breeds. The meat from Pantaneiro was the one that retained most water, being the darkest, with less shear force and more succulent. In general, the fatty acid profile did not differ between breeds with the exception of C16:0 which was higher in Curraleiro Pé-Duro. The results showed that the Curraleiro Pé-Duro and Pantaneiro breeds were able to express their potential, even in the absence of genetic improvement programs, becoming economically competitive and with great potential to improve their characteristics.

Key-words: *Bos taurus ibericus*, carcass traits, efficiency, locally adapted breeds, meat quality.

RESUMO

QUALIDADE DE CARCAÇA E DA CARNE EM BOVINOS CURRALEIRO-PÉ-DURO, PANTANEIRO E NELORE

Maíra de Carvalho Porto Barbosa**,** Concepta Margaret McManus Pimentel
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As raças Curraleiro Pé-Duro e Pantaneiro, localmente adaptadas, foram introduzidas no Brasil desde o período de colonização sendo submetidas a processos de seleção natural e atualmente são animais adaptados às condições locais do clima brasileiro. Apesar disso, o rebanho comercial é formado principalmente por raças *Bos taurus indicus* que passaram por diversos melhoramentos genéticos, como a Nelore. A preferência por animais melhorados e de alta produtividade associada ao pouco conhecimento sobre a qualidade de carcaça e de carne das raças locais fez com que muitos animais naturalizados deixassem de ser utilizados na produção, levando ao risco de extinção. Com o objetivo de comparar as características de carne e de carcaça de duas raças locais com uma comercial, criadas em sistemas de manejo semelhantes, observando qualidades quantitativas e qualitativas dos cortes e do acabamento de carcaça, foram analisados 15 novilhos das raças Curraleiro Pé-Duro, Pantaneiro e Nelore após um confinamento de 112 dias. Foram realizadas pesagens e medições pré-abate com auxílio de ultrassom e após o abate as carcaças foram tipificadas quanto à conformação, maturidade fisiológica, marmoreio e textura. Foram determinados pH, coloração CieLab, percentuais de osso, músculo e gordura, perfil de ácidos graxos, força de cisalhamento, capacidade de retenção de água e qualidade da carne por um painel sensorial. Não houve diferença no ganho de peso diário e no peso ao abate entre as raças. Nelore e Curraleiro depositaram mais gordura que Pantaneiro, enquanto Curraleiro e Pantaneiro tinham mais músculos que a Nelore, que também apresentava mais osso e maior porcentagem de cortes de segunda qualidade. O Nelore apresentou menos suculência do que o Pantaneiro e mais força de cisalhamento do que as outras raças. A carne do Pantaneiro foi a que mais reteve água, sendo a mais escura, com menor força de cisalhamento e mais suculenta. Em geral, o perfil de ácidos graxos não diferiu entre as raças, com exceção do C16:0 que foi maior no Curraleiro Pé-Duro. Os resultados mostraram que as raças Curraleiro Pé-Duro e Pantaneiro puderam expressar seu potencial, mesmo na ausência de programas de melhoramento genético, tornando-se economicamente competitivas e com grande potencial para aperfeiçoamento de suas características.

Palavras-chaves: *Bos taurus ibericus*, características de carcaça, eficiência, qualidade da carne, raças localmente adaptadas.

LIST OF ILUSTRATIONS

LIST OF TABLES

CHAPTER 1

1. INTRODUCTION

Different factors guide the Brazilian economy, and agribusiness has proven to be an essential driver of national economic growth. In 2019, the sum of the amount generated by agribusiness goods and services generated R$1.55 trillion or 21.4% of the Brazilian gross domestic product (GDP). Brazil stands out for its agrobiodiversity, and agriculture is the most expressive activity in the sector, corresponding to 68% of the generated value (R$ 1.06 trillion) and cattle raising, mainly beef, representing 32% (R$ 494.8 billion). Currently, Brazil is the largest exporter of beef and one of the largest exporters of agricultural products (Ermgassen et al., 2020), with 22% of the world cattle herd (Zia et al., 2019).

The Brazilian bovine herd consists mainly of commercial breeds, such as those from *Bos taurus indicus*. Brazilian taurine breeds have a greater capacity to adapt to heat and resistance to diseases (Boettcher et al., 2015; McManus et al., 2020) which demonstrates greater efficiency in the face of Brazilian climatic conditions, also representing an important aspect when considering the climate changes that have been taking place (Castanheira et al., 2010; Cardoso et al., 2016).

Numerous domestic animals were introduced for production, such as cattle, sheep, horses, goats and donkeys, which adapted over the years to form breeds adapted to local conditions. From an evolutionary point of view, locally adapted cattle come from Spain and Portugal (Mariante & Cavalcante, 2006) and were gradually distributed throughout the various Brazilian regions, being subjected to natural selection processes responsible for expressing in the animals the currently characteristics of adaptation to local conditions (Silva et al., 2012).

The recent introduction of exotic animals, considered with superior quality, has led to a reduction in the number of locally adapted animals and the extinction of several breeds (Rischkowsky & Pilling, 2007). Currently, the largest Brazilian herd is the Nelore (*Bos taurus indicus*) breed which, despite being more adapted to heat and more resistant to diseases

(McManus et al., 2020), has inferior meat quality than *Bos taurus taurus* breeds (Ferraz & Felício, 2010; Lobato et al., 2014). *Bos taururs taurus* breeds, which have a low adaptive capacity to the country's climatic and pasture conditions, together with *Bos taurus ibericus* breeds, made up of animals locally adapted to climatic conditions, comprising the other two groups of cattle that are predominant in the country. However, little is known about the quality of the meat of *Bos taurus ibericus* breeds, and in most of the studies already carried out, breeding programs were used (Carvalho et al., 2017).

The variety of cattle of different breeds with significant adaptive and productive characteristics makes it possible to combine them in different environments, managements and markets, maximizing productivity and profitability (Souza et al., 2022). On the other hand, breeding programs, which are widespread in beef cattle, use heterosis to combine breed differences and improve productivity but negatively affect the preservation of local bovine genotypes (MacNeil & Matjuda, 2007; Scholtz et al., 2008). In recent decades, the desire for greater productivity has driven genetic selection, which despite bringing productive gains, leads to considerable losses in the genetic variability of the herd. With the emergence of high productivity industrial breeds, the exploitation of local traditional breeds was largely abandoned, leading to the extinction of some and threatening animal genetic resources (Fioravanti et al., 2011). According to FAO (2021), of the more than 7,000 species of domestic animals distributed around the world, 2,035 are at risk of extinction, a number that can be underestimated by the number of animals in an unknown risk situation.

In this regard, it is important to preserve locally adapted beef cattle breeds in order to ensure their continued availability for meat production in the (sub)tropics by maintaining the variability of their adaptive genes (Scholtz & Theunissen, 2010). The use of their genetic resources, in addition to providing the survival of these breeds, can delineate economically important characteristics, helping to define market niches (Shabtay, 2015; Nyamushamba et al., 2017), and the sustainable development of genetic resources can preserve the breeds in danger of extinction (Taberlet et al., 2008).

In addition to the high productivity conferred on genetically selected animals, there is a belief that locally adapted animals have a lower production efficiency and lower carcass quality when compared to commercial breeds (Blackburn et al., 1998). Meat consumption is mainly shaped by the availability of a particular product and its quality (Esteves et al., 2018), but nutritional, cultural and sensory characteristics influence its acceptance

(Monsón et al., 2005). Sensory aspects in particular influence the acceptability of a given product by the consumer (Krystallis & Arvanitoyannis, 2006).

Few comparative studies between industrial and locally adapted breeds bring a lack of knowledge and foundation for the reintroduction of locally adapted cattle on the consumer's table. Another negative aspect is that in the studies already carried out, the animals used usually come from hostile environments and have a small body conformation (McManus et al., 2011), with a small number of studies comparing animals of different breeds, adapted and imported, reared under similar management systems and climatic conditions.

1.1. Justification

The growing demand for greater food production, due to the population growth, brings up the challenge of joing animal production and environment (Amaral et al., 2011). Reproductive selection originated several breeds with specific phenotypes, showing characteristics of agricultural interest (Tamminen, 2015). On the other hand, preserving animal genetic resources is vital for the sustainable development of rural areas and food security. It is estimated that 70% of the less favoured rural regions depend for their livelihoods of farm animals (FAO, 2015).

Other aspects that should influence production processes are climate change. Climate model projects predict that by the end of this century, there may be an increase in temperatures in South America of 1°C to 6ºC, mainly in tropical zones (Yahdjian and Sala, 2008). Environmental and climatic factors that interfere with the soils, the amounts of rain and sunlight also influence animal production (Silva et al., 2013). Furthermore, studies show that Brazilian livestock tends to move to the east and north (McManus et al., 2016), bringing new challenges to production.

Observing the perspectives of national livestock for the coming decades and considering the natural selection that has occurred in Brazilian local breeds over the centuries and in the face of often unfavourable environmental conditions, the importance of maintaining this genetic resource for animal production is highlighted (Silva et al., 2012). According to Tamminen (2015), when a breed has high levels of genetic diversity, animal production systems are more efficient in the face of environmental stress conditions.

Preserving the culture of rearing and consumption of products from locally adapted cattle is also an important factor to be considered. The rearing of a local bovine breed, with geographical indication, differentiates and adds value to the final product, incorporating factors that go beyond the product itself, such as regional history, culture, know-how and local identity (Neiva et al., 2011). The conservation of locally adapted breeds should be based on knowledge of historical aspects, the genetic relationship between them and economic and cultural factors that shape the use and the potential of these populations (Egito et al., 2014).

The meat from these animals has a different flavour, and their use leads to the appreciation of local culture and traditional knowledge. Regional differences in relating to ecosystems brings advantages such as the rational use of species, local sustainable development and can use the attributes of breeds that are more resistant to endoparasites and ectoparasites to meet market demands such as organic meat production (Fioravanti et al., 2008). Consumers seek the association of typicality and quality in these foods. The production chain for rearing locally adapted beef breeds also has a social aspect, related to the insertion and income generation for populations living in precarious conditions, with extensive breeding of these animals (Neiva et al., 2011).

The future perspective for animal production show that it will be necessary to replace animal breeds and species in the coming decades to keep up with environmental changes and new market demands (Yahdjian and Sala, 2008). Animal genetic resources will be critical in adapting to climate change (Mottet et al., 2018), especially considering that the selection of animals for high productive levels was accompanied by a greater susceptibility to environmental challenges. The necessity adaptation and the need for better animal management are two challenges to be faced (Gaughan et al., 2019). This highlights the importance of research to establish meat and carcass quality standards for locally adapted cattle such as Pantaneiro and Curraleiro Pé-Duro, opening paths for a possible reintroduction of meat from these animals in the consumer market.

1.2 Objectives

Compare the growth and carcass characteristics of three different breeds, two locally adapted (Pantaneiro and Curraleiro Pé-Duro), with an industrial cattle breed (Nelore) in feedlot. Knowing that comparative research on the Curraleiro Pé-Duro, Pantaneiro and Nelore under the same management condition is scarce, the specific objectives are:

a) Compare animals from three different breeds, raised in similar management systems;

b) Measure characteristics of weight gain, conformation and carcass quality;

c) Analyse sensory characteristics of commercial cuts;

d) Observe if there are characteristics that make locally adapted breeds commercially competitive.

2. LITERATURE REVIEW

2.1 Locally adapted breeds

Except for animals such as camelids and guinea pigs, already domesticated at the time of the discovery of Brazil, other domestic animals began to be introduced by Christopher Colombo on his second trip to the Americas in 1493. Coming from the Iberian Peninsula and North Africa, they were naturally selected by centuries (Primo, 2004), being fundamental for post-discovery territorial expansion, used as transport, workforce, food and clothing. At the beginning of the 20th century, Zebu cattle began to be imported and today constitute a large part of the national herd (Gama et al., 2016).

Although introduced on the continent in the 15th century, local breeds such as Pantaneiro and Curraleiro Pé-Duro began to gain recognition in recent decades. Curraleiro Pé-Duro cattle were recognized as a breed of animal performance interest by the Ministry of Agriculture, Livestock and Supply (MAPA) only in 2012, through Ordinance n.1.150. Pantaneiro, even without official recognition as a breed by MAPA, in 2010 was declared by Law n.9.393 as a cultural and genetic heritage of the state of Mato Grosso, as it constitutes a natural heritage bearing a reference to the identity, action and memory of Mato Grosso society. Both Curraleiro and Pantaneiro have common characteristics that have allowed their survival since their introduction in Brazil, such as adaptation to hostile environments (Castanheira et al., 2013).

With adaptive characteristics, Pantaneiro breed managed to develop in regions such as Pantanal, with flooded floodplains and food shortages, surviving over the centuries. Curraleiro Pé-Duro cattle acquired resistance to endoparasites and ectoparasites, adapting to diverse management conditions (Cardoso et al., 2016), being raised in extensive systems, with little human interference (Fioravanti et al., 2008). However, with the population increase experienced, especially after 1900, there was a change in how the individual related to animals. Lands have been increasingly exploited, leading to climate change and the extinction or threat of extinction of many species (Flint & Woolliams, 2008).

The loss of availability of diverse livestock breed resources with significant adaptive and productive differences prevents breed types from being matched with different environments, management capacities and markets – undermining the opportunity for sustainable production and profitability. The regions and countries that will thrive in a world with climate change (Llewellyn, 2007) will tend to be those that recognize its importance and inexorability, anticipate that there may be at least some implications for your industry (including farms) and take appropriate action well in advance.

Adequate domestic genetic diversity must be maintained to preserve populations (McManus et al., 2010) and ensure the long-term sustainable exploitation of livestock, especially in light of predicted climate changes, which include increasing average temperatures and decreasing days of growth (Romanini et al., 2008; Scholtz et al., 2010). The risk of extinction of some local breeds can generate irreparable losses, and today little is known about the productivity and adaptation of these animals (McManus et al., 2011). For Pantaneiro, for example, the Pantanal Biome Cheese Project is one of the pursuits for the preservation of the breed, maintenance of the local ecosystem, as well as a source of regular income for the local population (FAO, 2015).

The decrease in the use of already adapted breeds, with the intensification of the exploitation of animals introduced later, gave rise to the belief that local breeds were less productive. Despite the scarcity of scientific literature comparing breeds, McManus et al. (2002) verified that in the Pantanal, in a hostile environment, the reproductive performance of the Pantaneiro was superior compared to Nelore, an advantage probably due to the natural selection that occurred over the centuries. The ability of local breeds to survive, grow and reproduce is preserved, even in the face of adverse situations such as low availability of food, stress, diseases, parasites and high temperatures and humidity (Scholtz, 1988; Prayaga, 2004; Prayaga & Heanshall, 2005).

At the same time, the maintenance of locally adapted breeds is essential as they contain alleles that confer resistance to disease or survival in adverse conditions (Woolliams et al., 1986). Heat stress, for example, affects animal productivity and development (McManus et al., 2011) and breeds such as Curraleiro Pé-Duro and Pantaneiro have proven to be well adapted (McManus et al., 2009; McManus et al., 2011; Silva et al., 2015). High temperatures also reduce food intake and changes in metabolism, negatively affecting production and leading to economic losses. Locally adapted cattle, in the face of extreme climatic and environmental conditions, demonstrate practically unaltered performance with high reproductive efficiency, disease resistance, longevity and low mortality rate (Cardoso et al., 2016).

Bianchini et al. (2006) observed characteristics consistent with heat tolerance for the Pantaneiro and Curraleiro Pé-Duro breeds and some body measurements similar in size to Nelore cattle. Several studies analysed body characteristics of the Pantaneiro, Curraleiro Pé-Duro and Nelore breeds, but comparative research on the three breeds under the same management condition is scarce. In a comparative study on the development of Pantaneiro and Nelore calves under similar environmental conditions in the Pantanal, Santos et al. (2005) showed that Pantaneiro calves at birth, despite having lower weight, had greater body length than Nelore. At that time, the daily weight gain, although not significant different, was greater for Pantaneiro (0.389 kg/day) than for Nelore (0.383 kg/day). These findings led the authors to conclude that studies on the efficiency of weight gain in local breeds should be better evaluated.

Comparing the post-weaning daily weight gain (DWG), the records of Nelore cattle over three decades showed a DWG of 0.430 ± 0.19 kg/day (Rezende et al., 2014). Value similar to that found by Abreu et al. (2002) for Pantaneiro cattle in their natural environment, of 0.429kg/day from weaning at 205 days, but higher than that reported by Carvalho et al. (2013) for Curraleiro Pé-Duro cattle, which were 0.215kg/day from birth to 210 days of life. These studies are not comparative, as they were carried out with individual breeds; therefore, the present study aimed to compare the growth and carcass characteristics of Pantaneiro and Curraleiro Pé-Duro cattle with Nelore in commercial feedlot.

Carvalho et al. (2013) observed that Curraleiro cattle raised on pasture in the state of Piauí, without supplementation, but with access to water and mineral salt, showed variable average weight gain according to the time of year and pasture quality. These authors suggested that animals with an additional food supply might perform better. In a comparative study of historical and contemporary research, Cooke et al. (2020) reported that *B. taurus* grazed for less time than *B. indicus* and gained less weight until weaning but had greater average daily weight gain when in feedlot.

2.2 Carcass quality

The number of edible products in the bovine carcass increases as the animal grows, with the most intense growing period being in the first 15-18 months of life. Carcass yield is subject to numerous influences and depends on the breed, sex, rearing system, feeding, age and individual characteristics of the animal (Pečiulaitienė et al., 2015). Live animal measurements, such as thoracic perimeter, anterior and posterior height, body length and croup width, together with the subjective assessment of body condition and conformation, are essential tools that can determine the ideal time for slaughter (Pinheiro et al., 2007).

Ultrasound measurement is a relatively inexpensive and repeatable, accurate method of *in vivo* carcass evaluation, capable of providing accurate measurements of the fat thickness and area of the *Longissimus* muscle, accurately predicting the composition of the bovine carcass when associated with the live weight of the animal (Realini et al., 2001). Ultrasound technology also allows predicting the degree of marbling and its development, aiding in the evaluation of beef cattle breeding programs (Tokunaga et al., 2021).

According to Galvão et al. (1991), tissues are responsible almost exclusively for the quantitative and qualitative characteristics of the carcasses. Bone is the tissue with the earliest development, followed by muscle, which is the most important in carcass enhancement. In contrast, adipose tissue is what most interferes with tissue composition. The morphological composition of the carcass depends on the proportion in which the different tissues are found, mainly muscle, fat and bones (Pečiulaitienė et al., 2015). During commercialization, regardless of the morphological composition, the consumer purchased these different parts together and at an identical price (Carvalho, 1998).

In vivo biometric measurements have a high correlation with the carcass. They can be used to estimate their measurements (Cunha et al., 1999), allowing to predict characteristics such as carcass yield and conformation and cut yield (Pinheiro et al., 2007). Zembayashi & Emoto (1990) found a significant relationship between carcass size and the amounts of muscle, fat and bones in the carcass. In the lean animals, there was a positive relationship with the proportion of bones and a negative with the amount of fat and muscle. While carcass circumference was highly correlated with muscle and fat growth. In lambs, Wood & MacFie (1980) observed that the body length was correlated with the internal length of the carcass, this correlation being a good indication of the weight and its characteristics.

When comparing local cattle breeds to commercial ones, Blackburn et al. (1998), observed that the local breeds did not show differences in conformation and marbling compared to commercial breed. A similar pattern of conformation between locally adapted breeds and *B. indicus* can be explained by the fact that, although these animals adapt well to tropical and subtropical regions, they generally have less marbling in carcasses than *B. taurus* cattle, mainly because of a reduction in the volume of intramuscular adipocytes (Cooke et al., 2020).

According to Jorge et al. (1997), estimating the carcass yield is an essential factor in the evaluation of the animal's performance. Lorenzoni et al. (1984) and Peron et al. (1993), showed higher yields in typical bovine carcasses in comparative studies between Zebu and European breeds. Costa et al. (2007) comparing Nelore and crossbred (Nelore x Holstein) animals did not observe any significant difference in carcass yield.

Economically, a higher yield of special hindquarters is more desirable than other cuts, as it is a region with a greater predominance of prime cuts (Jorge et al., 1997). The cuts in which the Nelore had the highest percentage of weight, despite belonging to the back, are considered non-noble cuts. This demonstrates that, despite not being considered commercial breeds, Curraleiro Pé-Duro and Pantaneiro have characteristics similar to those of Nelore, an essential factor to encourage their use in commercial meat production.

2.3 Meat quality

Meat is primarily made up of skeletal musculature with adjacent connective tissue and fat. It has a complex organization, which varies between different species and between muscles of the same species (Lawrie, 2005). The composition of the carcass must meet market demands to be more valued. The way that the composition is distributed, that is, the percentage of muscle, fat and bone, is essential, influencing the commercial quality of the carcass. According to Kempster et al. (1976), the best carcasses are those with the maximum proportion of muscle, an adequate proportion of fat and minimum amount of bone. Muscles have intrinsic properties such as the structure of the connective tissue matrix and myofibrils, glycogen content and proteolytic activity, which can undergo changes depending on the pre-slaughter stress to which the animal is subjected. In addition, post-slaughter processing conditions and methods and storage time also influence meat quality (Oddy et al., 2001).

It is necessary to understand that the musculature, developed and differentiated for physiological purposes, suffers the action of numerous intrinsic and extrinsic stimuli (Lawrie, 2005) to understand what meat is and what led to its conversion from muscle. Thus, the quality of meat is defined by a series of factors, which, for the consumer, are mainly the colour and flavour (Swatland, 2004). Oxymyoglobin is the pigment responsible for the intense red colour seen in beef (Hayes et al., 2009). When oxymyoglobin is oxidized to metmyoglobin, the pigment turns brown, resulting in consumer rejection of the product due to the understanding that dark coloured meat comes from old animals or has been exposed for sale for a long time (Fletcher, 2002).

Changes in myoglobin cause discolouration of the cooled meat as a consequence of some lipid oxidation reactions. Therefore, frozen beef's palatability and "shelf life" is limited mainly due to lipid oxidation and surface discolouration. Some technologies have been tested to ensure meat quality during storage, especially the use of antioxidants in pre-slaughter animal feed (Lynch et al., 1999; Dufrasne et al., 2000; O'Grady et al., 2001; Carmo et al., 2017) which, in addition to delaying lipid oxidation in beef, may act by decreasing myoglobin oxidation.

Fat represents another important component of meat, exerting influence on the final value of the product. Higher fat content in meat usually occurs concomitantly with a decrease in moisture, protein and mineral (Rodrigues & Andrade, 2004). Felício (1999) and Rodrigues & Andrade (2004) inferred that meat with higher water content has higher protein content or lower fat content. This fact may be due to the protein-water and fat-water ratio. There is a depreciation in the value of the carcass when it has a high-fat content, and its presence is directly related to less water loss during the conservation period (Bueno et al., 2000).

In addition to colour and flavour, tenderness and fatty acid profile are essential in determining meat quality and have implications for human health (Wood et al., 2008). When comparing *B. indicus* and *B. taurus* cattle, Bressan et al. (2011) demonstrated that greater amounts of saturated fatty acids and lower quantity of monounsaturated fatty acids were accumulated in *B. indicus*, especially when raised in intensive systems. Currently, there is a growing concern about the fat and cholesterol content present in animal products (Carvalho & Brochier, 2008). Some fatty acids are not produced by the body and need to be ingested in food (Novello et al., 2010).

In extensive farming, Nelore meat was less tender than Angus meat and had lower levels of cholesterol, which despite having higher levels of omega-3 (n-3) fatty acids and conjugated linolenic acid (CLA), had a proportion of omega -6 for omega-3 (n-6 / n-3) indifferent, but below average (1.73) (Rossato et al., 2010). Meat tenderness is related to changes in meat tissue components and the weakening of myofibrils (Warris, 2000). Many studies show an association between marbling and sensory characteristics such as tenderness, palatability, flavour and juiciness (Warner et al., 2010). Thus, important factors in determining meat quality are colour, texture, marbling and tenderness (Müller, 1987), freshness and weight loss during cooking (Souza et al., 2004).

The acceptance of meat by consumers and their degree of satisfaction are determined by a response to the factors that characterize the quality of a particular cut (Tonetto et al., 2004). According to Huffman et al. (1996), the main factor associated with the acceptance of beef by consumers is tenderness, representing 51%, flavour and juiciness were the other two most mentioned characteristics, with 29% and 10% respectively. As for Koohmaraie et al. (2003), consumers consider smoothness the most important quality component. An increasingly demanding consumer market, which is not satisfied only with more economical values of certain products, demands that there is more uniformity and quality in meat cuts and, consequently, studies on the factors that influence the tissue and the chemical composition of the cuts (Jardim et al., 2007).

Several studies have been carried out comparing the meat quality of *Bos taurus indicus* (Nelore, Brahman) with *Bos taurus taurus* breeds, such as Angus (Martins et al., 2015; Pereira et al., 2015; Rodrigues et al., 2017), Wagyu (Dias et al., 2016), Senepol (Schatz et al., 2020), Hereford, Caracu (Mendonça et al., 2021), compounds such as Canchim (Giusti et al., 2013) or crossbred (Bressan et al., 2016). While the locally adapted Curraleiro-Pé-Duro and Pantaneiro breeds have adapted to the environment for over 500 years, most of the information available on traits such as meat growth and quality comes from breeding experiments (Carvalho et al., 2015; Rodrigues et al., 2018; Afonso et al., 2020).

Carvalho et al. (2017) compared Nelore and Curraleiro-Pé-Duro carcasses at 28 months of age and found heavier Nelore with a smaller loin eye area. These authors found that the meat from Curraleiro was redder than the others, but without significant differences between the breeds for the other quality characteristics.

Muscular pH

After the animal's death, a series of biochemical reactions take place in the muscle, generating permanent post-mortem changes and turning the muscle into meat. The pH is one of the characteristics that change, being the primary indicator of the final quality of the meat. When blood circulation ceases, lactic acid remains in the muscle, leading to a drop in pH. The lower pH makes the meat softer and more succulent, with a slightly acidic taste and a characteristic odour (Zeola, 2002). This accumulation of lactic acid and the consequent drop in pH are responsible for transforming muscle into meat and influencing some parameters related to meat quality such as water holding capacity, weight loss during cooking, tenderness, colour, and flavour (Pardi et al., 1993).

The final pH can have both intrinsic and extrinsic influences. Among the inherent factors are muscle type, species, breed, age and sex, and among the extrinsic factors are food, fasting time, electrical stimulation and refrigeration (Sañudo et al., 1995). Animal stress for a prolonged period or intense pre-slaughter muscle exercises also interfere with pH by reducing glycogen and increasing the pH of meat (Watanabe et al., 1996). In cases where there is a slight drop in pH, with final values greater than or equal to 6.2, the meat is firm, with a dry surface and a dark colour called DFD meats (dark, firm, dry) (Apple et al., 1995). This condition reduces the shelf life of meat due to an increased possibility of microbial growth (Miller, 2001).

Another situation rarely reported in ruminants but common in pigs is the abrupt drop in pH caused by high muscle temperatures, greater initial relative anaerobiosis, muscle lactic acid in the first moments after death, high glycogen reserves and sensitivity to stress by the individuum (Bonagurio, 2001). The pH reaches values equal to or less than 5.8 in the first hour after death, and the final pH is between 5.3 and 5.6. In these cases, the meat is pale, soft and exudative, called PSE (Honikel & Fischer, 1977).

In usual situations, in the first post-mortem hour, when the carcass temperature is between 37ºC and 40ºC, there is a change in pH, which in live animals varies from 7.3 to 7.5. With a drop after death, the pH can reach 5.5 to 5.7 in the first six to 12 hours after slaughter, with a slight drop up to 24 hours post-mortem. The rate of muscle cooling during the development of rigour mortis influences glycolytic reaction rates and affects the rate of pH decline. In cattle, different cooling rates in other muscles can delay deep intramuscular cooling, allowing *post-mortem* glycolysis in these regions to be completed before cooling lowers the temperature to less than 15°C. Consequently, there is a greater propensity of the deeper muscles to undergo protein denaturation, similar to PSE pork (Kim et al., 2014).

Determination of pH can be done using electrodes introduced into the musculature, usually at zero hours (hot carcass) and up to 24 hours post mortem (cold carcass). The muscle of choice for monitoring pH values is the *Longissimus lumborum*, as it is relatively uniform in terms of insertion depth (Zeola, 2002).

Colour

Among the factors that determine the purchase of a cut of meat by the consumer are the colour and water retention capacity. Colour differences are associated with product quality (Sañudo, 2004), with meat colour being the determining factor in the choice, except in the presence of strange odours (Silva, 2008). According to Rodrigues & Andrade (2004), there is discrimination against darker meats by the consumer. Although determined by the amount of myoglobin and the relative proportions of this pigment (Medonça, 2017), meat colour is influenced by tissue composition and muscle structure (Weglarz, 2010).

Meat pigments can be found in the form of reduced myoglobin (purple in colour), oxymyoglobin (red colour) and metmyoglobin (brown colour) (Medonça, 2017). Myoglobin is responsible for the meat characteristic colour, forming oxymyoglobin when exposed to air. Continuous exposure causes the colour to change to brownish-red, reddish-brown, and brownish-green (Pearson & Dutson, 1994). Colour has an indirect influence on the shelf life of meat due to rejection by consumers and prolonged shelf life (Dabés, 2001), being associated with a hard texture and coming from older animals.

Despite the consumer's perception, the colour of the meat can be influenced by several factors, such as, the increased formation of metmyoglobin due to microbial growth predisposed to the lack of hygiene at slaughter (Silva, 2008). Factors such as nutrition, freezing, maturation time, age and slaughter weight, stress conditions before slaughter and a drop in pH can change the colour of the meat (Sañudo et al., 2000; Alcade & Negueruela, 2001). Pre-slaughter stress and carcass storage temperature directly influence the pH of the meat, which in turn changes its colour (Bonagurio, 2001). According to Sainz (1996), in slaughtered animals with few glycogen reserves, the meat does not reach the desired final pH to produce standard colour, regardless of the animals' age and slaughter weight.

The measurement of meat colour can be done objectively or subjectively (Maciel et al., 2011). Among the objective forms are chemical processes, which determine the amount of myoglobin per gram of meat, and physical methods, performed using a reflectometer, spectropolarimeter or colourimeter. Subjective procedures are determined by visual observation, which can be performed by a sensory panel or using standardized comparison tables (Monte, 2006). In an experimental study, Jackman et al. (2009) compared marbling and luminosity tests to the results obtained in a sensory panel. The results showed that the colour and marbling of the L*ongissimus thoracis* provided reliable information about the quality of beef. There was no significant difference for the studied breeds for these parameters, which can be inferred that they were qualitatively similar.

Water holding capacity

Water holding capacity along with other characteristics such as pH, degree of fat coverage, connective tissue and muscle fibre are closely related to meat tenderness (Pardi et al., 2001). The need to assess water holding is directly linked to the general appearance of the product at the time of purchase or when processed and is of fundamental importance in terms of quality, whether the destination is direct consumption or industrialization (Roça, 2010).

The water holding capacity (WHC) of meat is the amount of water the meat can retain during cutting, heating, crushing and pressing (Warner, 2014) and the lower the holding capacity, the greater the loss of nutritional value by exudate released, resulting in less tender and drier meat (Zeola, 2007). WHC determines visual acceptability, weight loss and cooking yield, and the sensory characteristics of consumption (Warner, 2017), representing a crucial criterion for evaluating meat quality (Szmańko et al., 2021).

In meat, there is a water:protein ratio of about 3.5:1, containing approximately 75% water in lean muscles (Honikel, 2004). Most of the water in muscle is present in the myofibrils, in the spaces between the thick myosin filaments and the thin actin/tropomyosin filaments (Lawrie, 2005). In a live animal, in a muscle with a pH of approximately 7, more than 95% of the water is inside the cells. Still, after slaughter, as the pH drops, the water is passed to the extracellular space between the cells, appearing as a drip in the cell surface of the meat (Warner, 2014).

Measuring the water holding capacity usually involves the application of force that can be natural or applied (Warner, 2014), such as gravity (drip losses), heat treatments, pressure on filter paper or centrifugation (Maciel et al., 2011). But despite the importance of WHC in determining meat quality, a precise analytical method for its evaluation has not yet been developed (Szmańko et al., 2021).

Cooking weight loss

The water holding capacity measured at cooking and water loss is critical to industry and consumer satisfaction (Maciel et al., 2011). The loss of water from cooking influences colour, shear strength and juiciness (Bonagurio, 2003), representing a critical quality characteristic associated with meat yield when consumed (Pardi et al., 1993).

In the analysis of cooking loss of water, samples are weighed before heat application, cooled, dried and weighed again to determine cooking loss (Szmańko et al., 2021). Cooking loss has a strong relationship with the degree of ageing, temperature and cooking conditions, having, among all WHC measurements, the highest correlation with juiciness (Warner, 2014). Factors such as genotype, pre- and post-slaughter management conditions and the methodology used in sample preparation interfere in the amount of cooking loss (Lawrie, 2005). All WHC methods also depend on the pH of the meat, which changes after death due to the formation of lactic acid from the muscle type and animal species due to its variable composition and structure (Honikel, 2004).

Tenderness

Texture is a sensory property of food that expresses all the sensations characteristic of a product's mechanical, geometric and surface attributes, perceptible through mechanical and tactile receptors, and, if applicable, visual and auditory. Meat texture is generally referred to as tenderness, an indicator of food texture, considered an essential attribute of the organoleptic characteristics of meat by consumers (Gularte et al., 2000). Of all the attributes of sensory meat quality, texture and tenderness are considered the most important by the average of consumers (Lawrie, 2005; Koohmaraie & Geesink, 2006).

The final tenderness of meat is determined by several factors such as genetics (Rubensam et al., 1998), animal species, maturity, carcass finish, use of growth promoters (Felicio, 1999), carcass cooling speed, fall rate pH, final pH, maturation time (Felicio , 1999; Ferguson et al., 2001), age and sex (Shackelford et al., 1995), colour, water holding capacity, post mortem glycolysis rate (Ferguson et al., 2001), collagen quantity and solubility (Purslow, 2005), sarcomere length (Koohmaraie et al., 1996b), myofibrillar protein degradation (Koohmaraie, 1994), as well as rearing, feeding and pre-slaughter system factors (Ferguson et al., 2001).

Tenderness can be defined as the ease with which the meat can be chewed or the ease of penetration and resistance to cutting the myofibrils to rupture during mastication (Gularte et al., 2000). It is a determinant for the final price of the product. Shackelford et al. (1995) observed that, in a panel of trained judges, in the evaluation of ten cuts of meat, the cut known as tenderloin had the highest score for tenderness and, although it had lower scores for aroma and juiciness, it continued to be the commercial cut of higher price and greater appreciation in the market, showing the importance of the expected tenderness of the meat for the consumer.

Many of the sets of factors responsible for meat tenderness can be controlled to produce tenderer meat (Ferguson et al., 2001). Although genetics and diet influence texture, regardless of these factors, beef has 4.46 kgf, being defined as the softest meat (Forrest et al., 1979; Felicio, 1999; Zapata et al., 2000). Slaughter weight, according to Gularte et al. (2000), as it increases, causes changes in collagen and myofibrillar proteins, making the meat harder, that is, increasing the shear force. Sañudo et al. (1996), studying the shear force, showed that in animals of intermediate weight at slaughter, higher values of shear force were found. This is due to the physical state of collagen and its low solubility and the amount of fat deposition.

The constitution and solubility of collagen have been studied in order to understand the difference in tenderness in animals of different ages. There is usually a decrease in tenderness as the animal gets older, which can be explained by the increase in strength and stability of the bonds, leading to greater heat resistance (Okeudo & Moss, 2005; Purslow, 2005). During cooling, shortening occurs due to cold, which also influences the softness. This phenomenon happens before rigour mortis due to the rapid cooling of the carcass. Some sarcoplasmic organelles have a compromised calcium retention function, which is then released into the sarcoplasm in an uncontrolled manner. Calcium, in the presence of ATP, results in strong contraction, which shortens the fibres, decreasing the tenderness of the meat (Dabés, 2001).

Protecting the meat, for example, by covering the carcass fat, when exposed to low temperatures is an important method of control, especially in slaughterhouses that use cold rooms at low temperatures. This can reduce cold shortening and minimise water loss from beef (Sainz, 1996; Safari et al., 2001). On the other hand, when the carcass temperature is still high, above 35 °C, and there is an abrupt drop in the pH values to below 6, the pH/temperature ratio can cause another phenomenon that leads to a reduction in tenderness, known as heat shortening (Thompson, 2002).

The causes of induration during the first 24 hours *post-mortem* have been extensively reviewed, and several articles suggest reasons for this increase. Shortening of the sarcomere has been suggested as a cause of decreased muscle sensitivity during slaughter up to 24 hours after death. *Post-mortem* changes and cooling lead, respectively, to shortening of the sarcomeres and increasing muscle fibre diameter, culminating in the initial hardness of beef (Koohmaraie, 1996). Furthermore, according to Seabra et al. (2001), meat must have a period of maturation after slaughter to reach its ideal tenderness. The maturation and degradation of *post-mortem* myofibrillar proteins occur due to the enzymatic systems of the striated muscles, which have the multicatalytic protein complex, the cathepsins and the calpains. Apparently, calpains prove to be the most active enzymes in the meat tenderization process.

Due to the difficulty in objectively evaluating the firmness and texture of the meat, these factors are usually evaluated through sensory analysis (visual, tactile and taste). The disadvantage of subjective methods lies in the variability of findings and the individual influences of each taster. On the other hand, there is the advantage of observing the chewing sensation of the meat. Among the objective methods used to grade the texture, the most used and accepted is the shear force by the Warner Bratzler equipment, which presents the maximum force to break a meat sample (Delgado, 2001).

Fatty acid profile of meat

The fatty acid profile of the meat, although little interferes with the final value of the carcass (Madruga, 2004), directly influences the nutritional and sensory quality of the meat, with a higher degree of saturation being directly proportional to a lower quality (Mahgoub et al., 2002). The composition of fatty acids has been studied by several authors. Acids can be modified in quantity and quality according to sex (Webb et al., 1998), breed (Bianchi et al., 2003), slaughter weight (Pérez et al., 2002; Santos-Silva et al., 2002), food (Yamamoto et al., 2005; Lambertucci et al., 2013), animal, age, genotypes and raising system (Sañudo et al., 2000; French et al., 2003; Hoffman et al., 2003; Salvatori et al., 2004).

Diet is one of the aspects that most influences the composition of muscle fatty acids. A diet with a higher proportion of polyunsaturated fatty acids confers an increase in unsaturation and a reduction in the relative content of saturated and trans-monounsaturated fatty acids in ruminant meat (Geay et al., 2001). Forage-fed animals, finished on pasture, with little or no supplementation with concentrate, may have lower levels of saturated fatty acids and higher levels of unsaturated fatty acids in the composition of total body fat, as forages have a higher content of unsaturated fatty acids (Lambertucci et al., 2013).

However, higher concentrations of unsaturated fatty acids can be observed in confined animals compared to grazing animals, as diets with high amounts of concentrate provide lower ruminal pH values, decreased lipolysis and a consequent decrease in the extent of biohydrogenation of ruminal fatty acids (Medeiros, 2002). The concentration of linoleic (C18: 2) and linolenic (C18: 3) acids in meat can be high if animals are fed diets rich in cereal oil or seeds (Yamamoto et al., 2005).

Fatty acids naturally present in fats are constituted by an even number of carbon atoms and present a chain without branches (Oliveira et al., 2003). They are composed of a chain with 6 to 24 carbon atoms, joined by single or double bonds, with a carboxyl group and a hydrocarbon tail called a methyl group (Manhezi et al., 2008). What defines whether or not the acid is saturated is the absence or presence of double bonds. Chains without double bonds are termed saturated and chains with one or more double bonds are unsaturated (Champe, 1996). As for the location of the double bond, the Greek letter delta is used to indicate the carbon preceding the double bond, and the letters refer to the first carbon adjacent to the carboxyl group, the greek letter beta is designated to the second carbon (Krummel, 1998) and the terminal carbon of the fatty acid molecule is called the omega carbon (Graziola et al., 2002).

Intramuscular fat is composed of 20 different types of fatty acids, with 16 to 18 carbon atoms, containing varying degrees of saturation, with about 44% saturated fatty acids and 45% monounsaturated fatty acids. Fatty acids oleic, palmitic, stearic, linoleic, palmitoleic and myristic represent 92% of the total acids. A small portion is composed of polyunsaturated fatty acids, such as conjugated linoleic acid, resulting from incomplete biohydrogenation suffered by lipids in the rumen (Morales et al., 2015). As long-chain fatty acids are not subject to modification by ruminal microorganisms, there is a favouring increase in the deposition of these polyunsaturated fatty acids in muscle, improving the nutritional and functional quality of meat Ponnampalam et al. (2001).

Conjugated linoleic acid is of great importance for human health and meat from ruminants is its only source and must be obtained from the diet (Moreira et al., 2002). Acting in the modulation of lipid metabolism by inhibiting the synthesis of fatty acids and the activity of lipogenic enzymes (Marinova et al., 2001), it has anticarcinogenic (Blankson et al., 2000), antiatherosclerosis, antithrombotic, hypocholesterolemic properties, immunostimulatory and acts to increase muscle mass, reduce body fat and prevent diabetes (Schmid et al., 2006). About 80% of conjugated linoleic acid in meat is present in the form of the cis-9, trans-11 isomer, constituting the most biologically active compound (Bolte et al., 2002).

Knowledge of the types of fatty acids present in beef has been of interest to the population, who are increasingly seeking quality of life and adopting attitudes compatible with disease prevention (Beresford et al., 2006; Scollan et al., 2006). Twenty-three fatty acids are essential for human growth and development (Hardman, 2002). Fat and cholesterol levels are among the biggest concerns of consumers (Zapata et al., 2000; Carvalho & Brochier, 2008), although studies have shown that the type of fatty acid consumed is much more related to high cholesterol levels than to amount ingested (Hu et al., 2001). Changes in the lipid composition of the diet, with better quality of ingested fatty acids, can lead to changes in ingested serum cholesterol levels (Castro et al., 2004).

The fatty acid profile varies according to its place of deposition. Intramuscular fat concentrates a large amount of conjugated linoleic acid compared to subcutaneous fat (Mir et al., 2004). In subcutaneous fat, there is a prevalence of polyunsaturated fatty acids (54.1%), mainly oleic acid (C18: 1), and in intermuscular and intramuscular fat, the predominance is saturated fatty acids (57.1% and 53.5%, respectively) and, in greater quantity, there is monounsaturated oleic acid (32.2% and 36.6% respectively). It was observed that in British breeds raised predominantly at pasture, there was a deposition of monounsaturated intramuscular fat with a predominance of C18: 1 (Di Marco et al., 2007). Myristic saturated fatty acid (C14: 0) has a hypercholesterolemic effect, palmitic acid (C16: 0) had the least hypercholesterolemic effect and stearic acid (C18: 0) showed no effect on cholesterol (French et al., 2003)

By directly influencing the nutritional and sensory quality of meat, a higher degree of fatty acid saturation leads to a lower quality due to its adverse effects on human health (Mahgoub et al., 2002), as they increase serum cholesterol levels in humans (Ewin, 1997). However, fatty acids from ruminants were shown to have no relationship with the risk of coronary heart disease in men and showed an inverse relationship between consumption and cardiovascular disease in women (Jakobsen, 1999; Jakobsen et al., 2008).

Marbling

Properties of the *longissimus thoracis* such as colour, marbling and texture are used by some countries to classify carcasses according to expected feed quality (Jackman et al., 2009). Characteristics like flavour, juiciness and tenderness are affected by different degrees of intramuscular fat, representing one of the determining factors in consumer choice when purchasing meat products (Giaretta et al., 2018). The lubricating effect caused by marbling influences flavour and improves juiciness, and acts as a protection against meat drying during cooking (Aldai et al., 2007).

Studies on animal development concluded that intramuscular fat has a late development, being deposited later than in the abdomen, between the muscles and in the subcutaneous tissue. Therefore, the commercial characteristic of marbling has late maturity (Pethick et al., 2004). Another factor that affects the amount of fat is the portion of muscle being analyzed. Faucitano et al. (2004) observed that both the intramuscular fat content and the marbling score vary along the longissimus muscle of pigs. Despite this, marbling measurements taken on one muscle may be predictive of marbling on other muscles of the same carcass (Konarska et al., 2017).

Calkins et al. (1981) found that the composition of muscle fiber type is more highly related to marbling than to shear strength or softness classification, with a greater relationship between fiber and marbling in more mature animals. Meat acceptability tests, although subjective and expensive, can be used to define standards such as fat distribution in marbling (Jackman et al., 2009), and although the main method for grading marbling is based on visual inspection, the subjectivity of the analyzes calls into question their validity. Several objective tests have been developed, but the applicability within slaughterhouses is questioned, due to accuracy or high cost (Ferguson, 2004).

Konarska et al. (2017), researching different forms of measuring marbling, compared three methods: trained personnel, near-infrared spectroscopy and image analysis and showed that marbling measurements based on image analysis obtained different results from the sensory panel. On the other hand, they observed a strong relationship between near-infrared spectroscopy and sensory evaluation. An appropriate degree of marbling is related to favourable juiciness, tenderness, palatability and flavour of the meat. This directly affects consumer decisions, being, in most developed countries, the main evaluation index to classify meat quality, usually correlating marbling score with price (Cheng et al., 2015).

Eye muscle area

The fattening of beef cattle allows obtaining optimal proportions of meat, bone and fat (Tatum et al., 1986). In this aspect, some elements are used to predict the amount of muscle mass of an animal. Measurements of muscle eye area (EMA), carcass weight and subcutaneous fat thickness effectively estimate lean meat weight (Hopkins & Roberts, 1995). In assessing carcass quality, the measurement of EMA proved to be a good predictor of most carcass characteristics (Rashad et al., 2019).

Among the EMA measurement methods are the analysis of digitized images, ultrasound and Hennessy classification probe. Pomar et al. (2001), comparing the three methodologies with the area and the actual depth of the EMA, found that a greater degree of precision was obtained with the digitized images and the probe presented as the least accurate method.

The EMA size infers certain aspects of the carcass, such as weight gain, pH and carcass quality. McGilchrist et al. (2012), in a comparative study with muscle eye area, pH and carcass colour found that as EMA increased, it reduced the number of animals with meat pH higher than 5.7 and, consequently, reduced the number of cuts dark in colour, improving the quality of the meat. In another study, Gonzalez et al. (2019) found that in heifers was a relationship between very long muscle area, age and daily weight gain. As heifers increased their average daily weight gain and age, the EMA also increased.

Conformation, physiological maturity of the carcass and killout percentage (KO%)

The parameters that determine the economic value of beef are mainly focused on factors related to carcass characteristics, such as good conformation, low-fat level and a high proportion of desirable cuts in retail. Thus, there is a direct relationship between the conformation of the carcass and the price of the meat in the market. On the other hand, the final consumer chooses products whose sensory attributes are more attractive, that is, meats with adequate colour, more tenderness and flavour and with the quantity and quality of fat adequate to their needs (Aldai et al., 2007).

The conformation and physiological maturity of the carcass are related as the animal grows. In the first 15-18 months of life, intensive muscle growth in young cattle, which, associated with an adequate diet, flavours the formation of heavier and more muscular carcasses with a high percentage of high-value soft parts (Pečiulaitienė et al., 2015). Intrinsic and extrinsic factors to animals, such as sex, feed management, genetics, finishing systems type (Rotta et al., 2009), age (Aleksić et al., 2001) and breed, affect carcass efficiency and morphological composition (Berg et al., 2003). Furthermore, the morphological composition of the carcass depends on the proportion of individual tissues. The main ones are muscle, fat and bone tissue. Muscle tissue consists of about 50-65 per cent of the carcass (Pečiulaitienė et al., 2015).

There is a differentiated growth between the three main tissues of the bovine carcass (muscle, fat and bone). There is an initial and low-impulse bone development, followed by intermediate muscle growth and, later, by high-impact adipose tissue growth, occurring mainly in the fattening phase. Maturity and slaughter weight must find a balance because, from a certain point onwards, there is an increase in animal weight, a reduction in the muscle percentage, and an increase in the fat percentage (Berg & Butterfield, 1968). With an increase in carcass maturity, there is also an increase in the red colour, lightness of the meat, and the fat's yellowness. Tenderness, flavour and acceptability tend to decrease in older animals compared to groups of young and intermediate animals (Moon et al., 2006).

In kill-out percentage, sometimes referred to as dressing percentage, the carcass weight is measured as a percentage of the overall live weight of the animal. The high kill-out percentage is generally desirable, but it doesn't directly relate to the animal's live weight. Because the heavy live animal with a heavy carcass is a percentage, it is possible to have the same kill-out as a percentage of a light live animal with a light carcass (Coyne et al., 2019). This percentage provides comparative data on carcass yield.

Keane & Allen (1998), comparing the finishing of carcasses in extensive and intensive rearing systems, verified that the kill-out percentage was higher in animals from the intensive system and a better carcass conformation. However, Minchin et al. (2009) compared three groups of dairy cows fed with a diet containing silage and different amounts of concentrate. In the group fed only with silage there were observed that the dietary treatment did not affect the kill-out percentage.

From a genetic point of view, there is a significant genetic correlation between the hot carcass weight and the kill-out percentage and between this and the loin eye area (Pariacote et al., 1998). Although there is controversy in the studies' results, the comparison of animals finished in the same system provides reliable data on carcass yield.

Changes in animal production in the last century have almost led to the extinction locally adapted cattle breeds like Curraleiro Pé-Duro and Pantaneiro (Rischkowsky & Pilling, 2007). Little is known about the characteristics of their meat and carcass, which represents a barrier to their use in production systems. Culturally, their products and by-products are highly appreciated among breeders (Sereno, 2002; Fioravanti et al., 2011) and the association of tradition, market demand for differentiated foods and meats with particular flavours and characteristics can encourage these animals rearing with consequent preservation of your genetics.

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CHAPTER 2

LOCAL BRAZILIAN CATTLE BREEDS: PERFORMANCE AND CARCASS TRAITS

ABSTRACT

Little is known about the performance of locally adapted cattle in Brazil. In this study, growth and carcass traits of Pantaneiro and Curraleiro Pé-Duro cattle breeds with no genetic improvement were compared with commercial Nelore. Fifteen 30-month-old steers of each breed were used and kept in a feedlot for 112 days after 21 days of adaptation with ultrasound measurements performed to assess eye muscle area, subcutaneous fat thickness, hip fat and gluteus medius depth. After slaughter, carcasses and commercial cuts were weighed and analyses regarding marbling, conformation, texture and physiological maturity were performed. Eye muscle area and subcutaneous fat thickness were measured. Age was determined and the hindquarter was deboned. A portion of *Longissimus thoracis* was used to determine the percentages of muscle, bone and fat. Other measurements performed were CieLab colour space, Killout percentage, cooling losses, compactness index and bone%. Statistical analyses carried out using SAS® v.9.3 (Statistical Analysis System Institute, Cary, North Carolina) included analysis of variance (PROC GLM) with fixed effected including breed as well as date of slaughter and initial/final weight on test used as a covariate. Correlations (PROC CORR) were calculated. Multivariate analyses included principal factor (PROC FACTOR), discriminant (PROC STEPDISC, DISCRIM) and canonical (PROC CANCORR, CANDISC) analyses. There was no difference in daily weight gain, marbling, conformation and physiological maturity in slaughter weights between the breeds. Nelore and Curraleiro deposited more fat than Pantaneiro, Curraleiro and Pantaneiro had more muscle than Nelore, which also had more bone and a higher percentage of second-quality cuts. Despite the differences between Nelore and Curraleiro, both had similar gluteus medius depths. Pantaneiro and Curraleiro were superior for leg compactness index and had higher eye muscle area than Nelore. Although there was no difference in daily weight gain and slaughter weight between breeds, Curraleiro Pé-Duro had a lower initial weight when compared to Nelore, a difference that disappeared after the confinement period.

The local breeds Curraleiro Pé-Duro and Pantaneiro, submitted to adequate environmental and dietary conditions, expressed their genome with greater potential and presented characteristics similar to those of the Nelore, proving to be animals with great productive potential and economically competitive

Key-words: bone, commercial cuts, Curraleiro Pé-Duro, fat, muscle, Nelore, Pantaneiro.

RESUMO

Pouco se sabe sobre o desempenho das raças bovinas locais do Brasil. Neste estudo, as características de crescimento e carcaça das raças Pantaneiro e Curraleiro Pé-Duro, sem melhoramento genético, foram comparadas com as da raça Nelore comercial. Quinze novilhos de 30 meses de cada raça foram usados e mantidos em confinamento por 112 dias após 21 dias de adaptação com medidas de ultrassom realizadas para avaliar a área de olho de lombo, espessura de gordura subcutânea, gordura de quadril e profundidade do glúteo médio. Após o abate, as carcaças e cortes comerciais foram pesados e foram realizadas análises quanto ao marmoreio, conformação, textura e maturação fisiológica. A área de olho de lombo e a espessura da gordura subcutânea foram medidas. A idade foi determinada e o traseiro foi desossado. Uma porção do *Longissimus thoracis* foi usada para determinar as porcentagens de músculo, osso e gordura. Outras medidas realizadas foram o espaço de cor CieLab, porcentagem de killout, perdas por resfriamento, índice de compacidade e porcentagem óssea. As análises estatísticas realizadas usando SAS® v.9.3 (Statistical Analysis System Institute, Cary, Carolina do Norte) incluíram análise de variância (PROC GLM) com efeitos fixos, incluindo raça, bem como data de abate e peso inicial / final no teste usado como um covariável. As correlações (PROC CORR) foram calculadas. As análises multivariadas incluíram análises de fator principal (PROC FACTOR), discriminante (PROC STEPDISC, DISCRIM) e canônicas (PROC CANCORR, CANDISC). Não houve diferença no ganho de peso diário, marmoreio, conformação e maturidade fisiológica nos pesos de abate entre as raças. Nelore e Curraleiro depositaram mais gordura que Pantaneiro, Curraleiro e Pantaneiro tinham mais músculos que Nelore, que também tinha mais osso e maior porcentagem de cortes de segunda qualidade. Apesar das diferenças entre Nelore e Curraleiro, ambos apresentaram profundidades glúteo médio semelhantes. Pantaneiro e Curraleiro foram superiores para índice de compacidade das pernas e apresentaram maior área de olho de lombo que Nelore. Embora não tenha havido diferença no ganho de peso diário e no peso ao abate entre as raças, o Curraleiro

Pé-Duro teve um peso inicial inferior quando comparado ao Nelore, diferença que desapareceu após o período de confinamento. As raças locais Curraleiro Pé-Duro e Pantaneiro submetidas a condições ambientais e dietéticas adequadas expressaram seu genoma com maior potencial e apresentaram características semelhantes às do Nelore, revelando-se animais com grande potencial produtivo e economicamente competitivos.

Palavras-chaves: cortes comerciais, Curraleiro Pé-Duro, gordura, músculo, Nelore, osso, Pantaneiro.

1. INTRODUCTION

Locally adapted breeds are thought to show lower production efficiency and carcass quality than meat breeds under commercial conditions (Blackburn et al., 1998). This probably arises from their small frame size (McManus et al., 2011), usually obtained in harsh environments and few comparative studies exist.

In Brazil, it is known that locally adapted cattle breeds originated from *Bos taurus ibericus* cattle brought from the Iberian Peninsula during the colonization period, and these have adapted to the local environments. These include the Brazilian Cerrado (savannah and semi-arid hinterland) and Pantanal (world´s largest wetlands), where the Curraleiro Pé-Duro and Pantaneiro breeds have developed respectively. These ecosystems are characterised by high ambient temperatures and prolonged dry seasons (approximately 6 months) with seasonal flooding in the Pantanal. The arrival of zebu type cattle (mainly Nelore derived from the Indian Ongole breed) in the early 20th century led to the replacement of these breeds in commercial production systems (Egito et al., 2002) and to the rapid expansion of Brazilian cattle production in the last 30 years, which means that Brazil now has the world´s largest commercial beef herd.

Little information exists on the performance of these locally adapted breeds, especially in comparison with commercial breeds. Bianchini et al. (2006) showed that Curraleiro Pé-Duro and Pantaneiro were similar in size to Nelore cattle for several body measurements, but these were adult animals and were not weighed. Nevertheless, McManus et al. (2011) showed that shoulder height, body length, and heart girth were important in differentiating between these breeds for heat tolerance. Since these locally adapted breeds are of *Bos taurus* origin, they have also been assumed to present slower growth rates but superior meat quality to the *Bos indicus* breeds (Fioravanti et al., 2010) once again without comparative studies in similar environments.

Abreu et al. (2002) found a birth weight of 26kg and 114kg for weight corrected for 205 days for Pantaneiro cattle in their natural environment resulting in an average daily gain (ADG) of 0.429kg. Carvalho et al. (2013) found birth weight and 210 days weight for male Curraleiro Pé-Duro cattle of 21.3 and 68.68kg respectively (ADG of 0.215kg/day), below of the observed in the literature for Nelore cattle on native pasture in the Pantanal (0.650 kg/day, Itavo et al., 2008) and 29.5 kg and 157.95 kg at birth and at 205 days for Nelore in Northeastern Brazil (ADG = 0.626kg/day, Holanda et al., 2004). These studies were pre-weaning, but Rezende et al. (2014) relate a postweaning gain in Nelore of 0,430kg/day in the Pantanal in animals born between 1978 and 2007. These studies are not comparative as they were carried out with individual breeds. Therefore, the aim of the present study was to compare growth and carcass traits in Pantaneiro and Curraleiro Pé-Duro cattle with Nelore under commercial feedlot conditions.

2.MATERIAL AND METHODS

Animal care throughout the study followed animal welfare protocols for animal production. *In vivo* invasive procedures were not performed and the animals were slaughtered for commercial purposes with subsequent analysis performed.

Fifteen 30-month-old steers of each of three breeds (Curraleiro Pé-Duro, Pantaneiro and Nelore - Figure 2.1) were kept in a feedlot, with covered area and shade for food, at Veterinary School of the Federal University of Goiás, for 112 days of experiment after 21 days of adaptation.

Figure 2.1 - Curraleio Pé-Duro, Pantaneiro and Nelore used in the study.

Curraleiro Pé-Duro came from two herds. Six animals were acquired from a breeder in the municipality of Monte Alegre-GO and nine from a breeder in the municipality of Mimoso-GO. The Pantaneiro and the Nelore both were originated from a single herd. Pantaneiro animals were acquired from the Conservation Nucleus of the Pantaneira breed of Embrapa. Nelore animals came from a breeder in the region of Petrolina-GO. Curraleiro Pé-Duro and Pantaneiro cattle used in the study had not gone through any selection process to improve their productive qualities.

The animals received a balanced diet, twice a day, according to their requirements, following the recommendations of the National Research Council – NRC (1996). The diet had 70% of the nutrients from concentrate and 30% from roughage (sorghum silage), considering the consumption orts of 5% to 10%. Mineral salt and water were provided *ad libitum*. Total digestible nutrients (NDT) were provided at 74.30%, with minimum crude protein of 15% and calcium, phosphous, sodium, potassium and magnesium where included in the ratio's macronutrients.

At the begining of the experiment, animals were weighed (IW) and then every 14 days until the day before slaughter. Eye muscle measurements (eye muscle area - EMA; subcutaneous fat thickness – FT; hip fat – HF and depth of gluteus medius muscle - GMD) were made using an Aloka SSD-500 ultrasound with a linear 17.2cm and a 3.5MHz transducer every 28 days for the first three measurements, then every 14 days, immediately following the weight measurements.

The animals were slaughtered after a 24 hour fast on three dates, with one-third of each genetic group in each group. The animals were slaughtered in an abattoir with federal inspection in Palmeiras de Goiás. After slaughter, the animals were bled out, the viscera and internal organs, feet, tail, skin and head were removed. The half carcasses were weighed to obtain the hot carcass weight (HCW). The carcasses were subjectively typified for marbling, physiological maturity, texture and a conformation. The evaluations of the eye muscle area (EMA) and fat thickness (FT) were carried out on the left carcass through a cross section between the 12^{th} and 13^{th} rib.

Conformation was measured on a 12-point scale (Muller, 1987) ranging from 12- very good+; 11- very good; 10- very good-; 9- good+; 8- good; 7- good-; 6- regular+; 5- regular; 4- regular-; 3- bad+; 2- bad and 1- bad-. Physiological maturity (USDA, 2017) was determined through determining cartilage ossification of the spinous processes of the thoracic and lumbar vertebrae and between the sacral vertebrae. The cartilage ossification scale varies from A to E, where A: corresponds to the animal that is between 9 to 30 months, B: animal that is between 30 to 42 months, C: between 42 to 72 months, D: between 72 to 96 months and E: over 96 months. Each of these were then subdivided in three (+, 0 and -, - being younger and + being older). These were then transformed on a scale of 1 (E+) to 15 (A-).

Samples were taken from the *Longissimus thoracis* muscle between the 10^{th} and 12^{th} rib. Two steaks, approximately 2cm thick each, were vacuum-packed and frozen for subsequent analysis for texture and degree of marbling. Carcass marbling was classified according to the degree of intramuscular fat deposition in the *Longissimus. thoracis*. The evaluations are usually made by comparing the muscle with the standards and following the point scale, where 1 corresponds to a trace, 2- light, 3- small, 4- medium, 5- moderate and 6- abundant (Felício, 2005).

Carcass texture of the meat in the carcass was evaluated by visual examination of the granulometry of the cross section of the *Longissimus thoracis*, in the EMA, whose granulometric degree depends on the caliber of the muscle fiber bundles, that is, on the diameters of the muscle fascicles (Müller, 1987). Another important factor to be considered is the degree of delimitation between the muscle fascicles imposed by the thickness of the perimysium, the connective tissue sheath that surrounds each of these muscle fascicles. Carcass texture was rated on a scale of 1 (very coarse) to 5 (very fine).

Carcasses remained in a cold chamber for 24 hours at 4°C and were weighed again to determine the weight of the cold carcass (CCW). From each right cooled half-carcass, the *Longissimus thoracis* was cut between the 11^{th} to 13^{th} ribs, called HH section (Hankins e Howe, 1946). This was divided in two subsamples of approximately 8cm wide each, which were identified, vacuum packed and frozen immediately for subsequent determination of the percentages of muscle, bone, fat.

CieLab colour space was determined on three points of the carcass and then averaged to determine L* (luminosity), a* (green to red spectrum) and b* (blue to yellow spectrum) using a Minolta CR-300 (Osaka, Japan). The pH after 24 hours of slaughter was verified from the right half carcasses using a pH meter (Model HI 99163, Brand Hanna, Brazil), which were then separated divided between the fifth and sixth thoracic vertebra to form forequarters and hindquarters. The hindquarter was boned in commercial cuts: tenderloin, top sirloin, bottom sirloin, rump cap, the eye of round, knuckle, topside and silverside.

Using the parameters defined by the Ministry of Agriculture (MAPA, 2004), Federal Inspection Service (SIF) age was also defined (Bungenstab, 2012: D = male or female bovine with teething milk without falling from the clamps; J2 = young male or female bovine with two permanent incisor teeth (tweezers), without falling from the first dentition; J4 = young male or female bovine with four permanent incisor teeth (forceps and 1° averages), without dropping the second average of the first dentition; I = male or female cattle with more than four and up to six permanent incisor teeth, without falling from the corners of the first dentition; A = male or female cattle with more than six incisor teeth in the second dentition).

Killout percentage (KO %) was calculated as (hot carcass weight* 100)/slaughter weight; loss of carcass on cooling (LC) = 100- (cold carcass weight*100)/hot carcass weight and bone percentage (bone%) = 23.7-3.0*(cold carcass weight/carcass length).

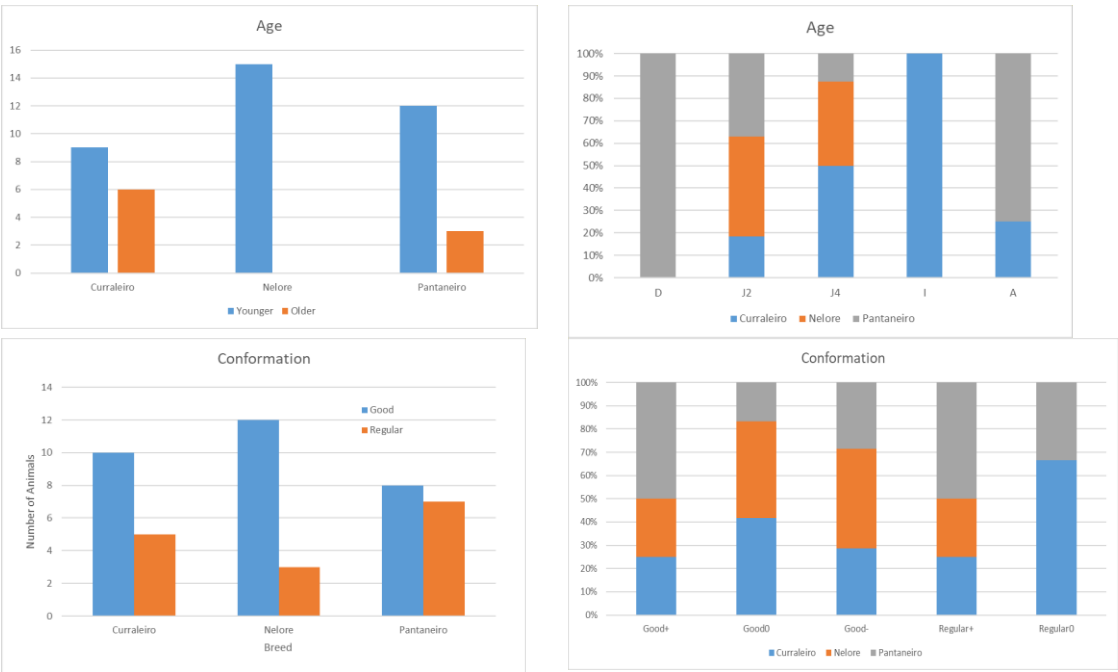
To calculate the compactness index, the following measurements were performed, according to Sañudo and Sierra (1986): leg length (distance between the perineum and the anterior edge of the tarsus metatarsal articular surface), croup width (maximum width between the trochanters of both femurs, taken with a compass), internal length of the carcass (maximum distance between the anterior edge of the ischiopubic symphysis and the anterior edge of the first rib at its midpoint). Carcass compactness was found by cold carcass weight divided by internal carcass length. Leg compactness was calculated by leg circumference divided by leg length.

Statistical analyses were carried out using SAS® v.9.4 (Statistical Analysis System Institute, Cary, North Carolina) included analysis of variance (PROC GLM) with fixed effected including breed as well as date of slaughter and initial/final weight on test used as a covariate. Correlations (PROC CORR) were calculated.

Multivariate analyses were carried out on standardised (STANDARD) data in accordance with Sneath and Sokal (1973). This analysis was used to place animals in groups in accordance with their degree of similarity and verify the discriminatory capacity of the original traits in the formation of these groups. Data were divided into groups according to live animal and slaughter, carcass, cuts, fatty acids, and meat quality. Stepwise (STEPDISC) and canonical discriminant (CANDISC) analyses, as well as discriminant analyses (DISCRIM) were carried out. Canonical correlations (CANCORR) between live animal and slaughter traits and the other groups were also carried out. These were used to determine the characteristics to predict the group to which a given animal most closely identified, select a subset of the quantitative variables for use in discriminating among the breeds, and summarize between-class variation similar as principal components summarize total variation. Correspondence analysis (CORRESP) was used to compare animals and traits with qualitative traits (dental age, conformation, physiological maturity and marbling).

3.RESULTS

No differences between breeds were seen for conformation (regular to good+), physiological maturity (D- to A+), or marbling (trace- to light+), while differences were seen for SIF age (A to J4) where Curraleiro had marginally higher classification (Figure 2.2). Data from mean, standard deviation and minimum and maximum values for traits evaluated are presented in Table 2.1.



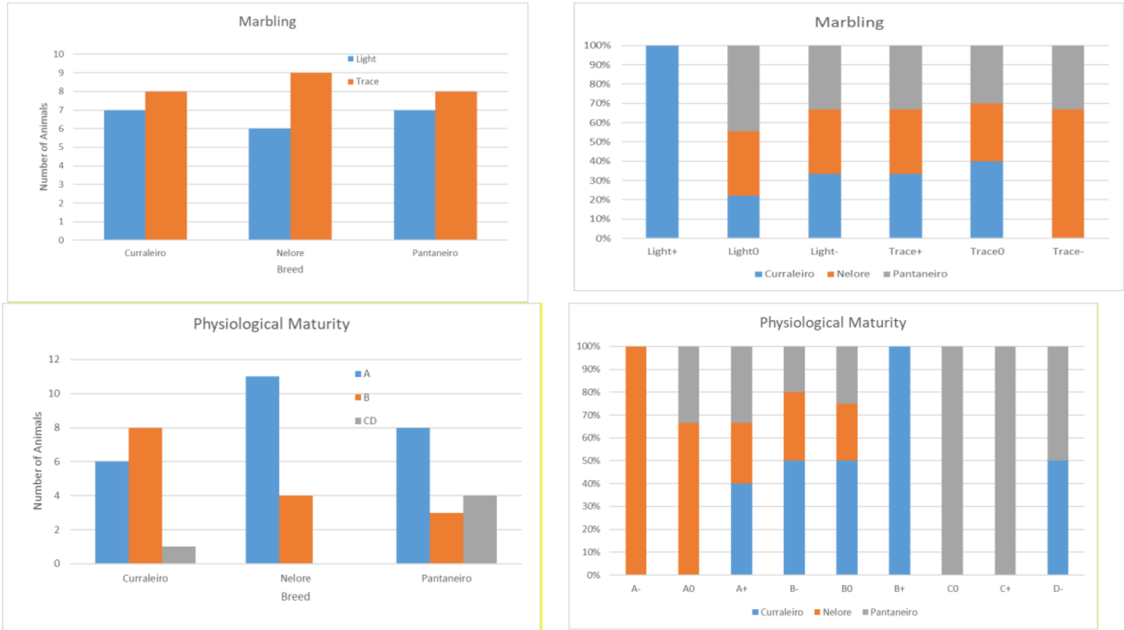


Figure 2.2. Distribution of animals per breed and per dental age, conformation, marbling and physiological maturity of the carcass.

Table 2.1. Mean, standard deviation, minimum and maximum values for traits evaluated.

Variable	Abbreviation	Mean	Std Dev	Minimum	Maximum
Beginning of Experiment					
Initial weight (kg)	IW	309.27	68.29	182.00	515.00
Initial eye muscle area (cm^2)	IEMA	43.74	9.37	27.62	76.78
Initial eye muscle fat (cm)	IEMF	0.32	0.07	0.20	0.50
Initial hip fat (cm)	IHF	0.27	0.07	0.10	0.40
Initial gluteus medius depth (cm)	IGMD	6.82	0.85	4.80	8.50
Slaughter					
Slaughter weight (kg)	SW	456.96	86.07	263.00	686.00
Half cold carcass weight (kg)	CCW	113.36	25.91	58.90	192.10
Conformation score	CS	10.0222	1.1178	8.0000	12.0000
Physiological maturity score	PM	12.1111	2.1130	6.0000	15.0000
Texture	Tex	2.66	0.88	1.20	4.80
Marbling	Marb	3.38	1.34	1.00	6.00
pH24h	pH	5.78	0.18	5.43	6.25
Carcass L*	CL*	29.60	3.88	20.23	34.53
Carcass a*	Ca*	4.68	1.43	1.86	8.66

Carcass b*	Cb*	6.77	1.77	1.66	10.24
Carcass length (cm)	Cl	132.94	7.10	114.00	148.00
Leg length (cm)	LL	69.12	7.09	43.00	78.50
Leg thickness (cm)	LT	23.35	2.54	18.50	29.50
Arm perimeter (cm)	AP	34.36	3.16	27.00	44.00
Arm length (cm)	AL	49.07	14.41	33.00	78.50
Carcass compact index	CCI	1.69	0.31	0.99	2.60
Leg compact index	LCI	0.75	0.19	0.43	1.10
Eye muscle area slaughter (cm^2)	SEMA	66.12	11.68	42.89	118.74
Eye muscle fat slaughter (cm)	SEMF	5.32	1.90	2.00	11.00
Slaughter hip fat (cm)	SHF	0.40	0.05	0.30	0.50
Slaughter gluteus medius depth (cm)	SGMD	8.96	1.39	6.00	11.80
Hot carcass weight (kg)	HCW	216.09	63.14	119.50	390.50
Full cold carcass weight (kg)	FCCW	212.38	61.48	117.80	384.20
Kill out %	KO%	49.99	2.84	41.07	56.64
Bone %	Bone%	21.16	0.47	19.81	22.22
Cooling loss %	CooL	1.41	1.24	1.04	4.00
Rates of growth					
Daily weight gain (kg/day)	DWG	1.5308	0.3557	0.5876	2.1443
R*Eye muscle area	REMA	0.2188	0.1021	0.0185	0.5047
R*Eye muscle fat	REMF	0.0010	0.0008	-0.0010	0.0041
R*Hip fat	RHF	0.0013	0.0008	0.0000	0.0031
R*Gluteus medius	RGM	0.0220	0.0136	-0.0021	0.0577
Carcass Cut Weights (kg)					
Left carcass	LC	114.51	25.62	60.00	194.50
Right carcass	RC	115.40	26.64	59.50	196.00
Hind end	HE	65.04	13.45	34.90	101.60
Hindend without rump and sirloin	HE-RS	36.64	7.95	20.00	56.50
Front end	FE	48.32	12.82	22.20	90.50
Tenderloin	TL	1.59	0.30	0.92	2.13
Rump cap	Rump	1.54	0.32	0.80	2.33
Top sirloin	TS	3.01	0.71	1.50	4.54
Bottom sirloin	BS	1.16	0.31	0.58	2.09
Eye of round	EyeR	2.18	0.59	0.97	3.52
Knuckle	Knu	4.37	1.01	2.25	7.12
Topside	Top	7.19	1.73	2.87	10.83
Silverside	Sil	4.14	1.13	1.97	7.39
Bone	B	0.68	0.17	0.36	1.03

Muscle	M	2.05	0.57	1.01	4.44
Fat	F	0.95	0.27	0.40	1.59
Percentages					
Hind end	%HE	57.64	2.30	52.89	62.31
Hind end without rump and sirloin	%HE-RS	32.42	1.59	29.41	36.28
Front end	%FE	42.36	2.30	37.69	47.11
Tenderloin	%TL	1.42	0.13	1.11	1.72
Rump cap	%Rump	1.38	0.21	1.01	1.81
Top sirloin	%TS	2.65	0.18	2.36	3.06
Bottom sirloin	%BS	1.03	0.15	0.76	1.69
Eye of round	%EyeR	1.91	0.20	1.52	2.37
Knuckle	%Knu	3.87	0.30	3.30	4.53
Topside	%Top	6.35	0.63	3.10	7.47
Silverside	%Sil	3.63	0.36	2.86	4.58

3.1. Analyses of variance

Curraleiro were lighter than Nelore at the beginning of the experiment (Table 2.2A), but this difference disappeared at slaughter. There was no significant difference in daily weight gain between the breeds, although the Nelore was numerically higher than the other two breeds.

There was no difference in slaughter weights between the three genetic groups for slaughter weight and daily weight gain (Table 2.2A). Nelore and Curraleiro deposited more fat than Pantaneiro, and the Pantaneiro grew more in shoulder height (R*GM) than the other two breeds.

While there was no difference between Nelore and Curraleiro for carcass compactness index (CCI), both Pantaneiro and Curraleiro were superior for leg compactness index (LCI). This is due to the fact that Nelore have longer legs, without having a significantly larger perimeter. Both Pantaneiro and Curraleiro showed higher eye muscle area than Nelore, as measured by ultrasound at slaughter, but no differences were seen between breeds for fat at slaughter (Table 2.2 B).

Table 2.2. Analysis of variance for slaughter traits and rates of change in Brazilian cattle breeds.

A

	IW	IEMA	IEMF	IHF	IGMD	SHF	SGMD	SW kg	DWG kg/day	R*EMA Mm/day	R*FT Mm/day	R*Hip m/day	R*GM m/day	Text	CL*	Ca*	Cb*	pH24
R^2	0.25	0.10	0.09	0.09	0.03	0.24	0.64	0.84	0.11	0.21	0.23	0.10	0.28	ns	0.14	0.03	0.14	0.28
CV	19.56	20.78	22.25	23.32	12.46	10.51	9.84	1.96	23.04	43.51	79.79	59.48	54.91	29.96	12.78	31.72	25.69	2.37
Breed	***	ns	Ns	ns	ns	ns	***	0.07	ns	ns	*	ns	*	ns	ns	ns	ns	**
Date						ns	ns	ns	ns	ns	Ns	ns	ns	0.06	ns	ns	0.06	Ns
IW						***	***	***	ns	***	Ns	ns	ns	ns	ns	ns	ns	Ns
C	264.8^{b}	39.60	0.33	0.27	6.74	0.28	9.13^{a}	452.22	1.48	0.26	0.0012^{a}	0.0013	0.022^{ab}	2.80	28.28	4.51	6.57	5.86
N	346.8^{a}	45.52	0.29	0.25	7.04	0.24	9.53^{a}	475.46	1.66	0.22	0.0011^{ab}	0.0015	0.027^{a}	2.52	30.29	5.05	6.90	5.72
P	316.2^{ab}	46.09	0.35	0.30	6.68	0.29	8.21^{b}	443.18	1.45	0.17	0.0004^{b}	0.0009	0.016^{b}	2.64	30.50	4.62	6.88	5.74

B

	Cl	LL	LT	AP	AL	SEMA	SEMF	LC	RC	CCW	HCW	CCI	CLI	KO%	CooL	Bone%
R^2	0.67	0.74	0.64	0.79	0.90	0.68	0.06	0.87	0.86	0.86	0.86	0.85	0.91	0.51	0.11	0.85
CV	3.25	5.48	6.95	4.48	10.05	10.60	36.91	8.64	9.27	8.97	8.91	7.43	8.56	4.24	88.22	0.90
Date	Ns	Ns	*	**	***	*	Ns	Ns	Ns	Ns	Ns	***	***	ns	ns	*
Breed	Ns	***	*	Ns	***	*	Ns	Ns	*	Ns	Ns	***	***	ns	ns	**
IW	***	***	***	***	ns	***	Ns	***	***	***	***	***	**	**	ns	***
C	131.53	64.16^{c}	23.37^{ab}	34.69	45.08^{b}	69.16^{a}	6.04	114.69	114.88^{ab}	113.14	229.56	1.69^{ab}	0.82^{a}	50.26	1.41	21.16^{ab}
N	133.07	74.56^{a}	24.11^{a}	34.28	53.69^{a}	61.89^{b}	4.82	117.99	120.78^{a}	117.87	238.78	1.77^{a}	0.68^{c}	50.22	1.27	21.04^{b}
P	134.23	68.64^{b}	22.56^{b}	34.12	48.42^{b}	67.33^{a}	5.10	110.84	110.55^{b}	109.07	221.40	1.61^{b}	0.76^{b}	49.50	1.55	21.28^{a}

R^2 – Coefficient of determination; CV – coefficient of variation; IW – Initial weight; C – Curraleiro; N – Nelore; P – Pantaneiro; KO% - Kill Out %; Cl - Carcass length (cm); LL – leg length (cm); LT – Leg thickness (cm); AP – Arm perimeter (cm); AL – arm length (cm); CCI – Carcass compact Index; CLI – Compact leg index; IEMA – Initial eye muscle area; IEMF – initial eye muscle fat; SEMA – Eye muscle area at slaughter; SEMF – Slaughter eye muscle fat; IHF – Initial hip fat; IGMD – Initial gluteus medius depth; SHF- Slaughter Hip fat; SGMD – Slaughter gluteus medius depth; LC – Left half carcass weight; RC – right half carcass weight; CCW – cold carcass weight; HCW – hot carcass weight; SW – slaughter weight; DWG – Daily weight gain (kg/day); R*EMA – Rate of growth of eye muscle area; R* FT – Rate of growth of fat thickness; CooL – cooling Loss (%); R*Hip – rate of growth of hip height; R*GM – rate of growth of gluteus medius; Text- Texture; CL* - carcass luminosity; Ca* - carcass green to red; Cb* - carcass blue to yellow. Ns – not significant; * P<0.05; ** P<0.01; *** P<0.001; Different letters in the column indicate significant differences using the Tukey test (P<0.05).

No differences were seen between breeds for carcass colour (CieLab), with carcasses being more red than green and more yellow than blue. Breed affected several cut weights (Table 2.2A). Curraleiro had heavier front end while Nelore had heavier eye of round, silverside, topside, knuckle and sirloin, all hind end cuts.

Nelore cattle through were subjected to several genetic selection programs, which may justify a greater weight of the hindquarters, a place where nobler cuts are found. In the case of Curraleiro, an indirect selection may have occurred due to its traditional use for pulling heavy loads, leading to a more muscular frontend. Despite the differences between those breeds, both had similar slaughter gluteus medius depth, significant differing only for the Pantaneiro (Table 2.2A).

Table 2.3. Analysis of variance for meat cut weights in Brazilian cattle breeds.

	Front end	Hind end	HE-RS	Tenderloin	Rump cap	Top sirloin	Bottom sirloin	Eye of round	Knuckle	Topside	Silverside
R^2	0.85	0.84	0.87	0.72	0.65	0.82	0.56	0.83	0.84	0.80	0.86
CV	10.77	8.56	8.16	10.23	13.00	10.32	7.06	10.56	9.67	11.26	10.74
Breed	ns	*	***	*	ns	***	ns	***	***	**	***
Date	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
IW	***	***	***	***	***	***	ns	***	***	***	***
C	49.80	63.35^{ab}	34.71^{b}	1.55^{ab}	1.55	2.93^{b}	1.17	2.00^{b}	4.17^{b}	6.94^{b}	4.04^{b}
N	48.99	68.88^{a}	40.40^{a}	1.70^{a}	1.62	3.33^{a}	1.15	2.50^{a}	4.83^{a}	8.03^{a}	4.57^{a}
P	46.18	62.88^{b}	34.82^{b}	1.52^{b}	1.46	2.76^{b}	1.17	2.02^{b}	4.12^{b}	6.60^{b}	3.82^{b}

R^2 – coefficient of determination; CV – coefficient of variation; IW – Initial weight; C – Curraleiro; N – Nelore; P – Pantaneiro; HE-RS - Hindend without rump and sirloin. Different letters in the column indicate significant differences using the Tukey test (P<0.05). * P<0.05; ** P <0.01; *** P<0.001; ns – not significant.

Table 2.4. Analysis of variance for percentages of cuts in Brazilian cattle breeds.

	%HE	%HE-RS	%Front	Tenderloin	Rump Cap	Top Sirloin	Bottom Sirloin	Eye of Round	Knuckle	Topside	Silverside	Bone	Muscle	Fat
R2	0.50	0.63	0.50	0.28	0.66	0.4	0.19	0.65	0.48	0.27	0.47	0.30	0.43	0.22
CV	3.10	3.29	4.22	8.75	9.73	5.86	14.21	6.69	6.12	9.42	7.87	14.22	6.08	13.38
Breed	ns	***	Ns	Ns	ns	**	ns	**	**	*	**	*	***	Ns
Date	**	0.08	**	Ns	**	Ns	ns	*	*	Ns	**	Ns	*	Ns
B*D	**	***	**	<0.10	ns	Ns	ns	ns	ns	Ns	ns	ns	ns	Ns
C	0.57	0.317[b]	0.426	0.015	0.014	0.026[b]	0.010	0.018[b]	0.038[b]	0.063[ab]	0.035[b]	17.39[b]	57.50[a]	25.10
N	0.58	0.335[a]	0.425	0.014	0.013	0.028[a]	0.010	0.021[a]	0.040[a]	0.067[a]	0.039[a]	20.22[a]	53.03[b]	26.74
P	0.58	0.321[b]	0.419	0.014	0.014	0.025[b]	0.011	0.018[b]	0.038[b]	0.060[b]	0.035[b]	18.42[ab]	56.12[a]	25.46

Abbreviations: R^2 – coefficient of determination; CV – coefficient of variation; %HE - % Hind end; %HE-RS - % Hind end without rump and sirloin; Ns – not significant; * P<0.05; ** P<0.01; *** P<0.001; Different letters in the column indicate significant differences using the Tukey test (P<0.05).

Nelore had more bone, but fat did not differ between breeds. Curraleiro and Pantaneiro had more muscle than Nelore but did not differ between them. Nelore had a higher percentage of less noble cuts but no differences were found for higher value cuts (Table 2.4). This finding was confirmed by the highest percentage of HE-RS found for Nelore. There was no difference in KO% among the breeds. There was a significant difference between bone %, mainly between Pantaneiro and Nelore (Table 2.2B).

3.2. Correlations

Correlations between initial and slaughter weight and percentages demonstrated that initial weight, slaughter weight and daily weight gain had a high correlation with the killout percentage but were negatively correlated with bone percentage. Elevated carcass efficiency was related to a low bone percentage.

Carcass traits (Table 2.5B) correlation showed that the carcass length had a high correlation with all cuts. Animals with a higher conformation have a higher quantity of prime cuts. Physiological maturity negatively correlated with the amount of muscle present in the carcass.

Analysing data from live animals, post-slaughter and carcass traits, both initial weight and kill out percentage have a high correlation with conformation score and meat cuts. The percentage of bones is negatively correlated with the conformation score and meat cuts, that is, the greater the bone weight, the lesser amount of meat obtained in deboning. Physiological maturity had an inverse relationship with the kill out percentage, demonstrating that animals with less maturity had higher carcass yield.

Table 2.5. Correlations between live and slaughter data (A) and carcass (B) traits in Brazilian cattle and between live, slaughter and carcass traits (C)

Correlations A

	pH24h	SW	DWG	REMA	REMF	RHF	RH	IW	IEMA	IEMF	IHF	IGMD	HCW	FCCW	KO%	CooL
SW	-0.50															
DWG	-0.09	0.56														
REMA	-0.28	0.71	0.43													
REMF	0.05	-0.11	0.11	0.25												
RHF	0.13	0.16	0.01	0.45	0.33											
RH	-0.72	0.29	-0.09	0.05	0.20	-0.10										
IW	-0.54	0.94	0.29	0.73	-0.08	0.25	0.35									
IEMA	-0.19	0.75	0.31	0.41	-0.21	-0.01	0.05	0.76								
IEMF	0.07	0.36	-0.05	0.18	-0.71	0.03	-0.26	0.41	0.57							
IHF	-0.01	0.29	0.23	-0.08	-0.35	-0.66	-0.17	0.23	0.54	0.35						
IGMD	-0.06	0.57	0.43	0.63	0.12	0.40	-0.27	0.58	0.52	0.36	0.25					
HCW	-0.43	0.99	0.60	0.74	-0.06	0.20	0.25	0.93	0.78	0.36	0.30	0.62				
FCCW	-0.44	0.99	0.59	0.74	-0.08	0.19	0.25	0.93	0.79	0.38	0.30	0.62	1.00			
KO%	-0.21	0.74	0.65	0.64	0.19	0.18	0.12	0.66	0.66	0.20	0.36	0.76	0.82	0.81		
CooL	-0.02	0.31	0.42	0.16	0.37	0.21	0.05	0.18	0.16	-0.25	0.03	0.24	0.31	0.27	0.29	
Bone%	0.46	-0.98	-0.59	-0.75	0.06	-0.20	-0.28	-0.92	-0.75	-0.36	-0.27	-0.63	-0.99	-0.99	-0.83	-0.25

SW - Slaughter weight (kg); DWG - Daily weight gain (kg/day); REMA - R*Eye muscle área; REMF - R*Eye muscle fat; RHF - R*Hip fat; RH - R*Height; IW - Initial weight (kg); IEMA - Initial eye muscle area (cm2); IEMF - Initial eye muscle fat (cm); IHF - Initial hip fat (cm); IGMD - Initial gluteus medius depth; HCW - Hot carcass weight (kg); FCCW - Full Cold carcass weight (kg); KO% - Kill out %; CooL - Cooling loss %; pH24h – pH after 24 hours.

Correlations B

	CS	PM	Tex	Marb	CL*	Ca*	Cb*	CL	LL	LT	AP	AL	SEMA	SEMF	LC	RC	CCW	HE	HR-RS	FE	TL	Rump	TS	BS	EyeR	Knu	Top	Sil	B	M	F
PM	-0.48																														
Tex	-0.21	0.28																													
Marb	-0.02	0.35	0.35																												
CL*	-0.04	-0.34	-0.26	-0.01																											
Ca*	-0.39	0.32	0.19	0.28	-0.10																										
Cb*	-0.12	-0.20	-0.10	0.03	0.79	0.27																									
CL	0.65	-0.41	-0.49	0.14	0.25	-0.02	0.21																								
LL	0.41	-0.16	-0.51	0.02	0.15	0.07	0.18	0.73																							
LT	0.64	-0.38	-0.53	0.01	0.18	-0.02	0.22	0.85	0.72																						
AP	0.71	-0.56	-0.44	-0.10	0.04	-0.09	0.14	0.82	0.71	0.84																					
AL	0.43	0.06	-0.19	-0.05	-0.20	-0.23	-0.52	0.37	0.30	0.33	0.10																				
SEMA	0.59	-0.71	-0.52	-0.07	0.30	-0.05	0.38	0.78	0.50	0.75	0.87	-0.11																			
SEMF	-0.02	-0.06	-0.11	-0.13	0.06	-0.42	-0.28	0.21	0.11	0.13	0.07	0.37	-0.09																		
LC	0.74	-0.60	-0.46	-0.04	0.20	-0.03	0.23	0.89	0.76	0.88	0.94	0.25	0.85	0.03																	
RC	0.73	-0.59	-0.46	-0.05	0.21	-0.03	0.23	0.89	0.77	0.88	0.93	0.28	0.84	0.04	1.00																
CCW	0.74	-0.60	-0.46	-0.04	0.19	-0.03	0.23	0.89	0.76	0.87	0.94	0.25	0.85	0.02	1.00	1.00															
HE	0.70	-0.51	-0.44	0.03	0.22	0.05	0.25	0.91	0.81	0.88	0.90	0.31	0.80	0.02	0.99	0.99	0.99														
HR-RS	0.68	-0.46	-0.42	0.00	0.18	0.10	0.24	0.87	0.84	0.86	0.90	0.29	0.78	-0.03	0.98	0.98	0.98	0.99													
FE	0.77	-0.67	-0.47	-0.11	0.16	-0.11	0.20	0.85	0.69	0.84	0.96	0.18	0.88	0.01	0.99	0.98	0.99	0.95	0.93												
TL	0.60	-0.29	-0.42	0.03	0.09	0.14	0.14	0.85	0.89	0.86	0.85	0.35	0.66	0.11	0.91	0.92	0.91	0.94	0.96	0.85											
Rump	0.66	-0.49	-0.42	0.01	0.34	-0.01	0.36	0.83	0.75	0.90	0.78	0.34	0.73	-0.06	0.91	0.93	0.92	0.94	0.92	0.86	0.85										
TS	0.69	-0.38	-0.43	0.00	0.09	0.12	0.17	0.85	0.84	0.86	0.87	0.36	0.72	-0.06	0.95	0.96	0.95	0.97	0.99	0.90	0.96	0.91									
BS	0.76	-0.66	-0.57	-0.12	0.26	-0.26	0.13	0.85	0.63	0.89	0.87	0.36	0.83	0.14	0.93	0.94	0.93	0.91	0.87	0.94	0.80	0.88	0.84								
EyeR	0.70	-0.46	-0.36	-0.05	0.20	0.07	0.22	0.84	0.80	0.82	0.84	0.37	0.71	-0.01	0.95	0.96	0.95	0.97	0.98	0.90	0.95	0.92	0.97	0.86							
Knu	0.69	-0.43	-0.49	-0.02	0.14	0.11	0.18	0.88	0.80	0.89	0.89	0.32	0.77	-0.01	0.97	0.97	0.97	0.98	0.98	0.93	0.96	0.90	0.98	0.89	0.96						
Top	0.75	-0.40	-0.31	0.11	0.01	0.06	0.06	0.75	0.71	0.69	0.75	0.39	0.63	-0.17	0.87	0.87	0.88	0.89	0.90	0.84	0.83	0.83	0.93	0.75	0.90	0.88					
Sil	0.70	-0.53	-0.39	-0.07	0.13	0.03	0.18	0.81	0.78	0.81	0.90	0.27	0.78	-0.01	0.97	0.97	0.97	0.97	0.98	0.95	0.93	0.89	0.97	0.87	0.97	0.96	0.92				
B	0.44	-0.02	-0.33	0.04	0.09	0.15	0.03	0.66	0.85	0.69	0.59	0.52	0.34	0.13	0.71	0.73	0.71	0.78	0.82	0.61	0.91	0.73	0.84	0.62	0.85	0.81	0.72	0.77			
M	0.65	-0.72	-0.45	-0.14	0.19	0.00	0.30	0.79	0.65	0.80	0.94	0.02	0.92	-0.09	0.95	0.94	0.95	0.91	0.90	0.97	0.79	0.83	0.86	0.88	0.85	0.89	0.77	0.91	0.51		
F	0.50	-0.49	-0.58	0.06	0.46	-0.11	0.26	0.83	0.77	0.72	0.69	0.35	0.67	0.14	0.84	0.86	0.85	0.87	0.83	0.79	0.79	0.84	0.81	0.84	0.82	0.82	0.75	0.81	0.72	0.74	
pH24h	-0.26	-0.23	0.15	-0.42	-0.01	-0.49	-0.25	-0.45	-0.59	-0.33	-0.35	-0.02	-0.29	0.54	-0.43	-0.43	-0.44	-0.50	-0.55	-0.35	-0.56	-0.43	-0.58	-0.22	-0.53	-0.54	-0.58	-0.46	-0.56	-0.34	-0.41

PM - Physiological maturity score; TEX - Texture; Marb - Marbling; CL* - Carcass L*; Ca* - Carcass a*; Cb* - Carcass b*; CL - Carcass length (cm); LL - Leg length (cm); LT - Leg thickness (cm); AP - Arm perimeter (cm); AL - Arm length (cm); SEMA - Eye muscle area slaughter; SEMF - Eye muscle fat slaughter; LC - Left carcass; RC - Right carcass; CCW - Half cold carcass weight (kg); HE - Hind End; HR-RS - Hindend without rump and sirloin; FE - Front end; TL - Tenderloin; Rump - Rump Cap; TS - Top Sirloin; BS - Bottom sirloin; EyeR - Eye of round; Knu - Knuckle; Top - Topside; Sil - Silverside; B - Bone; M - Muscle; F - Fat; Ph24H - pH after 24 hours; CS - Conformation Score.

Correlations C

	SW	DWG	REMA	REMF	RHF	RH	IW	IEMA	IEMF	IHF	IGMD	HCW	FCCW	KO%	CooL	Bone%
CS	0.72	0.65	0.54	-0.30	0.19	-0.14	0.61	0.57	0.55	0.24	0.74	0.73	0.74	0.64	0.07	-0.74
PM	-0.54	-0.40	-0.52	0.04	-0.05	0.27	-0.48	-0.65	-0.38	-0.31	-0.36	-0.59	-0.60	-0.47	-0.04	0.57
Tex	-0.44	-0.24	-0.46	-0.09	-0.22	0.12	-0.47	-0.47	-0.12	-0.35	-0.40	-0.46	-0.46	-0.49	-0.18	0.44
Marb	0.03	-0.02	-0.32	-0.24	-0.58	0.45	0.01	0.05	0.03	0.28	-0.31	-0.05	-0.04	-0.18	-0.22	0.05
CL*	0.28	0.00	-0.10	-0.22	-0.04	-0.06	0.25	0.34	0.03	0.22	-0.18	0.20	0.19	-0.18	0.29	-0.15
Ca*	-0.01	-0.26	-0.06	0.27	-0.09	0.64	0.06	-0.10	-0.33	-0.30	-0.39	-0.03	-0.03	-0.14	0.03	0.03
Cb*	0.31	-0.12	-0.09	-0.44	-0.15	0.21	0.29	0.26	0.10	0.08	-0.40	0.23	0.23	-0.22	0.14	-0.20
CL	0.92	0.60	0.58	-0.09	0.03	0.20	0.84	0.75	0.31	0.46	0.58	0.89	0.89	0.69	0.41	-0.85
LL	0.76	0.44	0.44	0.11	0.03	0.46	0.73	0.54	-0.04	0.38	0.50	0.77	0.76	0.77	0.37	-0.78
LT	0.87	0.67	0.56	-0.14	0.12	0.13	0.74	0.68	0.36	0.41	0.54	0.88	0.87	0.77	0.44	-0.86
AP	0.91	0.45	0.69	-0.19	0.14	0.21	0.89	0.77	0.56	0.39	0.65	0.93	0.94	0.81	0.21	-0.94
AL	0.24	0.62	0.36	0.44	0.35	-0.23	0.13	0.03	-0.27	-0.04	0.64	0.26	0.25	0.45	0.41	-0.25
SEMA	0.84	0.37	0.61	-0.28	0.01	0.09	0.81	0.88	0.61	0.44	0.42	0.85	0.85	0.61	0.17	-0.82
SEMF	0.00	0.17	-0.14	0.20	0.14	-0.25	-0.04	0.12	0.00	0.28	0.30	0.03	0.02	0.21	0.42	0.03
LC	0.99	0.59	0.74	-0.07	0.19	0.24	0.93	0.79	0.39	0.31	0.63	1.00	1.00	0.82	0.29	-0.99
RC	0.99	0.61	0.74	-0.04	0.21	0.25	0.92	0.77	0.35	0.29	0.62	1.00	1.00	0.82	0.33	-0.99
CCW	0.99	0.59	0.74	-0.08	0.19	0.25	0.93	0.79	0.38	0.30	0.62	1.00	1.00	0.81	0.27	-0.99
HE	0.99	0.60	0.71	-0.02	0.17	0.31	0.92	0.77	0.28	0.29	0.60	0.99	0.99	0.81	0.35	-0.98
HR-RS	0.97	0.57	0.69	0.00	0.20	0.37	0.92	0.73	0.26	0.23	0.59	0.98	0.98	0.81	0.36	-0.98
FE	0.96	0.56	0.76	-0.14	0.21	0.18	0.92	0.79	0.48	0.30	0.63	0.98	0.99	0.80	0.18	-0.98
TL	0.91	0.54	0.60	0.10	0.23	0.46	0.86	0.66	0.17	0.23	0.59	0.92	0.91	0.83	0.45	-0.92
Rump	0.92	0.67	0.65	-0.10	0.14	0.17	0.81	0.68	0.23	0.27	0.52	0.92	0.92	0.72	0.40	-0.92
TS	0.94	0.56	0.71	0.02	0.26	0.36	0.90	0.69	0.24	0.18	0.63	0.95	0.95	0.82	0.31	-0.96
BS	0.92	0.67	0.76	-0.06	0.25	-0.01	0.83	0.76	0.43	0.35	0.68	0.94	0.93	0.78	0.35	-0.92
EyeR	0.95	0.61	0.69	0.07	0.29	0.35	0.88	0.68	0.19	0.13	0.60	0.96	0.95	0.78	0.43	-0.96
Knu	0.96	0.57	0.72	0.02	0.27	0.35	0.91	0.71	0.28	0.21	0.61	0.97	0.97	0.81	0.33	-0.97
Top	0.86	0.57	0.69	0.01	0.23	0.34	0.82	0.66	0.22	0.08	0.59	0.87	0.88	0.76	0.08	-0.90
Sil	0.95	0.52	0.73	0.01	0.30	0.32	0.92	0.76	0.32	0.16	0.64	0.97	0.97	0.83	0.28	-0.98
B	0.72	0.47	0.49	0.31	0.37	0.50	0.69	0.40	-0.11	0.00	0.53	0.72	0.71	0.69	0.55	-0.73
M	0.92	0.46	0.75	-0.13	0.11	0.19	0.89	0.80	0.47	0.33	0.54	0.95	0.95	0.76	0.17	-0.94
F	0.87	0.49	0.65	0.11	0.15	0.23	0.85	0.70	0.10	0.35	0.52	0.85	0.85	0.65	0.34	-0.83

CS - Conformation score; PM - Physiological maturity score; Tex - Texture; Marb - Marbling; CL* - Carcass L*; Ca* - Carcass a*; Cb* - Carcass b*; CL - Carcass length (cm); LL - Leg length (cm); LT - Leg thickness (cm); AP - Arm perimeter (cm); AL - Arm length (cm); SEMA - Eye muscle area slaughter; SEMF - Eye muscle fat slaughter; LC - Left carcass; RC - Right carcass; CCW - Half cold carcass weight (kg); HE - Hind end; HR-RS - Hindend without rump and sirloin; FE - Front end; TL - Tenderloin; Rump - Rump cap; TS - Top sirloin; BS - Bottom Sirloin; EyeR - Eye of round; Knu - Knuckle; Top - Topside; Sil - Silverside; B - Bone; M- Muscle; F - Fat; SW - Slaughter weight (kg); DWG - Daily weight gain (kg/day); REMA - R*Eye muscle área;

REMF - R*Eye muscle fat; RHF - R*Hip fat; RH - R*Height; IW - Initial weight (kg); IEMA - Initial eye muscle area (cm2); IEMF - Initial eye muscle fat (cm); IHF - Initial hip fat (cm); IGMD - Initial gluteus medius depth; HCW - Hot carcass weight (kg); FCCW - Full cold carcass weight (kg); KO% - Kill out %; CooL - Cooling loss %;

3.3. Factor analyses

The greater the length of the carcass and the eye area of the muscle, the less the marbling (Figure 2.3). The length, the thickness of the leg and the conformation score are positively related to the arm length, and all are negatively related to the level of physiological maturity of the animal.

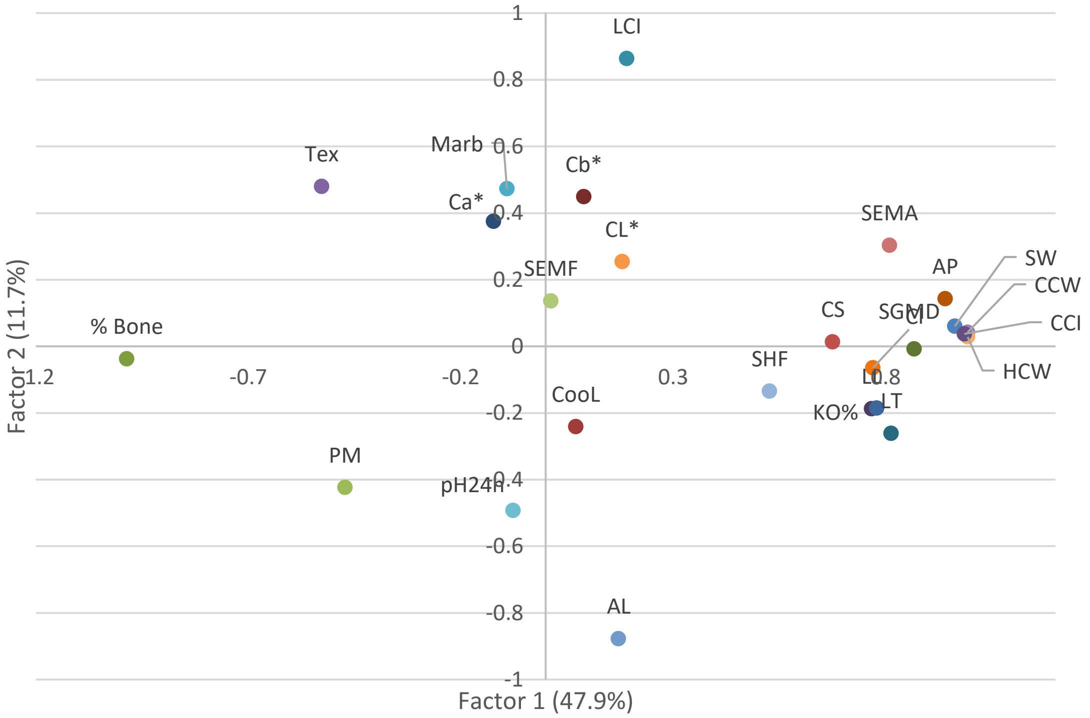


Figure 2.3. First two principal factors for carcass traits in Brazilian cattle breeds.

SEMA - Eye muscle area at slaughter; SEMF - Eye muscle fat slaughter; CL - Carcass length; Marb - Marbling; Ca* - Carcass a*; Cb* - Carcass b*; CL* - Carcass L*; PM - Physiological maturity score; AT - Arm thickness; LL - Leg length (cm); LT - Leg thickness (cm); CS - Conformation score; AL - Arm length (cm); AP - Arm perimeter; SHF - Slaughter hip fat; KO% - Kill out %; SGMD - Slaughter gluteus medius depth; SW - Slaughter weight; CCW – Half cold carcass weight; CCI - Carcass compact index; HCW - Hot carcass weight; Tex – Texture; LCI – Leg compact index; CooL – Cooling loss %.

There is a positive interference/relationship between initial weight and initial gluteus medius depth (Figure 2.4), daily weight gain, slaughter weight and eye muscle area. The eye muscle area is inversely related to the eye muscle fat, that is, the larger the muscle tissue, the smaller the adipose tissue.

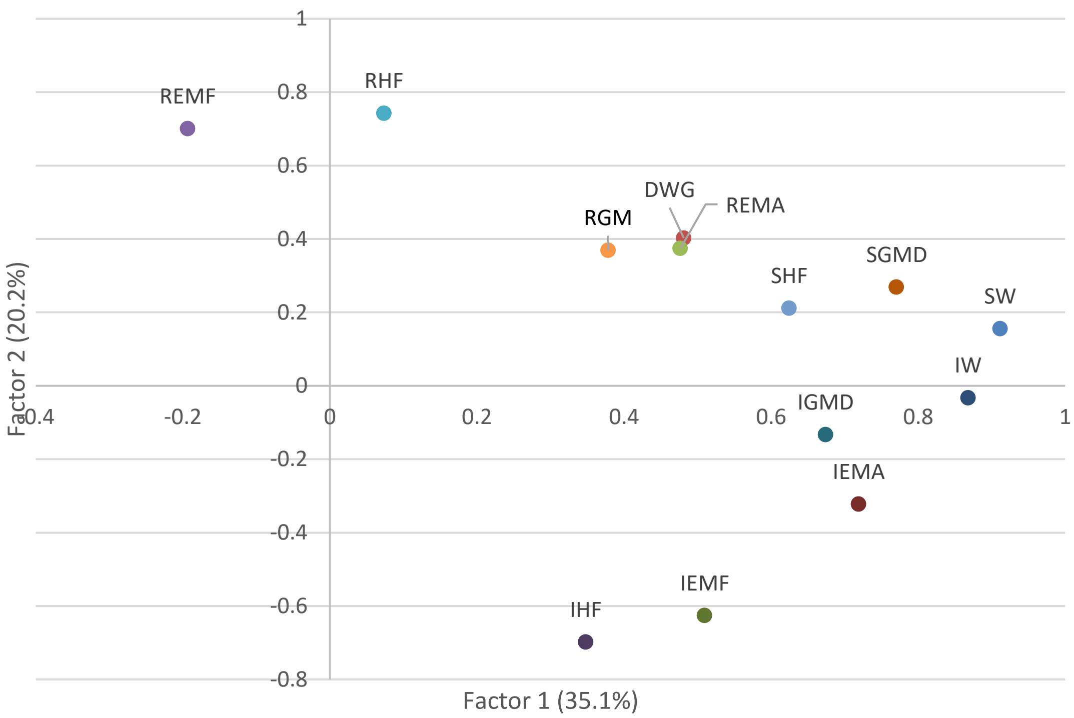


Figure 2.4. First two principal factors for growth traits in Brazilian cattle breeds.

SW - Slaughter weight; IW - Initial weight; DWG - Daily weight gain (kg/day); IEMA -Initial eye muscle area; REMA - Rate of growth of eye muscle area; IHF - Initial hip fat (cm); RHF - R*Hip fat; IEMF - Initial eye muscle fat (cm); REMF - R*Eye muscle fat; RGM - R*Gluteus medius; IGMD - Initial gluteus medius depth; SGMD - Slaughter gluteus medius depth; SHF - Slaughter hip fat.

In general, larger animals have heavier carcass cuts as expected. Nevertheless, in the second factor (Figure 2.5), a longer carcass length and proportion are reflected in smaller amounts of fats and bone composition. This finding was especially evident in Nelore cattle, which had more bone and less muscle. There is a strong relationship between the cuts silverside, topside and knuckle, but the relationship decreases for more noble cuts such as rump cap and filet.

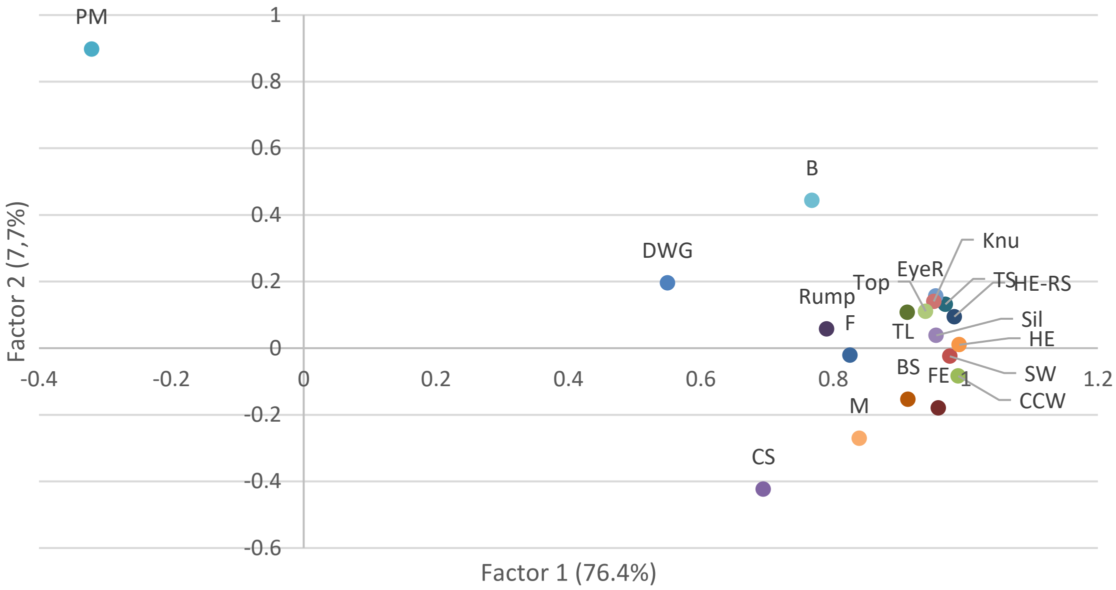


Figure 2.5. First two principal factors for weights of meats cuts and morphological measures in three Brazilian cattle breeds.

PM – Physiological maturity; DWG - Daily weight gain; M - Muscle; F - Fat; B - Bone; BS - Botton sirloin; Rump - Rump cap; Top - Topside; Sil - Silverside; TL – Tenderloin; EyeR - Eye of round; Knu - Knuckle; FE - Front end; SW - Slaughter weight; CCW - Half cold carcass; HE - Hind end; HE-RS - Hindend without rump and sirloin; TS – Topsirloin.

The higher the percentage of second quality cuts (Figure 2.6), the lower the percentage of prime cuts, as expected.

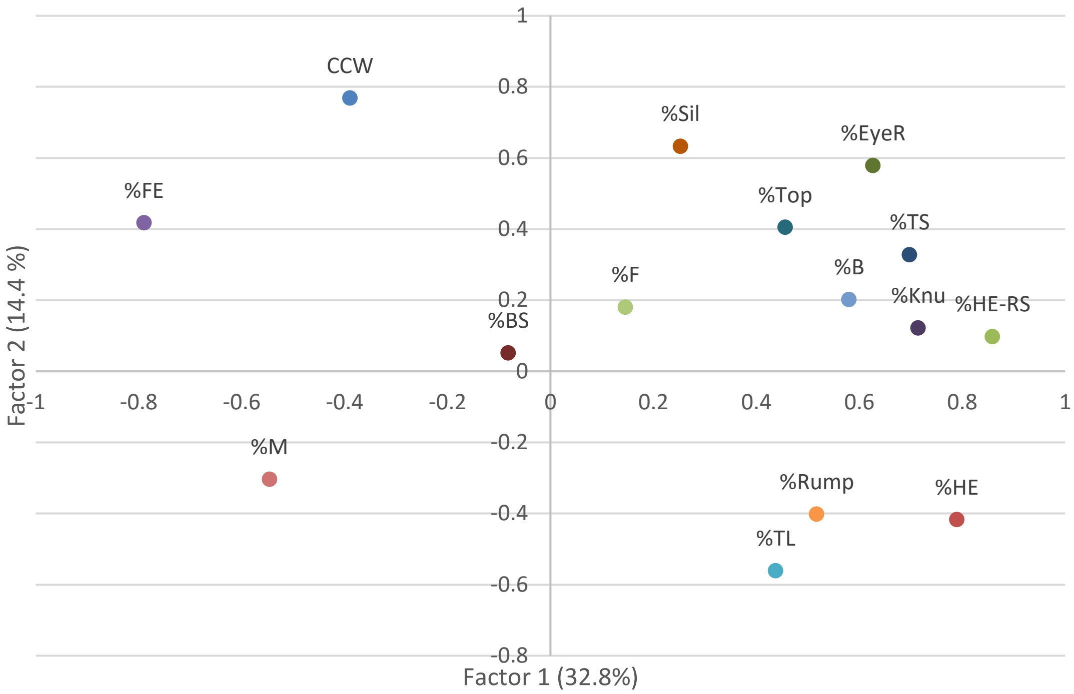
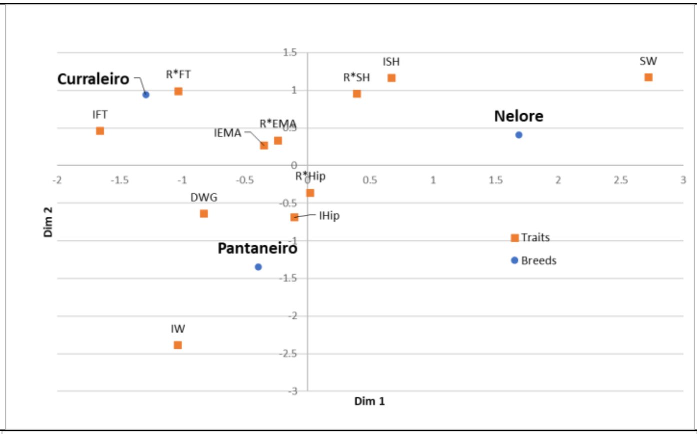
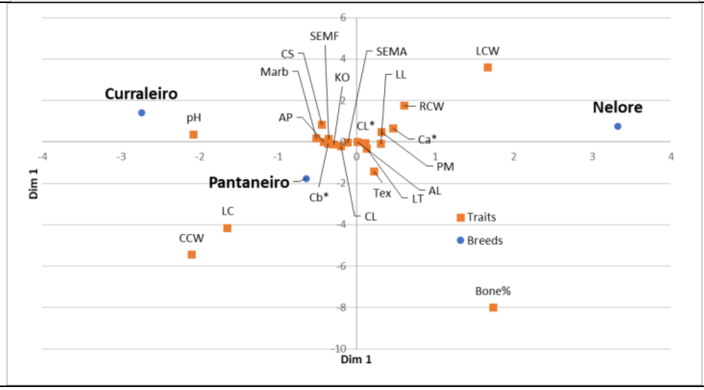


Figure 2.6. First two principal factors for percentages of different cuts of meat in locally adapted cattle.

CCW – Cold carcass weight; %FE - Percentage of front end; %M – Percentage of muscle; %F – Percentage of fat;%EyeR - Percentage of eye of round; %B – Percentage of bone; %BS - Percentage of botton sirloin; %Knu - Percentage of knuckle; %Sil - Percentage of silverside; %TS - Percentage top sirloin; %Top - Percentage of topside; %HE-RS - Percentage of hind end without rump and sirloin; %HE - Percentage of hind end; %Rump - Percentage of rump cap; %TL - Percentage of tenderloin.

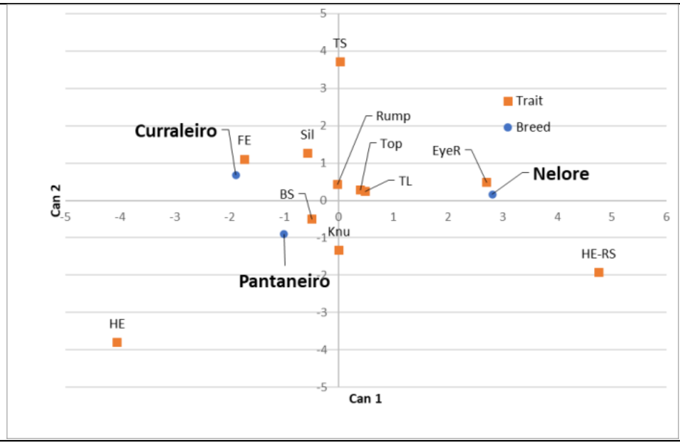
3.4. Discriminant and canonical analyses

In each of the discriminant analyses, the breeds were generally well defined within their specific group (Figure 2.7). Although Nelore was more linked to a heavier carcass, this seems to be related to bone percentages. Curraleiro, on the other hand showed increased fat deposition, with a heavier front end. The significant traits from step by step two breed discriminatory analysis are presented in Table 2.6.

<table>
<tr><th></th><th>Discriminant (% Classification)</th><th>Canonical Discriminant</th><th>Significant traits in stepwise discriminant analysis – all breeds</th></tr>
<tr><td>Initial and Slaughter Traits</td><td>
<table>
<tr><th></th><th>C</th><th>N</th><th>P</th></tr>
<tr><td>C</td><td>93.3</td><td></td><td>6.7</td></tr>
<tr><td>N</td><td>6.7</td><td>86.7</td><td>6.7</td></tr>
<tr><td>P</td><td>6.7</td><td>13.3</td><td>80</td></tr>
</table>
</td><td>
</td><td>Slaughter weight
Initial fat
Rate increase fat eye muscle area</td></tr>
<tr><td>Carcass Traits</td><td>
<table>
<tr><th></th><th>C</th><th>N</th><th>P</th></tr>
<tr><td>C</td><td>100</td><td></td><td></td></tr>
<tr><td>N</td><td></td><td>100</td><td></td></tr>
<tr><td>P</td><td></td><td></td><td>100</td></tr>
</table>
</td><td>
</td><td>Leg length
Physiological maturity
Slaughter fat EMA
Slaughter EMA
Carcass length
Conformation
CieLab a*
Bone percentage</td></tr>
</table>

Carcass Cuts

	C	N	P
C	93.3		6.7
N		93.3	6.7
P	14.3		85.7



Hind end
Hind end without rump and sirloin
Front end
Top sirloin
Eye of round

Figure 2.7. Stepwise, discriminatory and canonical analyses with carcass traits in Brazilian cattle breeds

C - Curraleiro Pé-Duro; N – Nelore; P – Pantaneiro; R*FT - Rate of growth of fat thickness; IFT - Inicial fat; IEMA - Initial eye muscle area (cm^2); R*EMA - Rate of growth of eye muscle area; R*Hip - Rate of growth of hip height; DWG - Daily weight gain (kg/day); IHip - Initial hip height; IW - Initial weight (kg); R*GM - Rate of growth of gluteus medius; ISH - Inicial shoulder height; SW - Slaughter weight (kg); SEMF - Eye muscle fat slaughter; SEMA - Eye muscle area slaughter; CS - Conformation score; Marb - Marbling; AP - Arm perimeter (cm); KO - Kill out; LC - Left carcass; CCW - Half cold carcass weight (kg); CL* - Carcass L*; Ca* - Carcass a*; Cb* - Carcass b*; CL - Carcass length (cm); LL - Leg length (cm); RCW - Right carcass weight; LCW - Left carcass weight; PM - Physiological maturity score; AL - Arm length (cm); LT - Leg thickness (cm); Tex - Texture; EMA - Eye muscle área; TS - Top sirloin; FE - Front end; Sil - Silverside; BS - Bottom sirloin; HE - Hind end; Knu - Knuckle; Rump - Rump cap; Top - Topside; TL - Tenderloin; EyeR - Eye of round; HE-RS - Hindend without rump and sirloin

Table 2.6. Significant traits from step by step two breed discriminatory analysis

	Pantaneiro vs Curraleiro	Pantaneiro vs Nelore	Curraleiro vs Nelore
Initial and Slaughter Traits	R*Fat EMA Initial weight Initial fat	R*Height Initial height Initial fat	Initial weight Initial hip height
Carcass Traits	Conformation Carcass length CL* Arm length	Leg length Physiological maturity Slaughter EMA Killout % pH 24 h Conformation Carcass length Leg thickness	Leg length Fat EMA slaughter Conformation Leg thickness
Carcass Cuts	Rump Hind end Front end	Eye of round Hind end Hind end without rump and sirloin Front end	Eye of round Hind end Hind end without rump and sirloin

R*fat EMA - R*eye muscle fat; CL* - Carcass L*; R*height – Rate of growth of height.

3.5 Correspondence analyses

Curraleiro Pé-Duro and Nelore breeds showed a more heterogeneous pattern of conformations and physiological maturity than Pantaneiro (Figure 2.8).

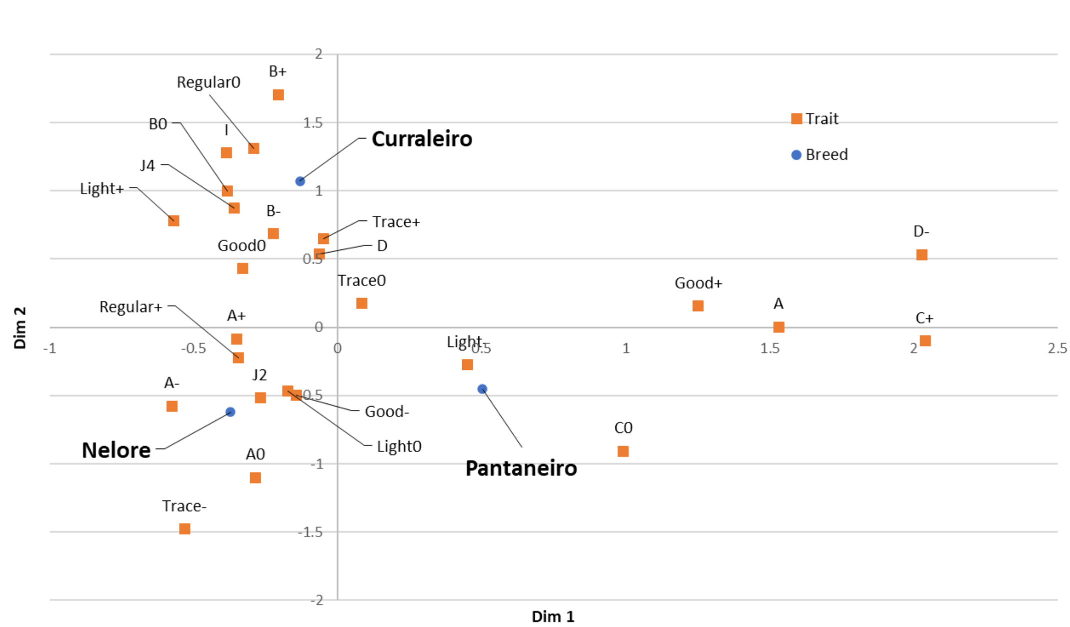


Figure 2.8. Correspondence analysis for qualitative carcass traits (conformations and physiological maturity) in Brazilian cattle breeds.

Conformation: 12- very good+; 11- very good; 10- very good-; 9- good+; 8- good; 7- good-; 6- regular+; 5- regular; 4- regular-; 3- bad+; 2- bad and 1- bad-. Physiological maturity (cartilage ossification scale) where A: animal between 9 to 30 months, B: 30 to 42 months, C: 42 to 72 months, D: 72 to 96 months and E: over 96 months; (+, 0 and -, - being younger and + being older). SIF Age: D = Male or female bovine with teething milk without falling from the clamps; J2 = Young male or female bovine with two permanent incisor teeth (tweezers), without falling from the first average s of the first dentition; J4 = Young male or female bovine with four permanent incisor teeth (forceps and 1 ° averages), without dropping the second average of the first dentition; I = Male or female cattle with more than four and up to six permanent incisor teeth, without falling from the corners of the first dentition; A = Male or female cattle with more than six incisor teeth in the second dentition.

4. DISCUSSION

The locally adapted cattle breeds used in the study have not undergone any genetic selection program. These breeds are usually reared in extensive systems and often adverse conditions, with scarcity of food and water and under high environmental temperature (Cardoso et al., 2016). Unlike the animals in this study, Britto (1987) stated that the Curraleiro is a small animal, weighing 380 kg for males and 300 kg for females. The slaughter weight observed in the present study showed that Curraleiro Pé-Duro can be much larger, with weights on average 452 kg after they were kept in a feedlot for 112 days.

Nelore, although raised predominantly in Brazil, has a global impact on the beef market considering that the country is one of the largest beef producers and exporters in the world. The breed has selection reports from the 1950s and has been subjected to genetic improvement programs for at least 40 years (Carvalheiro, 2014), leading to improvement in meat quality traits (Zuin et al., 2012; Magalhães et al., 2019). Even in the Pantanal (Oliveira et al., 2021) or Cerrado (Façanha et al., 2014), these locally adapted breeds are not considered for production or crossbreeding due to their perceived inferiority.

McManus et al. (2002) found that Pantaneiro had higher reproductive success than Nelore in similar conditions in the Pantanal. In a comparative study of the development of Pantaneiro and Nelore calves, under similar environmental conditions in the Pantanal, Santos et al. (2005) showed that despite the lower birth weight of Pantaneiro, calves of this breed had greater body length at birth than Nelore. At Santos et al. (2005) experiment, daily weight gain was similar for Pantaneiro (0.389 kg/day) and Nelore (0.383 kg/day). Such findings led the authors to conclude that studies on the efficiency of weight gain in naturalized breeds should be better evaluated. In addition to the productive advantages presented by Pantaneiro, meat is not the only product appreciated by local consumers. Nicola cheese is a traditional local product from the Pantanal, made with milk from Pantaneiro's cows, which expresses its own protein and fat characteristics (FAO, 2015).

Comparing the daily weight gain of Nelore, Curraleiro and Pantaneiro, they are related to the initial weigh. However, despite Nelore having a higher initial weight, the daily weight gain was similar for the three breeds. While there are no differences in weight at slaughter, there is a difference in weight distribution in the animal's body. Under similar management and with a supply of higher quality food, all three breeds showed good carcass finishing and a similar pattern of marbling. The relationship between concentrate supply and increased marbling (Strachan et al., 1993; Duckett et al., 2013; Rutherford et al., 2020) suggests that the improvement in the productive capacity of local breeds is an aspect that, when observed, confers desirable characteristics of the carcass and meat of these animals. Although there is no difference between slaughter weight and daily weight gain, Nelore had higher bone percentage and lower muscle percentage when compared to Curraleiro Pé-Duro and Pantaneiro, giving a lower carcass yield.

According to Cardoso et al. (2019), carcass yield and quality are important factors in assessing animal performance. The findings observed in the present study differed from those found by Lorenzoni et al. (1984) and Peron et al. (1993), who in comparative studies observed that European breeds showed higher yield in typically carcass cuts than Zebu. Costa et al. (2007), comparing Nelore and crossbred animals (Nelore x Holstein) did not observe a statistical difference in carcass yield. Carmo et al. (2017) defended that the beef carcass must provide maximum amount of muscle, minimum of bone, and a quantity of fat in line with consumer preference. In the present study, a higher percentage of bone was found in Nelore compared to Pantaneiro.

Economically, a higher yield of special hindquarters is more desirable concerning other cuts, as it is a region with a greater predominance of noble cuts (Luz et al., 2019). The cuts in which the Nelore had a higher percentage of weight, despite belonging to the back, are considered non-noble cuts. This demonstrates that, although they are not regarded as commercial breeds, Curraleiro Pé-duro and Pantaneiro have similar characteristics to Nelore, an important factor to promote their use in commercial meat production. Therefore when subjected to controlled food supply conditions, the breeds Curraleiro Pé-Duro and Pantaneiro can express their potential, becoming economically competitive.

Another factor of supposed influence on similar feed conversion may have been the thermoregulation capacity of these animals. Santos et al. (2005) and Barbosa et al. (2014)

found that both Nelore and Pantaneiro showed similar physiological characteristics and tolerance to heat. Cardoso et al. (2016) observed that Curraleiro Pé-Duro is a breed well adapted to challenging heat situations, and when compared to Nelore, the former presented lower rectal and surface temperatures.

Carvalho et al. (2013) observed that Curraleiro Pé-Duro cattle raised on pasture in the state of Piauí without supplementation, but with access to water and mineral salt salt *ad libitum*, presented variable average weight gain according to time of year and quality of pastures and suggested that animals with additional food supply could perform better. This was confirmed in the present study where animals of the Curraleiro Pé-Duro breed, when placed in feedlot with a diet containing concentrate, forage, mineral salt and water *ad libitum*, despite initially presenting significantly lower live weight than that of Nelore, had a weight gain during the confinement that led to non-significant differences in the slaughter weights of the two breeds.

In a comparative study, Cooke et al. (2020) reported that *B. taurus* grazes for less time than *B. indicus* and gains less weight until weaning but has greater average daily weight gain when in feedlot. Such facts can explain the divergent values found in the present study and by Britto (1987), whereby Curraleiro Pé-Duro managed to convert its lower initial weight to a final weight within the average of other breeds.

The colour of the meat, defined by the presence of pigments, is also dependent on tissue composition and muscle structure (Weglarz, 2010). The pigment myoglobin is responsible for the colour of the meat that, when exposed to air, forms the most intense red-coloured oxymyoglobin complex. Continuous exposure causes the colour to turn brownish red, reddish brown, and brownish-green (Pearson & Dutson, 1994). In an experimental study in which luminosity and marbling tests were compared to results observed in the sensory panel, Jackman et al. (2009) obtained results showing that the colour and marbling characteristics of the *longissimus thoracis* provide reliable information on the quality of beef.

For the studied breeds there was no significant difference for these parameters, which can be inferred that they were qualitatively similar. The values for lightness (L*) and redness (a*) are marginally lower than those reported by Muchenje et al. (2009) while yellowness (b*) is within the range reported. According to these authors the yellow colour comes from beta-carotene contained in forages. Low L* values may be caused by increased myoglobin, decreased muscle glycogen, or both, as well as yellow fat (Priolo et al., 2001).

While average carcass pH at 24 hours after slaughter were within ranges seen by other authors, whereby a value ≤5.8 is desirable (Viljoen et al., 2002; Wulf et al., 2002), although range values here (Table 2.2A) shows that some animals show higher values. This may be a higher variability for a non-selected trait. No significant differences were seen between breeds.

Despite the recommendations of Blackburn et al. (1998), the local breeds showed no differences concerning conformation and marbling compared to the commercial breed. A similar pattern of conformation between locally adapted breeds and *B. indicus* can be explained by the fact that although these animals adapt well to tropical and subtropical regions, they usually present carcasses with less marbling than *B. taurus* cattle, mainly because of a reduction in the volume of intramuscular adipocytes (Cooke et al., 2020) as a mechanism to improve your thermotolerance.

5. CONCLUSIONS

The locally adapted *Bos taurus ibericus* breeds, when subjected to adequate environmental and dietary conditions, showed great productive potential. There was no difference in daily weight gain and in slaughter weights between the breeds, although Curraleiro Pé-Duro had a lower initial weight when compared to Nelore, a difference that that no longer existed after the confinement period. Nelore and Curraleiro deposited more fat than Pantaneiro, Curraleiro and Pantaneiro had more muscle than Nelore, which also had more bone and a higher percentage of poor-quality cuts.

The fact that local animals have not gone through genetic improvement programs, together with the results found, demonstrate that Curraleiro Pé-Duro and Pantaneiro may have their desirable characteristics enhanced if genetic improvement programs are adopted. These animals can have an economically viable production, in addition to generating attractive products for new market niches.

6. ACKNOWLEDGEMENTS

Thanks are due to CAPES for scholarships as well as CNPq and FAPEG for financing.

7. CONFLICT OF INTEREST

No conflict of interest could be identified in this study.

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9. ATTACHMENTS

9.1. Canonical correlations

Correlations Between the VAR Variables and Their Canonical Variables		Correlations Between the VAR Variables and Their Canonical Variables		Correlations Between the VAR Variables and the Canonical Variables of the WITH Variables		Correlations Between the WITH Variables and the Canonical Variables of the VAR Variables	
	V1		**W1**		**W1**		**V1**
SW	1.00	CS	0.66	SW	1.00	CS	0.66
DWG	0.55	PM	-0.41	DWG	0.55	PM	-0.41
R*EMA	0.42	Tex	-0.41	R*EMA	0.42	Tex	-0.41
R*EMF	-0.07	Marb	0.01	R*EMF	-0.07	Marb	0.01
R*HF	0.10	CL*	0.28	R*HF	0.10	CL*	0.28
R*RH	0.49	Ca*	-0.08	R*RH	0.49	Ca*	-0.08
IW	0.90	Cb*	0.17	IW	0.90	Cb*	0.17
IEMA	0.65	CL*	0.88	IEMA	0.65	CL*	0.88
IEMF	0.33	LL	0.76	IEMF	0.33	LL	0.76
IHF	0.27	LT	0.77	IHF	0.27	LT	0.77
IGMD	0.46	AP	0.91	IGMD	0.46	AP	0.91
		AL	0.16			AL	0.16
		SEMA	0.75			SEMA	0.75
		SEMF	0.02			SEMF	0.02
		LC	0.97			LC	0.97
		RC	0.98			RC	0.98
		CCW	0.98			CCW	0.97
		pH	-0.09			pH	-0.09
		KO%	0.60			KO%	0.60
		CL	0.14			CL	0.14
		Bone%	-0.96			Bone%	-0.96
	V1		**W1**		**W1**		**V1**
SW	0.79	HE	0.83	SW	0.79	HE	0.83
DWG	0.29	HR-RS	0.80	DWG	0.29	HR-RS	0.80
R*EMA	0.43	FE	0.84	R*EMA	0.43	FE	0.84
R*EMF	-0.19	TL	0.74	R*EMF	-0.19	TL	0.74

R*HF	0.22	Rump	0.57	R*HF	0.22	Rump	0.57
R*RH	0.23	TS	0.78	R*RH	0.23	TS	0.78
IW	0.89	BS	0.84	IW	0.89	BS	0.84
IEMA	0.73	EyeR	0.76	IEMA	0.73	EyeR	0.76
IEMF	0.40	Knu	0.80	IEMF	0.40	Knu	0.80
IHF	0.13	Top	0.76	IHF	0.13	Top	0.76
IGMD	0.66	Sil	0.84	IGMD	0.66	Sil	0.84
		B	0.55			B	0.55
		M	0.75			M	0.75
		F	0.64			F	0.64
		pH24h	-0.06			pH24h	-0.06

Figure A2.1 – Canonical correlations

CHAPTER 3

LOCAL BRAZILIAN CATTLE BREEDS: MEAT QUALITY IN

ABSTRACT

Brazilian meat production is based on *Bos taurus indicus* Nelore cattle, that tend to show poorer meat quality when compared to *Bos taurus taurus* breeds. As there is little information on comparisons with *Bos taurus ibericus* breeds, the aim of this study was to compare meat quality between two local breeds (Curraleiro-Pé-Duro and Pantaneiro) Nelore breed, reared under the same conditions. Fifteen 30-month-old steers of each breed were reared in a feedlot for 112 days. After slaughter, meat was examined for quality parameters and evaluated for degree of pH, shear force, water holding capacity, colour, fatty acid profile and sensory analysis in which texture, succulence and palatability were analysed. Statistical analyses were carried included analysis of variance (PROC GLM), correlations (PROC CORR) and multivariate analyses, including discriminant (PROC STEPDISC, DISCRIM) and canonical (PROC CANCORR, CANDISC) analyses. Results showed that despite the higher live weight at slaughter of Nelore cattle, this breed had a higher percentage of bone in relation to Curraleiro Pé-Duro and lower percentage of muscle when compared to the other two breeds. Nelore also showed less succulence than Pantaneiro and more shear force than the other breeds. Pantaneiro's meat had the most capacity to retain water, lower shear force and was more succulent when compared to the other breeds, presenting a darker colour. In general, the fatty acid profile did not differ between breeds, with the exception of palmitic acid, which was higher in Curraleiro Pé-Duro. Locally adapted *Bos taurus ibericus* breeds show more desirable carcass and meat quality traits when compared with Nelore breed.

Key words: Bone, Curraleiro Pé-Duro, fatty acid, muscle, Nelore, Pantaneiro, softness, succulence, tenderness.

RESUMO

A produção brasileira de carne é baseada em bovinos *Bos taurus indicus*, principalmente no Nelore, que tendem a apresentar pior qualidade de carne quando comparada às raças *Bos taurus taurus*. Como há poucas informações sobre comparações com raças *Bos taurus ibericus*, o objetivo deste estudo foi comparar a qualidade da carne entre duas raças locais (Curraleiro-Pé-Duro e Pantaneiro), deste último grupo, com o Nelore, criadas nas mesmas condições. Quinze novilhos de 24 meses de cada raça foram criados em confinamento por 97 dias. Após o abate, a carne foi examinada quanto aos parâmetros de qualidade sendo avaliadas para grau de pH, força de cisalhamento, capacidade de retenção de água, coloração, perfil de ácidos graxos e análise sensorial na qual foram analisadas textura, suculência e palatabilidade. As análises estatísticas foram realizadas incluindo análise de variância (PROC GLM), correlações (PROC CORR) e análises multivariadas incluindo análises discriminantes (PROC STEPDISC, DISCRIM) e canônicas (PROC CANCORR, CANDISC). Os resultados mostraram que apesar do maior peso vivo ao abate do gado Nelore, parece haver uma relação com os valores encontrados para maior porcentagem de osso em relação ao Curraleiro Pé-Duro e menor de músculo quando comparado às outras duas raças. O Nelore também apresentou menos suculência do que o Pantaneiro e mais força de cisalhamento do que as outras raças. A carne do Pantaneiro foi a que mais reteve água, apresentou menor força de cisalhamento e foi mais suculenta quando comparada às demais raças, apresentando uma cor mais escura. Em geral, o perfil de ácidos graxos não diferiu entre as raças, com exceção do ácido palmítico que foi maior no Curraleiro Pé-Duro. As raças localmente adaptadas *Bos taurus ibericus* apresentaram características de carcaça mais desejáveis e melhor qualidade de carne quando comparadas com a Nelore.

Palavras-chaves: Ácidos graxos, Curraleiro Pé-Duro, maciez, músculos, Nelore, ossos, Pantaneiro, suculência.

1.INTRODUCTION

Agrobiodiversity is one of the pillars of Brazil's position of one of the major exporters of agricultural products worldwide, and the primary beef exporter (Ermgassen et al., 2020) with more than 22% of the world herd (Zia et al., 2019). Ferraz & Felicio (2010) and Lobato et al. (2014) describe the main beef production systems in Brazil. While zebu (*Bos taurus indicus*) cattle are the main beef breed, several locally adapted *Bos taurus ibericus* breeds (such as Curraleiro-Pé-Duro and Pantaneiro) have been shown to be well adapted (McManus et al., 2009; McManus et al., 2011; Silva et al., 2015; Cardoso et al., 2016; McManus et al., 2016) to the poor pastures and stressful environmental conditions where most of these beef breeds are reared (McManus et al., 2016). These genetic resources have been seen to be genetically distinct (Egito et al., 2007; Souza et al., 2022), and a possible source of alternative income for farmers (Neiva et al., 2011, Felix et al., 2013).

After the animal's death, a series of metabolic changes start and promote the transformation of muscle into meat. Meat consists mainly of proteins and lipids (Lacerda et al., 2014). Fatty acids, present in lipids in different forms, are influenced by sex (Webb et al., 1998), breed (Bianchi et al., 2003), slaughter weight (Pérez et al., 2002 Santos-Silva et al., 2002) and age.

Parameters such as colour (Mancini & Hunt, 2005), tenderness and fatty acid profile of meat are important in determining meat quality and have implications for human health (Wood et al., 2008). The tenderness of meat, despite being one of the attributes most appreciated by consumers and an important aggregator of value, is an extremely variable characteristic (Destefanis et al., 2008). Meat tenderness is related to changes in meat tissue components and the weakening of myofibrils (Warris, 2000).

Many studies showed an association between marbling and sensory characteristics such as tenderness, palatability, flavour and juiciness (Okumura et al., 2007;

Warner ; et al., 2010; Iida et al., 2015; Shahrai et al., 2020). Among the forms of evaluation of tenderness, there are the objective and the subjective ones, such as the random sensory panel. The Warner-Bratzler shear force is an objective methodology that assesses how tender the meat is (Destefanis et al., 2008).

B. indicus cattle have been shown to accumulate higher amounts of saturated fatty acids (SFA) than *B. taurus*, especially in intensive finishing systems (Bressan et al., 2011). On the other hand, Rossato et al. (2010) found Nelore beef less tender than Angus when reared at pasture and with lower cholesterol levels. They also had higher n−3 fatty acids and conjugated linolenic acid (CLA) contents, but the omega-6 to the omega-3 ratio (n−6/n−3) did not differ and was below the average (1.73).

Several studies have been carried out comparing the meat quality of the *Bos taurus indicus* (Nelore, Brahman) with *Bos taurus taurus* breeds such as Angus (Martins et al., 2015; Pereira et al., 2015; Rodrigues et al., 2017), Wagyu (Dias et al., 2016), Senepol (Schatz et al., 2020), Hereford and Caracu (Mendonça et al., 2021), composites such as Canchim (Giusti et al., 2013) or crossbreds (Bressan et al., 2016). While the locally adapted Curraleiro Pé-Duro (shortened to Curraleiro) and Pantaneiro breeds have adapted to the environment over 500 years, more information is available on characteristics such as growth and meat quality as from crossbreeding experiments (Carvalho et al., 2015; Rodrigues et al., 2018; Afonso et al., 2020).

The aim of the present study was to compare meat quality of locally adapted *Bos taurus ibericus* Curraleiro Pé-Duro and Pantaneiro steers with *Bos taurus indicus* Nelore raised under feedlot conditions.

2.MATERIAL AND METHODS

Animal care throughout the study followed animal welfare protocols for animal production. *In vivo* invasive procedures were not performed and the animals were slaughtered for commercial purposes with subsequent analysis performed.

Fifteen 30-month-old steers of each of three breeds (Curraleio Pé-Duro, Pantaneiro and Nelore) were kept in a feedlot, at the Veterinary School of the Federal University of Goiás, for 112 days of experiment after 21 days of adaptation (Figure 3.1). Curraleiro Pé-Duro came from two herds. Six animals were acquired from a breeder in the municipality of Monte Alegre-GO and nine from a breeder in the municipality of Mimoso-GO. The Pantaneiro and the Nelore both were originated from a single herd. Pantaneiro animals were acquired from the Conservation Nucleus of the Pantaneira breed of Embrapa. Nelore animals came from a breeder in the region of Petrolina-GO. Curraleiro Pé-Duro and Pantaneiro cattle used in the study had not gone through any selection process to improve their productive qualities.

Figure 3.1 - Curraleio Pé-Duro, Pantaneiro and Nelore used in the study.

The animals received a balanced diet, twice a day, according to their requirements, following the recommendations of the National Research Council – NRC (1996).

The diet had 70% of the nutrients from concentrate and 30% from roughage (sorghum silage), considering the consumption orts of 5% to 10%. Mineral salt and water were provided *ad libitum*. Total digestible nutrients (NDT) were provided at 74.30%, with minimum crude protein of 15% and calcium, phosphous, sodium, potassium and magnesium where included in the ratio's macronutrients.

At the begining of the experiment, animals were weighed (IW) and then every 14 days until the day before slaughter. The animals were slaughtered after a 24 hour fast on three dates, with one-third of each genetic group in each group. The animals were slaughtered in an abattoir with federal inspection in Palmeiras de Goiás. After slaughter, the animals were bled out, the viscera and internal organs, feet, tail, skin and head were removed. The half carcasses were weighed to obtain the hot carcass weight (HCW). Carcasses remained in a cold chamber for 24 hours at 4°C and were weighed again to determine the weight of the cold carcass (CCW). From each right cooled half-carcass, the *Longissimus thoracis* was cut between the 11^{th} to 13^{th} ribs, called HH section (Hankins e Howe, 1946). The evaluations of the eye muscle area (EMA) and fat thickness (FT) were carried out on the left carcass through a cross section between the 12^{th} and 13^{th} rib. Experimental details on the farm and even the slaughter described above are the same ones adopted by Barbosa et al., submitted.

The HH was divided in two subsamples of approximately 8cm wide each, which were identified, vacuum packed and frozen immediately for subsequent determination of i) the percentages of muscle, bone, fat and meat quality and ii) fatty acid (FA) profile. The frozen samples from the HH section were slowly thawed for evaluation of tissue composition of the carcass. pH using a pH meter (Model HI 99163, Brand Hanna, Brazil), and colour of the meat was evaluated. CieLab colour space was determined on the carcass and the section of the 12^{th} rib to determine L* (luminosity), a* (green to red spectrum) and b* (blue to yellow spectrum) using a Minolta CR-300 (Osaka, Japan).

The percentage of bone, muscle and fat was determined, after the physical separation of these components, according to the technique described by Hankins & Howe (1946), adapted by Müller et al. (1973). The proportion of muscle, adipose tissue and bones in the carcass was estimated based on the proportions of these components in the HH section, using the equations described below (where X is the percentage of the component of the HH section), developed by Hankins and Howe (1946):

(%M) Muscle: $Y = 16.08 + 0.80 X$

(%F) Fat tissue: $Y = 3.54 + 0.80 X$

(%B) Bone: Y = 5.52 + 0.57 X

Losses in the thawing and cooking process were determined in the same frozen samples and were carried out consecutively. To determine the water holding capacity of the meat, 2.5 cm thick steaks were extracted from the cranial portion of the *Longissimus thoracis*. The steak was weighed frozen (FZ), then placed on racks and thawed under refrigeration at a temperature of 7°C for 24 hours. The steaks were weighed again (T) to determine drip losses, which were expressed as a percentage of the initial weight (Qthaw) according to the methodology cited by Arboitte et al. (2011). After weighing, thermometers with a metallic penetration sensor were inserted into the geometric centre of the samples and placed in a pre-heated (170°C) oven. The samples were turned over when they reached 40^{o}C, allowing for uniform cooking, until the core temperature of the samples reached 71°C (15 minutes) and then removed (Wheeler et al., 1994). The samples were weighed to determine cooking loss (Qcook) and allowed to cool at room temperature (25°C) and refrigerated at 7^{o}C for 24h.

All samples were roasted in stainless steel trays, on a grill, and the weights noted before and after cooking. The trays allowed the evaluation of weight losses due to dripping and evaporation losses. Losses in the cooking process were obtained by the difference in weight before and after cooking (C) the steaks. Losses were expressed as a percentage of initial weight. The total loss was also calculated considering the sum of the drip and cooking losses (Qtot). The samples of *Longissimus thoracis* were baked in an electric oven at 170^{o}C, with two heat sources (upper and lower oven resistance), at a distance of 20cm between the two parts.

Shear force (SF) was determined on roasted steaks after cooling for 24 hours at 7^{o}C. Six to eight cylinders of 12.7 mm diameter per steak were extracted, with a pourer coupled to a drill in an iron support adapted for this function, which were cut perpendicularly to the fiber with an angle of 45° and diameter of 2 cm each, to determine the tenderness of the meat by measuring the shear force in kgf^2, using the Warner-Bratzler Meat Shear equipment (Zwick GmbH&Co. KG, Ulm, Germany) equipped with a cutting blade with a thickness of 1.016 mm and a load speed of approximately 20 cm per minute and a load capacity of 25 kgf cm^{-2}, considering the average of all readings after disregarding the maximum value (Arboitte et al., 2011).

Fatty acid determination was carried out on samples removed from the centre of the tenderloin dried in a lyophilizer for 48 hours. Fatty material was extracted with a mixture of chloroform and methanol, according to Bligh & Dyer (1959), and modified by Tullio (2004). The fatty acid composition was determined in a high-resolution gas chromatograph with a SP-

2560 capillary column, 100m long and 0.25 mm diameter, coupled with a flame ionization detector. The initial programmed temperature was 130º C for 1 minute, after which was raised to 170ºC at 6.5ºC/minute. Then it was raised to 215ºC at 2.75ºC/minute and maintained for 12 minutes. A final temperature rises from 215 to 230ºC was carried out at 40ºC/minute. The injector and detector temperatures were 270 and 280ºC, respectively, and 0.3 mL samples were injected in Split mode using hydrogen as a carrier gas. The identification of the methylated esters of the fatty acids was by comparing retention times with SIGMA fatty acid methyl ester mixture standards 189-19.

Meat quality and taste characteristics were measured in a sensorial panel trained by Embrapa Gado de Corte, Mato Grosso do Sul, using Dutcosky (2007) methodology. A hedonic scale from 1 (worst) to 9 (best) was used to evaluate texture, succulence and palatability. Prior to the analysis, the HH subsection samples were defrosted at 4 °C inside a standard refrigerator for 24h. A 5% common salt (NaCl) solution was added. After roasting, each sample was cut into portions, of approximately 20 g each. The samples were heated at the maximum potency in a microwave oven, for 30 seconds, to reach temperatures ranging from 45 °C to 50 °C. The heated samples were subjectively evaluated into an individual cabin, under white light.

Statistical analyses were carried out using SAS® v.9.3 (Statistical Analysis System Institute, Cary, North Carolina) included analysis of variance (PROC GLM) with fixed effected including breed as well as date of slaughter and initial/final weight on test used as a covariate. Correlations (PROC CORR) were calculated. Multivariate analyses included principal factor analyses (PROC FACTOR), discriminant (PROC STEPDISC, DISCRIM) and canonical (PROC CANCORR, CANDISC) analyses.

3.RESULTS

Means, variation, and ranges for the traits measured in this experiment are seen in Table 3.1. The animals in this study had a higher percentage of saturated than unsaturated fatty acids.

Table 3.1. Mean, standard deviation, minimum and maximum values for traits evaluated in three Brazilian cattle breeds.

Variable	Abbreviation	Mean	Std Dev	Minimum	Maximum
Fatty acids*					
Total fatty acids	TFA	0.03	0.02	0.01	0.07
C10:0		71.99	17.71	31.13	100.15
C12:0		4.66	8.40	0.00	43.49
C14:1		1.47	2.81	0.00	8.50
C15:0		1.08	3.09	0.00	13.12
C16:0		5.01	7.42	0.00	22.21
C16:1		0.29	1.31	0.00	6.07
C18:0		2.88	4.26	0.00	15.55
C20:2		3.81	6.50	0.00	30.88
C20:5n3		8.81	11.57	0.00	45.94
Saturated (%)	Sat	85.62	10.88	54.07	100.28
Unsaturated (%)	Unsat	14.38	10.88	0.00	45.94
Saturated/Unsaturated	Sat/Unsat	5.58	2.64	1.18	10.77
OMEGA3	n-3	18.06	10.63	4.78	45.94
Meat Cut characteristics					
Frozen (g)	FZ	239.63	49.34	160.50	379.40
Thawed (g)	T	224.12	46.30	152.50	356.40
Cooked (g)	C	160.48	39.03	98.50	253.50
Thawing loss %	Qthaw	0.0644	0.0224	0.0131	0.1123
Cooking loss %	Qcook	0.2879	0.0506	0.1349	0.3640

Total cooked %	Qtot	0.3335	0.0528	0.1906	0.4121
pH	pH	5.60	0.30	5.26	6.43
Length	Len	139.01	14.44	100.59	177.30
Width	Wid	64.01	7.12	50.16	90.74
Marbling 2	Marb2	2.24	0.43	2.00	3.00
Cut dissected					
Weight g	BMF	3.69	0.90	1.76	6.51
Bone %	%B	18.68	2.88	11.14	24.21
Muscle %	%M	55.55	4.04	45.31	68.16
Fat %	%F	25.77	3.54	17.08	32.24
Cut L*	L1	39.97	3.95	31.84	49.31
Cut a*	a1	22.52	2.27	18.55	27.07
Cut b*	b1	15.82	2.16	11.20	20.95
Shear force (kgf cm^{-2})	SF	8.51	2.61	1.72	13.41
Tenderness	Tend	5.70	1.18	3.83	8.67
Succulence	Succ	6.04	0.71	4.43	7.43
Palatability	Pal	6.07	0.64	4.83	7.83

[1]CIEL*a*b* colour space - L* (luminosity), a* (green to red spectrum) and b* (blue to yellow spectrum).

* - Values in percentage of the total fatty acid.

3.1 Analyses of variance

Nelore had a higher percentage of bone in the cut than Curraleiro (Table 3.2), and less muscle than both the other breeds. There was a significant difference of higher bone percentage of Nelore compared to Curraleiro and a lower muscle percentage when compared to Pantaneiro and Curraleiro.

The values found for Qthaw, Qcook and Qtot (Table 3.2), evidenced both after thawing and after cooking, demonstrate that Pantaneiro has a greater capacity to retain water than Curraleiro and Nelore. Curraleiro and Nelore retained water equally. Considering the pH, its initial value after slaughter was influenced by breed, with the Pantaneiro presenting the highest value.

Table 3.2. – Analysis of variance for cooking parameters and cut composition percentages in Brazilian cattle breeds.

	Qthaw	Qcook	Qtot	pH	pH24	%B	%M	%F	FZ	T	C
R^2	0.22	0.15	0.20	0.29	0.09	0.30	0.42	0.22	0.28	0.30	0.22
CV	32.23	16.99	14.84	4.67	3.03	14.21	6.09	13.39	15.29	15.91	19.38
Breed	*	*	**	**	ns	**	**	ns	0.06	0.06	0.06
Date	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
IW	0.08	ns	ns	ns	ns	**	ns	ns	ns	ns	ns
C	0.07^{a}	0.30^{a}	0.35^{a}	5.49^{b}	5.85	17.39^{b}	57.50^{a}	25.10	4.61	4.30	2.99
N	0.07^{a}	0.30^{a}	0.35^{a}	5.50^{b}	5.74	20.22^{a}	53.03^{b}	26.74	3.94	3.66	2.57
P	0.05^{b}	0.26^{b}	0.30^{b}	5.80^{a}	5.74	18.42^{ab}	56.12^{a}	25.46	4.39	4.17	3.09

R^2 – Coefficient of determination; CV – Coefficient of variation; IW – Initial weight; C – Curraleiro Pé-Duro; N – Nelore; P – Pantaneiro; Qthaw - Percentage of water lost in thaw; Qcook – Percentage of water lost in cooking; Qtot - Percentage of water lost in total; pH24 – pH after 24h; %B - Percentage of bone; %M - Percentage of muscle; %F - Percentage of fat; FZ - frozen; T - thawed; C - cooked weight.

Nelore meat showed higher luminosity, indicating a lighter coloured meat, while Pantaneiro had a darker meat (Table 3.4). Nelore had the cut more green than red when compared to Pantaneiro. Pantaneiro had the more succulent meat but this did not differ statistically (P>0.05) from the Curraleiro.

Shear force was significant for breed, Nelore meat had higher shear force than other breeds, followed by Curraleiro meat and then Pantaneiro, which had the lowest shear force. Nelore had higher initial weight when compared to Curraleiro Pé-Duro and, despite having higher weight at slaughter, the difference between breeds was not significant (Table 3.3).

Observing the values for tenderness, it is verified that they were significant for the breed, with the meat from Pantaneiro being the one with the greatest tenderness and juiciness when compared to the other two breeds, but this differed statistically only from the Nelore. It may also be noted that Nelore meat showed higher luminosity, indicating a lighter meat, while Pantaneiro had a darker meat.

Table 3.3. Analysis of variance for feedlot data and slaughter traits in Brazilian cattle breeds

	IW	SW kg	DWG kg/day
R^2	0.25	0.84	0.11
CV	19.56	1.96	23.04
Breed	***	0.07	ns
Date		ns	ns
IW		***	ns
C	264.8^{b}	452.22	1.48
N	346.8^{a}	475.46	1.66
P	316.2^{ab}	443.18	1.45

R^2 – Coefficient of determination; CV – coefficient of variation; IW – Initial weight; C – Curraleiro; N – Nelore; P – Pantaneiro; SW – slaughter weight; DWG – Daily weight gain (kg/day). Ns – not significant; * P<0.05; ** P<0.01; *** P<0.001; Different letters in the column indicate significant differences using the Tukey test (P<0.05).

Table 3.4. Analysis of variance for meat quality characteristics in Brazilian cattle breeds.

	Len	Wid	Marb	L1	a1	b1	SF	Tend	Succ	Pal
R^2	0.53	0.33	0.05	0.58	0.29	0.40	0.17	0.25	0.30	0.18
CV	7.46	9.52	19.67	7.00	9.42	11.67	29.40	18.77	10.34	10.01
Breed	ns	0.07	ns	***	0.06	***	*	*	***	ns
Date	*	ns	ns	ns	ns	*	*	*	ns	ns
IW	***	***	ns	ns	ns	ns	ns	ns	ns	ns
C	139.83	66.90	2.38	39.61^{b}	22.85	15.52^{ab}	8.44^{b}	5.73^{ab}	6.02^{ab}	5.97
N	136.33	60.66	2.16	42.98^{a}	23.24	17.20^{a}	9.51^{a}	5.41^{b}	5.57^{b}	5.90
P	140.87	64.48	2.19	37.29^{b}	21.46	14.72^{b}	7.55^{c}	5.94^{a}	6.52^{a}	6.32

R^2 – Coefficient of determination; CV – Coefficient of variation; IW – Initial weight; C – Curraleiro Pé-Duro; N – Nelore; P – Pantaneiro; Len – Length; Wid – Width; Marb – Marbling; L1 – Cut luminosity; a1 – Cut green to red spectrum; b1 - Cut blue to yellow spectrum; SF - Shear Force; Tend – Tenderness; Succ – Succulence; Pal – Palatability.

Table 3.5 Analysis of variance for fatty acid percentages in three Brazilian cattle breeds

	TFA	C10:0	C12:0	C14:1	C15:0	C16:0	C16:1	C18:0	C20:2	C20:5n3	Sat	Unsat	Sat/Unsat	Ω 3
R^2	0.28	0.35	0.09	0.38	0.11	*	Ns	ns	ns	ns	0.14	0.14	0.08	0.36
CV	50.89	20.89	180.69	157.72	283.71	98.37	371.21	147.27	177.82	130.91	12.41	73.79	48.38	52.58
Breed	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	0.08	0.08	ns	ns
Date	ns	*	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns
PI	**	ns	ns	ns	ns	**	**	ns	ns	ns	ns	ns	ns	*
C	0.025	75.38	5.19	0.99	1.29	8.03[a]	0.69	2.25	2.46	3.66	92.16	7.82	6.72	9.45
N	0.032	72.98	3.52	1.57	1.53	1.99[b]	0.21	2.29	4.36	11.98	82.32	17.71	5.29	23.09
P	0.026	67.61	5.26	1.84	0.41	5.00[ab]	0.37	4.09	4.61	10.79	82.38	17.63	5.00	19.03

TFA – Total fatty acids; Sat – Saturated; Unsat – Unsaturated; Sat/Unsat – Saturated/Unsaturated; Ω 3 – Omega 3.

In general, the fatty acid profile (Table 3.5) did not differ between breeds, except for C16:0 where the Curraleiro had higher levels, but not differing from the Pantaneiro.

Tenderness (-0.65 and -0.45), succulence (-0.75 and -0.51) and taste (-0.42 and -0.24) are negatively correlated with luminosity (L*) and b* (Blue to yellow colouring), respectively (Table 3.6). They were also negatively correlated with shear force as expected, and showed positive correlations between each other.

.

3.2 Correlations

Table 3.6. Correlations between meat quality and fatty acid traits in three Brazilian cattle breeds.

	TFA	C10_0	C12_0	C14_1	C16_0	C16_1	C18_0	c20_2	c20_5n3	%TFA	Sat	Unsat	Sat/Unsat	Omega3	FZ	T	C	D	CW	TC	pH	Len	Wid	Marb_Cut	L*	a*	b*	SF	Tend	Succ
C10_0	-0.55																													
C12_0	0.29	-0.65																												
C14_1	0.95	-0.69	0.37																											
C16_0	0.75	-0.59	0.17	0.66																										
C16_1	0.73	-0.79	0.33	0.77	0.82																									
C18_0	0.77	-0.78	0.45	0.90	0.57	0.76																								
c20_2	0.77	-0.78	0.45	0.90	0.58	0.77	1.00																							
c20_5n3	-0.81	0.20	-0.26	-0.69	-0.64	-0.51	-0.58	-0.58																						
%TFA	-0.32	0.60	-0.31	-0.41	-0.39	-0.44	-0.59	-0.59	0.17																					
Sat	0.21	0.50	-0.06	-0.02	0.16	-0.17	-0.16	-0.17	-0.68	0.29																				
Unsat	-0.22	-0.50	0.05	0.01	-0.16	0.17	0.16	0.16	0.69	-0.28	-1.00																			
Sat/Unsat	0.21	0.54	-0.20	-0.05	0.18	-0.25	-0.28	-0.28	-0.56	0.36	0.91	-0.91																		
Omega3	-0.81	0.20	-0.26	-0.69	-0.64	-0.51	-0.58	-0.58	1.00	0.17	-0.68	0.69	-0.56																	
FZ	0.58	-0.62	0.38	0.52	0.71	0.60	0.42	0.42	-0.36	-0.59	-0.04	0.04	0.01	-0.36																
T	0.58	-0.60	0.37	0.52	0.72	0.60	0.43	0.44	-0.39	-0.60	-0.01	0.00	0.04	-0.39	1.00															
C	0.48	-0.55	0.36	0.44	0.56	0.52	0.42	0.43	-0.31	-0.70	-0.06	0.06	-0.08	-0.31	0.93	0.93														
D	0.01	-0.29	0.15	0.04	0.11	0.17	-0.11	-0.11	0.29	-0.12	-0.39	0.39	-0.37	0.29	0.25	0.17	0.11													
CW	0.06	0.08	-0.12	0.00	0.16	0.00	-0.15	-0.15	-0.05	0.50	0.13	-0.13	0.30	-0.05	-0.17	-0.19	-0.53	0.17												
TC	0.06	0.01	-0.08	0.00	0.18	0.04	-0.17	-0.17	0.02	0.43	0.03	-0.02	0.19	0.02	-0.10	-0.13	-0.46	0.40	0.97											
pH	-0.24	0.37	-0.28	-0.24	-0.35	-0.30	-0.09	-0.10	0.06	-0.12	0.12	-0.12	0.04	0.06	-0.12	-0.07	0.21	-0.64	-0.75	-0.86										
Len	0.52	-0.74	0.20	0.57	0.78	0.85	0.62	0.63	-0.31	-0.64	-0.27	0.26	-0.31	-0.31	0.64	0.64	0.59	0.16	-0.08	-0.04	-0.18									
Wid	0.44	-0.49	0.34	0.40	0.52	0.55	0.38	0.38	-0.33	-0.47	-0.01	0.01	-0.06	-0.33	0.85	0.86	0.85	0.01	-0.30	-0.28	0.12	0.56								
Marb_Cut	-0.35	0.22	-0.24	-0.27	-0.30	-0.18	-0.23	-0.23	0.30	0.13	-0.15	0.15	-0.21	0.30	-0.26	-0.25	-0.15	-0.15	-0.21	-0.24	0.39	0.03	-0.11							
L*	0.47	-0.39	0.05	0.47	0.37	0.40	0.22	0.23	-0.06	0.09	-0.29	0.29	-0.08	-0.06	0.14	0.09	-0.11	0.50	0.50	0.59	-0.71	0.27	-0.11	-0.22						
a*	-0.33	0.11	-0.04	-0.37	-0.12	-0.26	-0.29	-0.29	0.29	0.21	-0.07	0.07	0.15	0.29	-0.13	-0.11	-0.27	-0.21	0.47	0.39	-0.19	-0.15	-0.08	-0.30	0.03					
b*	0.05	-0.19	-0.13	0.02	0.24	0.14	-0.07	-0.07	0.22	0.22	-0.29	0.29	-0.01	0.22	-0.02	-0.04	-0.28	0.22	0.69	0.69	-0.61	0.15	-0.16	-0.38	0.68	0.70				
SF	-0.06	0.00	-0.08	-0.08	0.19	0.01	-0.10	-0.10	0.02	0.40	0.05	-0.05	0.12	0.02	-0.28	-0.31	-0.56	0.22	0.82	0.82	-0.72	-0.03	-0.42	-0.36	0.37	0.45	0.68			
Tend	-0.33	0.31	-0.20	-0.34	-0.30	-0.18	-0.22	-0.22	0.15	-0.07	0.06	-0.06	-0.02	0.15	-0.07	-0.03	0.23	-0.48	-0.68	-0.75	0.84	-0.07	0.13	0.29	-0.65	-0.03	-0.45	-0.63		
Succ	-0.30	0.18	-0.17	-0.30	-0.10	-0.08	-0.12	-0.12	0.09	-0.21	0.06	-0.06	-0.08	0.09	0.09	0.13	0.38	-0.43	-0.74	-0.79	0.81	0.05	0.34	0.29	-0.75	-0.07	-0.51	-0.56	0.84	
Taste	-0.26	0.09	-0.18	-0.22	-0.19	0.04	-0.09	-0.08	0.22	0.06	-0.18	0.18	-0.27	0.22	-0.13	-0.10	0.12	-0.39	-0.57	-0.63	0.65	0.09	0.15	0.24	-0.42	-0.07	-0.24	-0.40	0.83	0.72

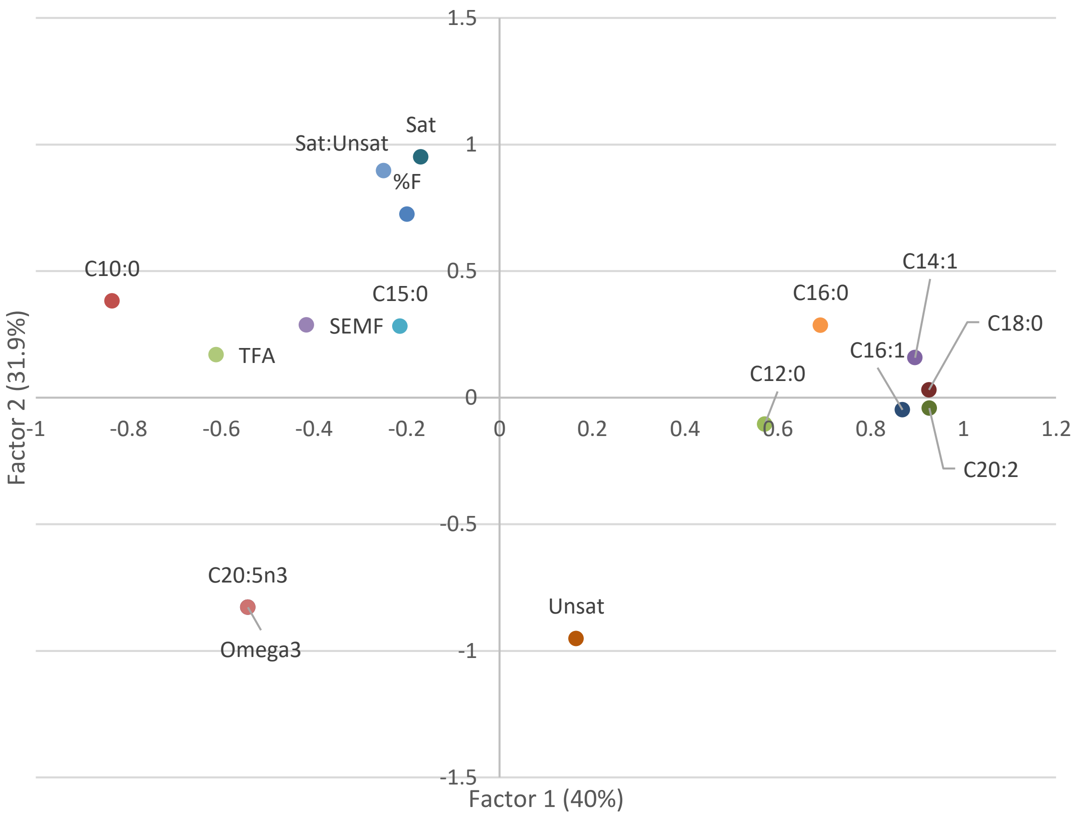
TFA - Total fatty acids; %TFA – Percentage of total fatty acids; Sat - Saturated; Unsat - Unsaturated; Sat/Unsat - Saturated/Unsaturated; FZ - Frozen; T - Thawed; C - Cooked; D - Dried; CW - Cooked weight; TC - Total cook; Len - Length; Wid - Width; Marb cut – Marbling; L* - luminosity; a* - green to red spectrum; b* - blue to yellow spectrum; SF - Shear force; Tend - Tenderness; Succ - Succulence; Taste – Palatability/flavour.

3.3 Factor analyses

Low total fatty acids were related to high values of C16:0, C18:0 and C20:2 but low C10:0, C20:5n3 (Figure 3.2A). High unsaturated was seen to be negatively related o saturated and sat:unsat ratio. Eye muscle fat was directly related with high values of saturated fatty acids and high sat:unsat ratio.

For meat quality traits it can be observed that pH after 24h negatively affected values of frozen, thawed and cooked (Figure 3.2B), inferring those meats with higher pH are more susceptible to weight loss between the freezing, thawing and cooking processes. Low juiciness and tenderness were related to high shear, as well as high cooking and total water losses. Juiciness and tenderness were also positively associated with taste. Higher shear was positively associated with higher a*, b* and L*.

A)



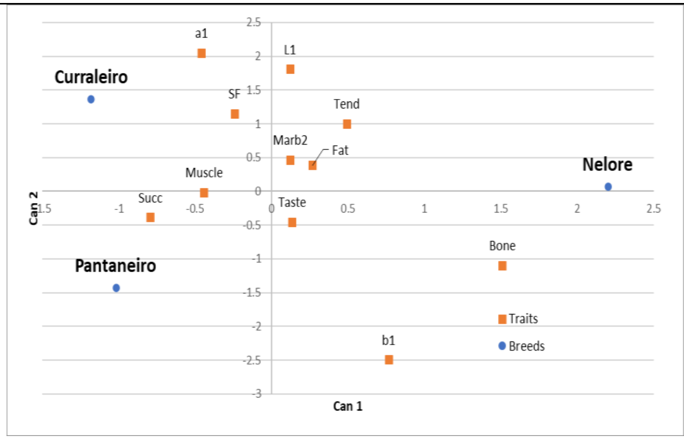
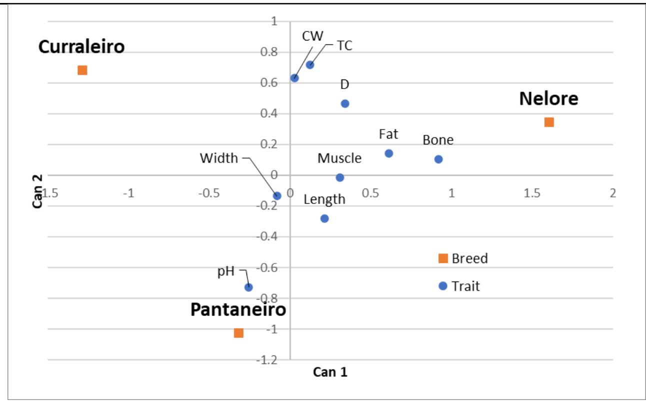
B)

Figure 3.2. First two principal components for (A) fatty acid and (B) meat quality traits in Brazilian cattle breeds.

TFA - Total fatty acids; Sat - Saturated; Unsat - Unsaturated; Sat:Unsat - Saturated/Unsaturated; Sat+Unsat: Saturated + Unsaturated: %F: Percentage of fat; SEMF - Eye muscle fat slaughter; Qthaw - Thawing loss %; Qcook - Cooking loss %; Qtot - Total loss %.

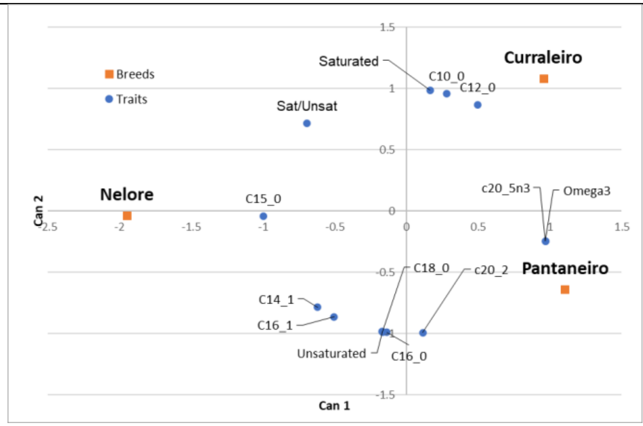
3.4 Discriminant and canonical analyses

In each of the discriminant analyses the breeds were generally well defined within their specific group (Figure 3.3). The poorest classification was for the Pantaneiro breed and the poorest discriminatory power with the fatty acids. Although Nelore was more linked to heavier carcass, this seems to be related to bone percentages. The locally adapted breeds had more succulent meat, possibly because of the fat deposition, especially saturated fats. The significant traits from step by step two breed discriminatory analysis were presented in Table 3.7.

<table>
<tr><th></th><th>Discriminant (% Classification)</th><th>Canonical Discriminant</th><th>Significant traits in Stepwise Discriminant Analysis – all breeds</th></tr>
<tr><td>Meat Quality</td><td><table><tr><td></td><td>C</td><td>N</td><td>P</td></tr><tr><td>C</td><td>100</td><td></td><td></td></tr><tr><td>N</td><td></td><td>100</td><td></td></tr><tr><td>P</td><td>20</td><td>6.7</td><td>73.3</td></tr></table></td><td>
</td><td>Bone
L1
A1
B1
Shear Force
Tenderness
Succulence
Marbling</td></tr>
<tr><td>L. thoracis et lumborum traits</td><td><table><tr><td></td><td>C</td><td>N</td><td>P</td></tr><tr><td>C</td><td>93.3</td><td></td><td>6.7</td></tr><tr><td>N</td><td>6.7</td><td>86.7</td><td>6.7</td></tr><tr><td>P</td><td>26.7</td><td>6.7</td><td>66.7</td></tr></table></td><td>
</td><td>Bone
pH</td></tr>
</table>

Fatty Acid Analyses

	C	N	P
C	60		40
N		85.7	14.3
P	12.5	12.5	75



None

Figure 3.3. Stepwise, discriminatory and canonical analyses with meat traits in Brazilian cattle breeds.

See Table 3.1 for Abbreviations. C: Curraleiro Pé-Duro, N: Nelore; P: Pantaneiro

Table 3.7. Significant meat quality traits from step by step two breed discriminatory analysis

	Pantaneiro vs Curraleiro	Pantaneiro vs Nelore	Curraleiro vs Nelore
Meat Quality	Bone Total cook	Bone	Bone Muscle
L. thoracis traits	Succulence Marbling Tenderness a* Taste	Bone L* Tenderness Succulence	Bone a* b* Marbling
Fatty Acid Analyses	Saturated	No fatty acids	C14_1

4. DISCUSSION

Pantaneiro and Curraleiro breeds presenting more muscle then Nelore breed, and less bone in case of Curraleiro, demonstrate that the greater weight at slaughter found for Nelore did not necessarily show a higher muscle proportion. The percentage values of bones, muscles and fat estimated in this study are below those described by Climaco et al. (2006), Perotto et al. (2000) and Barcellos et al. (2017). Climaco et al. (2006) analysing the percentage of bones, muscles and fats, from a cross section of the *Longissimus thoracis*, in whole Nelore cattle, confined for 113 and fed forage and concentrate, found values of 16.62% for bone, 68.53% for muscle, 14.86% for fat and a muscle/bone ratio of 3.29. Perotto et al. (2000), observed a bone percentage of 16.5±0.33%, a muscle percentage of 66.4±0.93% and a fat percentage of 15.1±1.10%. Barcellos et al. (2017) found 65.0% of muscle, 17.87% of fat and 11.05% of bone when evaluating the performance of Nelore steers finished in pasture and slaughtered at 36 months of age.

The observed percentages contrast with the study reported by Moura et al. (1998) where they identify 20.22% for bone, 53.03% for muscle, 26.74% of fat after feedlot for 135 days. In the present study Nelore cattle were slaughtered with an average age and weight of 22 months and 422kg. It is important to emphasize that the locally adapted breeds used in this study did not undergo genetic selection processes, especially when compared to animals of the Nelore breed (Carvalheiro, 2014). This demonstrates that work on improving existing qualities in locally adapted breeds can bring productive and sensory benefits.

The greater capacity to retain water from Pantaneiro could be associated with its pH values. A previous study demonstrated that high and low pH values were related to tenderer meats rather than intermediate pH, with variability in protein patterns and protein degradation rates (Wu et al., 2014). According to Silva et al. (1999), meats with higher pH are associated with a greater degree of tenderness or with a better final tenderness possibly associated with a greater water retention capacity of the meat, which explains the higher values of Qthaw, Qcook and Qtot in Pantaneiro. This was also seen by Hopkins et al. (2014), where an increase in final pH was accompanied by a decrease in drip loss.

Quality traits such as cooking loss, pH, lightness (L*) and redness (a*) were in line with Muchenje et al. (2009) while yellowness was somewhat higher (b*). pH had an important effect on the color, taste and texture of food. In meat with higher pH the myoglobin associated with muscle structure absorbs light rather than reflecting it, which leads to darker looking meat (Andrés-Bello et al., 2013).

Even with close pH values from hot to cold carcass, for all breeds the values were below 6.2 value from which DFD meat (dark, firm and dry) is considered, but the pH after 24 from Curraleiro was above the range considered as moderate DFD meat (5.8< pH< 6.2). Lowering the pH to values below 5.7 is related to an improvement in palatability (Thompson, 2002). A comparative survey between bovine breeds carried out by Mendonça et al. (2017) observed that the final pH of the Zebu breed animals was 5.52±0.01, a value lower than that found in this study.

The final pH values can be influenced by several variables, from sex, age to the season in which the animals are slaughtered. Węglarz (2010) found slightly lower pH values in cooler seasons having a considerable increase when compared to bulls slaughtered in the summer, suggesting that external factors such as high temperatures generate more pre-slaughter stress. Viljoen et al. (2002) and Wulf et al. (2002) suggested that a pH > 5.8 would compromise meat quality. Ijaz et al. (2020) suggested that the reduced glycogen content of DFD meat favors spoilage by microorganisms, decreasing shelf life. The mean value seen in the present study (5.6) is therefore acceptable, but range shows animals reaching values of 6.43.

These results may be associated with situations of thermal stress or pre-slaughter management. Studying the effects of pre-slaughter management on DFD meat, Pérez-Linares et al. (2015) showed that changes in the handling of pre-slaughter animals such as transport at times of milder temperature, waiting period in the slaughterhouse not prolonged and protected from the sun influenced the pH values and the incidence of DFD meat.

When compared to other breeds (Simmental and the Simmental x Nelore cross), Bianchini et al. (2007) observed that Nelore cattle also had less tender meat, but the pH values found after 24 hours of slaughter were lower those observed in the present study. This is in line with Fidelis et al. (2017), in which the pH was slightly above 5.5. The cooking loss for Nelore was 23.33%. For the shear force, using the Warner Bratzler Shear Force device, they found a value of 4.98 kgf 24 hours after slaughter, for fresh Nelore meat, a value below that shown when comparing naturalized and Nelore breeds. In the present study, no significant variations were observed in the drop in pH after slaughter and after 24h. The same was observed by Aferri (2005), who found no significant difference in pH values at the same intervals of 1 and 24 hours in the *Longissimus lumborum* of crossbred animals (Simmental, Nelore, Brangus).

Carvalho et al. (2017) compared Nelore and Curraleiro carcasses at 28 months of age and unlike this study found Nelore to be heavier with a lower rib eye area. These authors found that meat from Curraleiro was redder than the others, but no significant differences between breeds for the other quality traits. While these authors collected data from several herds in Piaui state, the present study looked at animals reared under the same management system for 97 days pre-slaughter.

For the CIEL*a*b* system, L* = 0 yields black and L* = 100 indicates diffuse white, a* is the green (negative) to red (positive) space, and b* varies from blue (negative) to yellow (positive). The meat examined in this experiment was seen to be positive for all values. 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. At pasture in Brazil, results show L* ranging from 32.3 to 39.1, a* ranging from 19 to 23.7 and b* from 4 to 9.3 (Rossato et al., 2010, Devincenzi et al., 2012, Amatayakul-Chantler et al., 2013). Our results showed wider ranges (Table 3.4), with b* being higher than those found in the two previous studies, especially for Nelore.

Zebu genes can decrease tenderness through muscle structure, physiology and enzymatic activity (Lawrie, 2005). Rossato et al. (2010) obtained shear force of grilled steak of the *Longissimus thoracicis* of 36-month-old Nelore of about 9.13 kg and 7.86 kg for Angus bulls. Nunes et al. (2011) comparing meat quality between different *Bos taururs taurus* breeds and their crosses with Nelore and Caracu, found higher shear force values for Nelore. The higher shear force from Nelore meat could be associated with his higher slaughter weight. According to Gularte et al. (2000), the slaughter weight can influence the tenderness of the meat because, with the increase in weight, there are changes in collagen and myofibrillar proteins that make the meat harder.

The Warner-Bratzler shear force measures the maximum force to cut off a sample of meat (Delgado, 2001; Novaković & Tomašević, 2017), with the Nelore meat the hardest to break. Despite differences in the sensitivity of sensory panels, when compared to more objective tests, Destefanis et al. (2008) compared the results of the shear strength test with the consumer's ability to differentiate different levels of softness in a sensory panel. It was observed that more than 55% of consumers differentiated between tough and intermediate and soft meats and about 62% differentiated between tender and intermediate and hard meats.

In the fatty acids analyses the only significant result was C16:0 levels from Curraleiro. This finding can be considered beneficial to the consumer's health. According to French et al. (2003), palmitic acid (C16:0) was considered to have lower hypercholesterolemic effect of saturated fatty acids when compared to other fatty acids. The higher percentage of saturated fatty acids can be explained due to the process of biohydrogenation in the rumen by the action of microorganisms. As consequence of this, ruminant meat tends to have a higher concentration of saturated fatty acids and a lower proportion of polyunsaturated:saturated ratio than meat from non-ruminants (Bruss, 1997). There is a difference in the deposition of fatty acids in ruminants and non-ruminants, with the main contributor to the development of meat flavor being its fat content and composition, giving distinct flavors to muscles containing different fatty acids (Arshad et al., 2018).

Although genetic factors, sex, age and the type of ruminal microorganisms impact the composition of fatty acids that will be absorbed by ruminants (Woods & Fearon, 2009), the amount and composition of beef fats are mainly influenced by the diet provided to the animal (Vahmani et al., 2015). Carmo et al. (2017), researching the effects of antioxidant supplementation on meat and carcass characteristics, found that the type of antioxidant provided in the diet can reduce or increase the concentration of certain muscle fatty acids. The composition of fatty acids in animals reared at pasture varies according to the forage and its characteristics, amount of light incidence and type of fertilizer received (Elgersma et al., 2015), as well as being influenced by the grains supplied in the diet (Hwang & Joo, 2017). The animals received the same diet, with the same lipid sources, suggesting that the higher C16:0 levels found for Curraleiro may be related to its genetics. A higher marbling evidenced in Curraleiro cattle, although not significant when compared to other breeds, may be related to higher levels of palmitic acid. According to De Smet et al. (2004), significantly higher C16:0 ratios were found in meats with more intramuscular fat. Studying the fat content of Hanwoo beef it was observed that the composition of saturated fatty acids was directly related to palatability and tenderness (Hwang & Joo, 2016).

The unique characteristics given to the flavour of the Curraleiro meat can be noticed in the preference of cattle breeders. While Piauí breeders prioritize characteristics of Curraleiro Pé-Duro cattle as resistance and adaptation to natural pastures in adverse regions

(Carvalho et al., 2001), Goiás and Tocantins breeders maintain the breeding of these animals based on tradition, flavour and quality of meat (Fioravanti et al., 2011). The higher marbling and higher concentration of palmitic acid in the meat of Curraleiro Pé-Duro are attributes that can give the differentiated flavour appreciated by the consumers.

5.CONCLUSIONS

Meat of locally adapted *Bos taurus ibericus* Brazilian breeds were seen to have sensory and qualitative advantages when compared to *Bos taurus indicus* Nelore cattle, both in terms of tenderness and fatty acid composition. The search for better quality meat opens the market for the sale of food from Curraleiro Pé-Duro and Pantaneiro breeds. When subjected to controlled conditions of feeding management, the data show that the local breeds studied can express their genome with greater potential, becoming economically competitive.

The use of genetic improvement programs can bring greater carcass yield and enhance the desirable characteristics present in the meat of these animals. In the case of two breeds that are included in the slow food ark of taste, the association of genetic improvement with the expression of the characteristic flavour given to meat by the aspects of local biomes, with native vegetation, traditional and organic management, are attributes that confer to products from Curraleiro and Pantaneiro, unique and differentiated characteristics, capable of meeting the new demands of the consumer market

6.ACKNOWLEDGEMENTS

Thanks are due to CAPES for scholarships as well as CNPq and FAPEG for project financiation.

7.CONFLICT OF INTEREST

No conflict of interest could be identified in this study.

8.LITERATURE CITED

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9. ATTACHMENTS

9.1. Canonical correlations

Correlations Between the VAR Variables and Their Canonical Variables

	V1
SW	0.79
DWG	0.29
R*EMA	0.43
R*EMF	-0.19
R*HF	0.22
R*RH	0.23
IW	0.89
IEMA	0.73
IEMF	0.40
IHF	0.13
IGMD	0.66

Correlations Between the VAR Variables and Their Canonical Variables

	W1
FZ	0.70
T	0.68
C	0.56
D	0.18
CW	0.01
TC	0.07
pH	-0.25
Len	0.68
Wid	0.54
Marb2	-0.15
L1	0.27
a1	-0.20
b1	-0.09
SF	-0.02
Tend	-0.34

Correlations Between the VAR Variables and the Canonical Variables of the WITH Variables

	W1
SW	0.79
DWG	0.29
R*EMA	0.43
R*EMF	-0.19
R*HF	0.22
R*RH	0.23
IW	0.89
IEMA	0.73
IEMF	0.40
IHF	0.13
IGMD	0.66

Correlations Between the WITH Variables and the Canonical Variables of the VAR Variables

	V1
FZ	0.70
T	0.68
C	0.56
D	0.18
CW	0.01
TC	0.07
pH	-0.25
Len	0.68
Wid	0.54
Marb2	-0.15
L1	0.27
a1	-0.20
b1	-0.09
SF	-0.02
Tend	-0.34

Succ	-0.19
Taste	-0.34

	V1
SW	-0.30
DWG	-0.07
R*EMA	-0.24
R*EMF	-0.08
R*HF	0.25
R*RH	-0.02
IW	-0.35
IEMA	-0.44
IEMF	-0.16
IHF	-0.53
IGMD	-0.41
%B	-0.29
%M	-0.21
%F	-0.35

	W1	W2	W3	W4
C10_0	0.12	0.42	0.00	-0.71
C12_0	-0.07	-0.33	-0.13	0.14
C14_1	0.05	0.12	-0.21	0.81
C15_0	-0.29	0.39	0.32	-0.12
C16_0	-0.27	0.15	-0.14	0.60
C16_1	-0.06	-0.03	-0.17	0.84
C18_0	-0.07	-0.07	-0.44	0.78
c20_2	0.02	-0.04	-0.44	0.77
c20_5n3	0.15	-0.63	0.48	-0.28
Satur	-0.18	0.72	-0.30	-0.39
Unsat	0.19	-0.72	0.30	0.39
Sat/Unsat	-0.22	0.79	-0.04	-0.28
Omega3	0.15	-0.63	0.48	-0.28

	W1	W2	W3	W4
SW	-0.30	0.24	0.31	0.54
DWG	-0.07	0.19	0.48	-0.18
R*EMA	-0.24	0.37	0.30	0.41
R*EMF	-0.08	0.29	0.62	-0.04
R*HF	0.25	0.04	0.31	0.07
R*RH	-0.02	0.13	0.55	0.44
IW	-0.35	0.19	0.20	0.70
IEMA	-0.44	0.11	-0.01	0.53
IEMF	-0.16	-0.20	-0.46	0.20
IHF	-0.53	-0.11	-0.28	0.06
IGMD	-0.41	0.03	0.12	0.26
%B	-0.29	0.21	0.71	0.34
%M	-0.21	0.06	0.15	0.70
%F	-0.35	0.48	0.25	0.38

Succ	-0.19
Taste	-0.34

	V1	V2	V3	V4
C10_0	0.12	0.42	0.00	-0.71
C12_0	-0.07	-0.33	-0.13	0.14
C14_1	0.05	0.12	-0.21	0.81
C15_0	-0.29	0.39	0.32	-0.12
C16_0	-0.27	0.15	-0.14	0.60
C16_1	-0.06	-0.03	-0.17	0.84
C18_0	-0.07	-0.07	-0.44	0.78
c20_2	0.02	-0.04	-0.44	0.77
c20_5n3	0.15	-0.63	0.48	-0.28
Satur	-0.18	0.72	-0.30	-0.39
Unsat	0.19	-0.72	0.30	0.39
Sat/Unsat	-0.22	0.79	-0.04	-0.28
Omega3	0.15	-0.63	0.48	-0.28

Figure A3.1 – Canonical correlations