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Meta-analysis of meat quality of cattle slaughtered with different subcutaneous fat thicknesses

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Abstract – The objective of this work was to evaluate, through meta-analysis, the impact of subcutaneous fat thickness on beef qualitative traits. Combined data from 13 studies were used, comprising 245 carcasses of male bovines slaughtered in Brazil. Effect size for all parameters was calculated as mean difference or standardized mean difference, at 95% probability. The meta-analysis of random and fixed effects was carried out when I^2>50% and I^2<50%, respectively, for each indicator separately, with means for fat thickness, classified in the "control" (3–6 mm), "low" (<3 mm), and "high" (>6 mm) groups. Carcasses in the "high" group showed greater intramuscular fat deposition, whereas those in the "low" group presented an intramuscular fat deposition similar to that of the control. When the fat thickness was below the recommended threshold of 3 mm, shear force increased. Subcutaneous fat thickness values greater than 6 mm induced a positive change in the perception of tenderness by the panel of evaluators. Beef carcasses with a subcutaneous fat thickness over 6 mm tend to accumulate more intramuscular fat content and are tenderer for consumers' acceptance. Carcasses with a fat thickness less than 3 mm produce tougher meat.

Index terms: beef cattle, carcass fat, intramuscular fat, shear force, tenderness.

Metanálise da qualidade da carne de bovinos abatidos com diferentes espessuras de gordura subcutânea

Resumo – O objetivo deste trabalho foi avaliar, por meio de meta-análise, o impacto da espessura de gordura subcutânea nas características qualitativas de carne bovina. Foram utilizados dados combinados de 13 estudos, compreendendo 245 carcaças de bovinos machos abatidos no Brasil. O tamanho do efeito para todos os parâmetros foi calculado como diferença média ou diferença média padronizada, a 95% de probabilidade. A meta-análise de efeitos aleatórios e fixos foi realizada quando I^2>50% e I^2<50%, respectivamente, para cada indicador separadamente, com as médias para espessura de gordura classificadas nos grupos "controle" (3–6 mm), "baixo" (<3 mm) e "alto" (>6 mm). As carcaças do grupo "alto" apresentaram maior deposição de gordura intramuscular, enquanto as do grupo "baixo" apresentaram deposição de gordura intramuscular semelhante à do controle. Quando a espessura da gordura estava abaixo do limite recomendado de 3 mm, a força de cisalhamento aumentou. Valores de espessura de gordura subcutânea maiores que 6 mm induziram mudança positiva na percepção de maciez pelo painel de avaliadores. As carcaças bovinas com espessura de gordura subcutânea superior a 6 mm tendem a acumular maior teor de gordura intramuscular e são mais macias para aceitação do consumidor. As carcaças com espessura de gordura inferior a 3 mm produzem carne mais dura.

Termos para indexação: bovinos de corte, gordura da carcaça, gordura intramuscular, força de cisalhamento, maciez.

Introduction

Consumers are increasingly demanding, and seeking tasty, healthy, and sustainably produced foods. The quality of meat depends on factors intrinsic to the animal, including breed, age, and sex (He et al., 2020) and extrinsic factors, e.g., handling, nutrition, and environment (Pivaro et al., 2016), determining the physicochemical quality, and technological and sensory aspects of meat. Beef fat is a determining factor for the quality (O'Quinn et al., 2012), healthiness and length of cattle production cycles (Ogino et al., 2016).

Slaughterhouses have adopted the thickness of subcutaneous fat as a criterion to reward producers, in view of its impact on the qualitative aspects of carcass and meat (Boito et al., 2018). Values below 3 mm are associated with greater chilling losses and cold-shortening effect, whereas thicknesses above 6 mm result in greater trimming of excess fat before carcass chilling or during deboning (Rodrigues et al., 2015). Both situations cause some type of damage to the beef production sector. Nevertheless, the extent of the impact of subcutaneous fat thickness on the qualitative traits of beef is not fully elucidated, and the existing studies describe conflicting results that warrant broader and more systematic analyses. When evaluating different degrees of subcutaneous fat, Dallantonia et al. (2015) found no effect on meat color and tenderness, which were influenced by aging time. However, for Iida et al. (2015), fat is one of the main factors in meat tenderness. Increased intramuscular fat deposition leads to "disorganization and weakening" of the perimysium structure, causing extracellular matrix remodeling (Wang et al., 2016).

To improve the food experience of consumers and ensure a future purchase, it is necessary to know how much the fat thickness factor can influence the qualitative aspects of beef.

The objective of this work was to evaluate, through meta-analysis, the impact of subcutaneous fat thickness on beef qualitative traits.

Materials and methods

Two independent reviewers selected scientific articles related to the quality of meat from steers finished in Brazil through an electronic search in the Scielo (2021) and Google Scholar (2021) databases. The criterion for choosing the question used in the search for articles was decomposed following the PICO tool (population, intervention, comparison and outcomes framework) (Sartori et al., 2017). The search protocol for P is meat quality, for I is carcass fat, for C is steers and for O is intramuscular fat content or shear force. For the search strategy, P is meat OR meat quality OR meat characteristics OR beef, I refers to subcutaneous cattle fat, C is beef OR steers and O encompasses intramuscular fat content OR shear force of meat.

At the end of the search process, 380 articles were found, 193 were obtained from the Google Scholar platform and 187 from the Scielo platform.

The articles used in the study underwent three screening stages before entering the database. The first consisted of eliminating double articles by reading the titles of the articles. Subsequently, each article had its abstract copied to "Google Forms" electronic forms and was subjected to a second screening, which was performed blindly. For this purpose, 10 electronic forms were prepared and saved in a virtual Google Drive folder. Each electronic form received equal numbers of article abstracts, and each article abstract had to appear in two forms, so that it was evaluated by two reviewers. Ten reviewers were chosen and instructed to access the Google Drive electronic address that contained the 10 electronic forms – one specific for each reviewer according to the order of access to the electronic address. The evaluators would classify the articles as "suitable" or "unsuitable". Articles deemed "suitable" must: 1) originate from primary research (field work); 2) address the meat quality traits of steers finished in Brazil; and 3) be peer-reviewed manuscripts published in indexed journals. If one of the aforementioned criteria were not met, the abstract would be classified as "unsuitable" and would not advance to the next step.

After the second screening, 54 articles remained. Then, these articles underwent a third screening, in which each article was evaluated in its entirety. The following criteria were used: 1) the article must include subcutaneous fat thicknesses between 3 and 6 mm (control) as at least one of its treatments; 2) the manuscript must contain information about sample size and the variability of the measurements of interest (i.e., standard deviation, standard error, or coefficient of variation). After this screening, 13 articles remained, which described the subcutaneous fat thickness and meat quality of 245 beef cattle, which were used to create the database (Table 1).

Data from each study were tabulated in Microsoft Office Excel spreadsheets for further analysis. Each treatment in the articles was considered a sample unit (one row) in the database. For each sample unit, information was extracted from Materials and Methods and Results, and the respective treatment was discussed. Data obtained from each study included authors' names, year of publication, and country of the study. Additionally, data on breed, sexual condition (intact or castrated), diet (roughage:concentrate ratio), housing method, and finishing period were collected. The following response variables were collected: intramuscular fat content (points), shear force (N), tenderness (as evaluated by a panel of evaluators; points), and meat color (points). Intramuscular fat content was visually determined in the longissimus muscle by assigning scores from 1 to 18, with 1 to 3 = traces; 4 to 6 = light; 7 to 9 = small; 10 to 12 = average; 13 to 15 = moderate; and 16 to 18 = abundant (Müller, 1987). The determination of tenderness was carried out based on the scores applied by the evaluators regarding chewing cubes of meat measuring 2.5 cm in width, height and depth. Scores were attributed from 1 to 9, where 1 = extremely tough; 2 = very tough; 3 = tough; 4 = slightly below average; 5 = average; 6 = slightly above average; 7 = tender; 8 = very tender; and 9 = extremely tender, according to the methodology proposed by Müller (1987). Meat color was determined in the longissimus muscle after exposure to air and classified as 1 = dark; 2 = dark red; 3 = slightly dark red; 4 = red; and 5 = bright red.

In the case of studies that reported the standard error of the mean (SEM), the standard deviation (σ) was obtained by the following equation: $\sigma = SEM/\sqrt{n}$

For studies that reported the coefficient of variation (CV%), the standard deviation (σ) was obtained by the equation below: $\sigma = MeanCV/100$

Statistical analyses were performed using the 'metacont' function of the 'meta' package (Schwarzer, 2016) in R software version 3.6.2 (R Core Team, 2019), with a random effects model. The effect size for each meat quality variable was calculated based on the bias-corrected standardized mean difference (Hedges, 1981). The effect size and the weighted contribution for each study in the meta-analysis, according to the classification of subcutaneous fat in the carcass (< 3 mm, 3–6 mm, and > 3 mm), were expressed as forest graphs, which were constructed using the 'forest' function.

The consistency of results between the experiments was quantified by the heterogeneity measures of the chi-square (Q) test and the I^2 statistic (Higgins et al. 2003), which quantifies the impact of heterogeneity on the meta-analysis, in an approach regardless of the number of studies and the metric effect of each treatment. Although the Q test is useful for identifying heterogeneity, the I^2 measure was used to measure heterogeneity (Lean et al., 2009). The I^2 statistic is given by:

Table 1. Characteristics of the studies evaluated.

Articles	n	Genetic group	Sexual condition[(1)]	Age (months)	System	Carcass weight (kg)	
						Hot	Cold
Barcellos et al. (2017)	20	Zebu	1	36	Pasture	-	314.0
Climaco et al. (2006)	40	Zebu	0	14	Pasture	-	253.4
Climaco et al. (2011) c1	10	Crossbreed	0	22	Feedlot	-	256.7
Climaco et al. (2011) c2	10	Crossbreed	0	22	Feedlot	-	262.2
Faturi et al. (2002)	24	Crossbreed	0	21	Feedlot	-	254.0
Menezes et al. (2014)	8	British	0	15	Pasture	191.4	186.0
Metz et al. (2009)	12	Crossbreed	0	25	Feedlot	289.0	283.4
Miotto et al. (2012) c1	12	Crossbreed	1	22	Feedlot	-	236.6
Miotto et al. (2012) c2	12	Crossbreed	1	22	Feedlot	-	228.4
Ribeiro et al. (2012)	28	Zebu	0	22	Feedlot	271.0	-
Rubiano et al. (2009)	37	Zebu	1	14	Feedlot	244.2	-
Vaz et al. (2002) c1	16	Crossbreed	0	14	Feedlot	200.8	196.2
Vaz et al. (2002) c2	16	British	0	14	Feedlot	200.6	195.1

[(1)]Sexual condition: 1 = non-castrated; 0 = castrated.

$$I^2(\%) = \frac{Q-(k-1)}{Q} \times 100.\ Q- > Q-.$$

in which: Q is the χ^2 heterogeneity statistic and k is the number of studies. The I^2 statistic describes the percentage of variation between studies due to heterogeneity. Negative I^2 values correspond to zero; consequently, I^2 is between 0 and 100% (Lean et al., 2009). Its value may not matter if it is in the range of 0 to 40%. However, a value of 30–60% generally indicates moderate heterogeneity; 50–90%, substantial heterogeneity; and a value in the range of 75–100% means considerable heterogeneity (Higgins et al., 2003). Additionally, funnel plots were used to assess publication bias in the meta-analysis, by applying the 'funnel' function (Kossmeier et al., 2019).

Results and discussion

The analyses for different degrees of carcass fatness in castrated or intact bovine males of different ages did not show substantial asymmetry in the analyzed variables, indicating no publication bias (Pacheco et al., 2021). Heterogeneity as measured by the I^2 test was greater than 50% for all qualitative traits of the meat evaluated in this meta-analytic study, thus warranting the adoption of a random effects model (Figure 1, 2, 3, and 4).

The increase in subcutaneous fat thickness in the carcass (high) increased (p=0.0506) the intramuscular fat deposition (Figure 1). However, the carcasses of animals with subcutaneous fat lower than 3-mm thick showed intramuscular fat deposition similar to those of the control animals, situated between 3 and 6 mm (p=0.6641). The intramuscular fat deposition is recognized as a genetic factor (Philippe et al., 2020) and depends on the energy level of the diet and the degree of carcass finish (Pethick et al., 2004). Another determining factor of marbling in beef is the nutritional level during the individual's pregnancy, as adipogenesis occurs in the middle third of pregnancy,

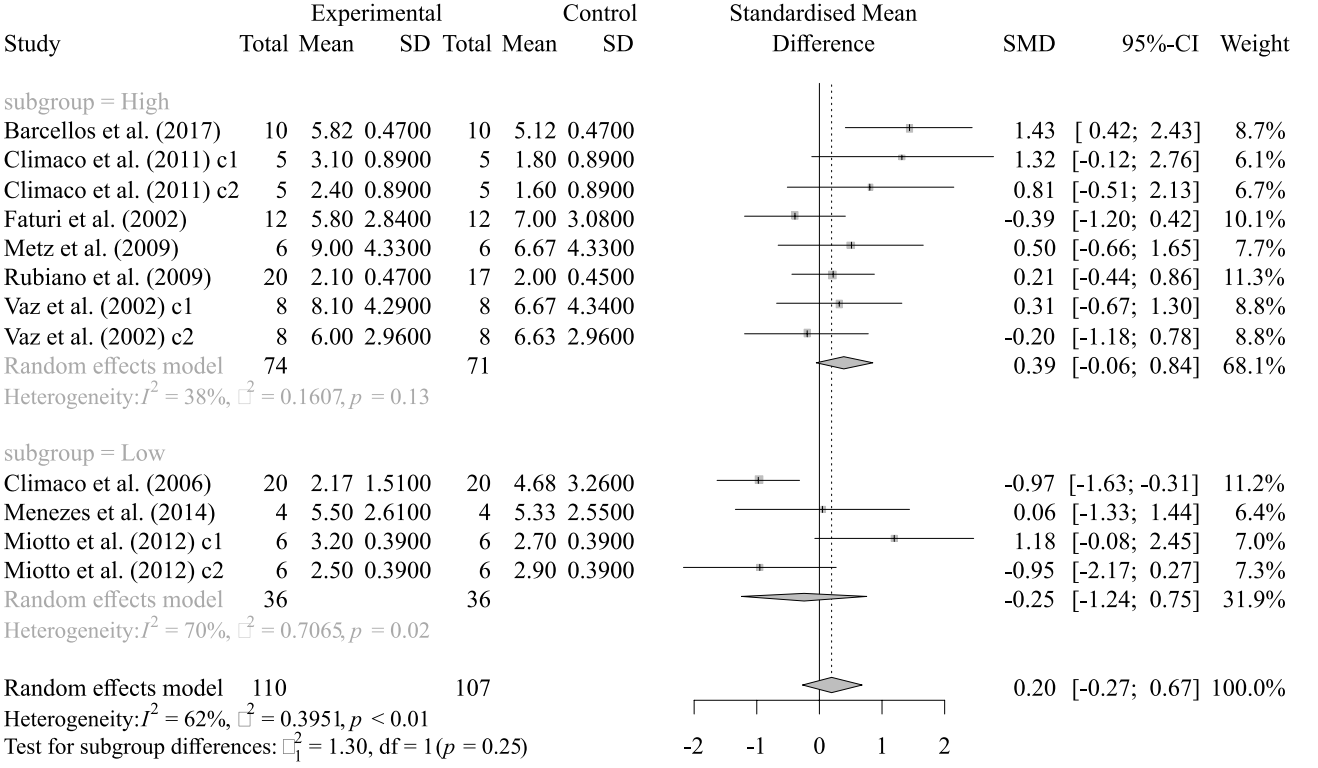

Figure 1. Forest plot of intramuscular fat content score for studies in which fat thickness was lower (low) or higher (high) than the values recommended by the Brazilian meatpacking industry (3–6 mm) (Barcellos et al., 2017). Intramuscular fat content was determined in the longissimus muscle by assigning scores from 1 to 18, with 1 to 3 = traces; 4 to 6 = light; 7 to 9 = small; 10 to 12 = average; 13 to 15 = moderate; 16 to 18 = abundant (Müller, 1987). SD, standard deviation; SMD, standardized mean difference.

which is responsible for the appearance of marbling fat in beef (Du et al., 2010). Arboitte et al. (2011) did not find differences in intramuscular fat content between the small and medium biotypes of the Aberdeen Angus breed; however, they found higher levels of intramuscular fat content in animals with a thicker subcutaneous fat.

Pethick et al. (2004) compiled data from North American, Australian, and Japanese studies with different breeds and crosses and found that there was no increase in intramuscular fat content up to 200 kg of carcass. The authors observed a linear growth in intramuscular fat content from 200 to 450 kg of carcass, with the maximum reached at 500 kg. The results of Arboitte et al. (2011) and Pethick et al. (2004) show that subcutaneous fat and higher slaughter weight are determinant for the degree of intramuscular fat content. In the present study, the non-significant difference in the intramuscular fat content is due to the low carcass weight of the animals involved in the meta-analysis.

The shear force increased (p=0.0835) when the fat thickness was below the recommended threshold of 3 mm (Figure 2). Shear force values were higher, reflecting the negative impact of chilling on carcasses with little fat cover. In such carcasses, the chilling process is faster, leading to cold shortening, one of the factors responsible for the decreased tenderness of meat cuts (Baldassini et al., 2017). Moreover, these carcasses become more dehydrated, which translates into less juicy cuts (Bonin et al., 2014).

Subcutaneous fat thicknesses exceeding 6 mm were associated with a positive change in the perception of tenderness by the panel of evaluators (p=0.0198) (Figure 3). Meat from animals with adequate fat cover and with a good degree of intramuscular fat content will be better evaluated in terms of tenderness, since fat requires less force to break down than muscle fiber (O'Quinn et al., 2012; Iida et al., 2015). The greater thickness of subcutaneous fat in the carcasses may represent higher energy density in the diets of

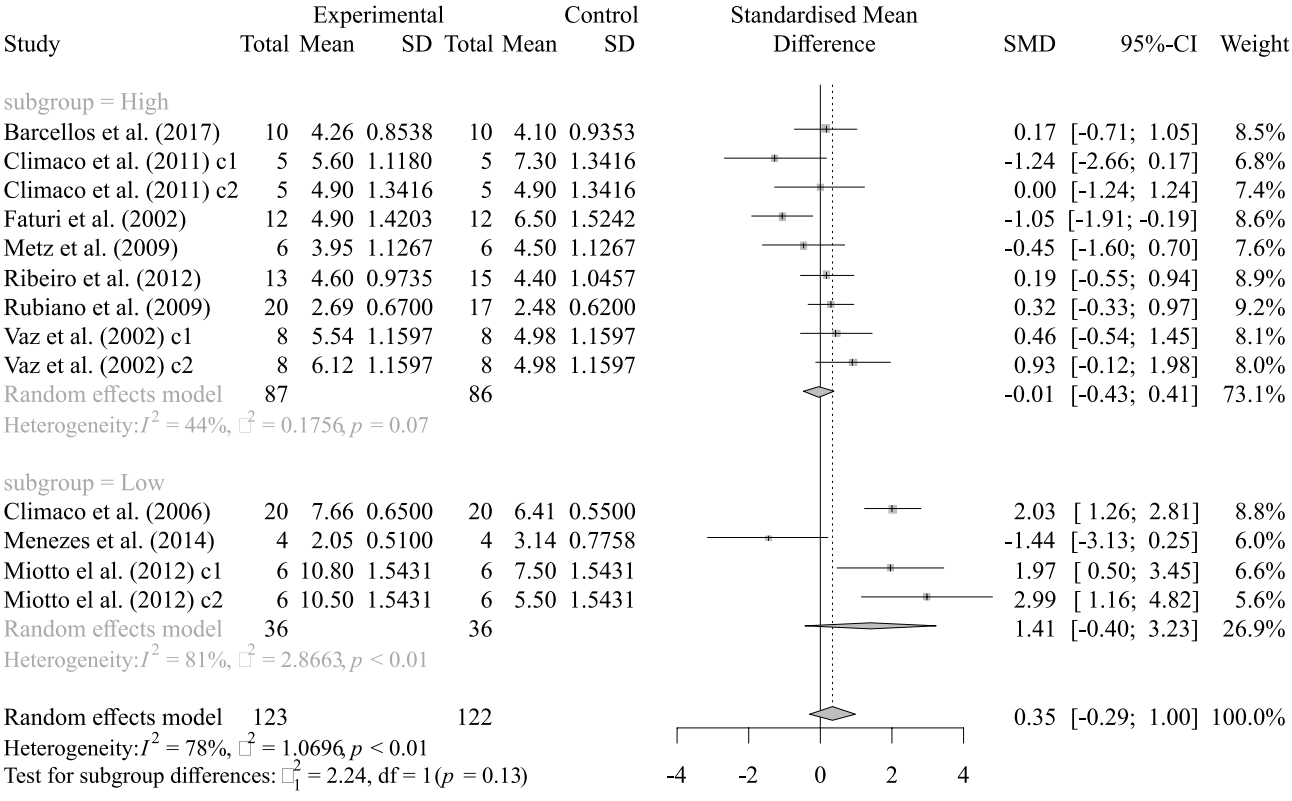

Figure 2. Forest plot of shear force for studies in which fat thickness was lower (low) or higher (high) than the values recommended by the Brazilian meatpacking industry (3-6 mm) (Barcellos et al., 2017). SD, standard deviation; SMD, standardized mean difference.

finishing animals. This characteristic of diets impacts the quality of the meat due to the rapid muscle growth that promotes the formation of collagen with greater solubility (Ito et al., 2012), improving the tenderness of the meat. The results of this meta-analysis confirm the importance of fat thickness of the cover in bovine

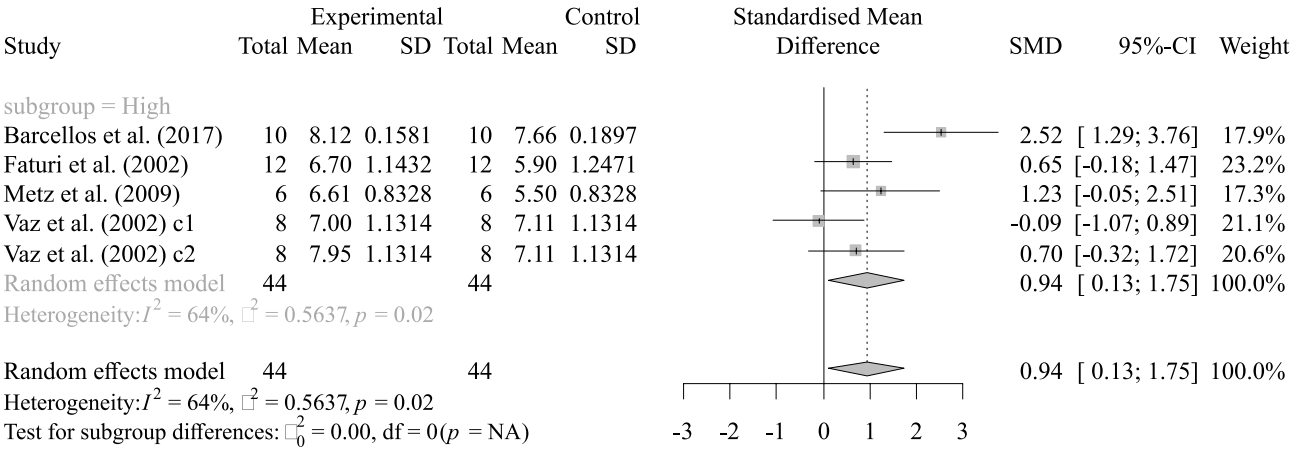

Figure 3. Forest plot of the evaluation of tenderness by the panelists for studies in which fat thickness was higher (high) than the values recommended by the Brazilian meatpacking industry (3–6 mm) (Barcellos et al., 2017). Scores were assigned from 1 to 9, where 1 = extremely tough; 2 = very tough; 3 = tough; 4 = slightly below average; 5 = average; 6 = slightly above average; 7 = tender; 8 = very tender; 9 = extremely tender, according to Müller (1987). SD, standard deviation; SMD, standardized mean difference.

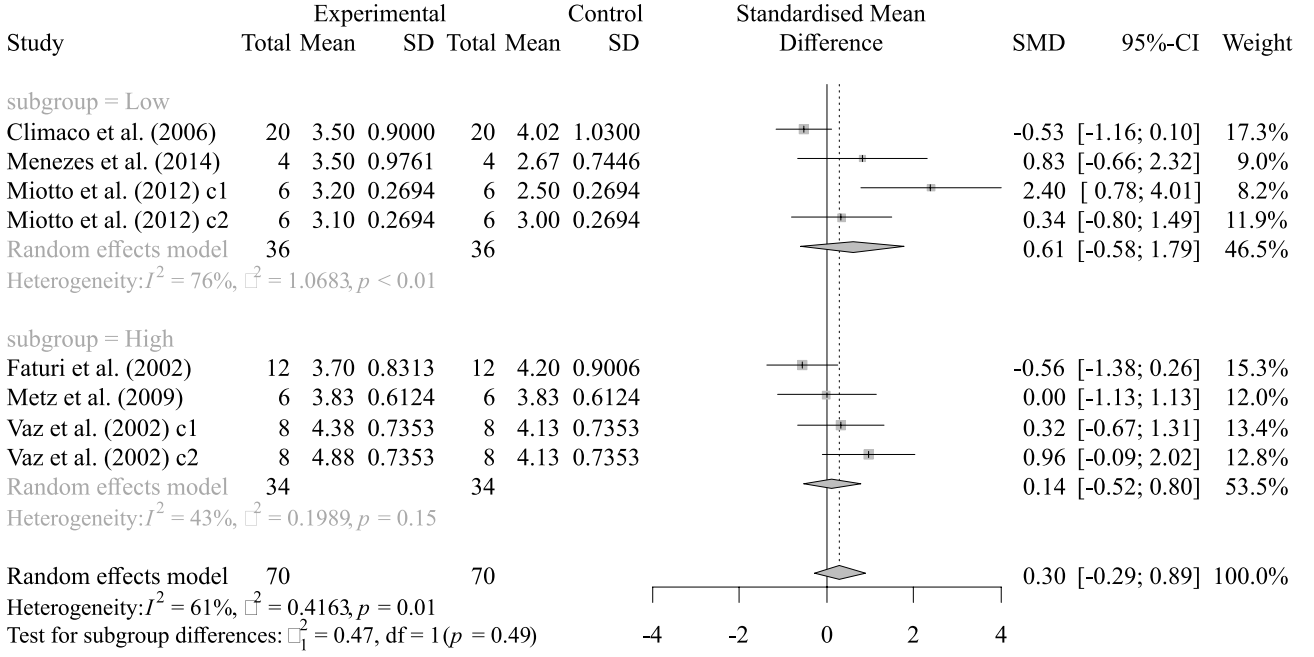

Figure 4. Forest plot of meat color values for studies in which fat thickness was lower (low) or higher (high) than the values recommended by the Brazilian meatpacking industry (3–6 mm) (Barcellos et al., 2017). Meat color was determined in the longissimus muscle after exposure to air as 1 = dark; 2 = dark red; 3 = slightly dark red; 4 = red; and 5 = bright red. SD, standard deviation; SMD, standardized mean difference.

carcasses for adequate levels of meat quality, since tenderness is the most important trait in the acceptance of meat consumers.

The different fat thicknesses evaluated in this meta-analysis did not lead to changes in meat color score ($p>0.05$) (Figure 4). The similar color of the meats as observed in this study occurs partly because the fat thicknesses found were within the recommended values for animal slaughter in Brazil (Boito et al., 2018). However, if the thickness of subcutaneous fat is lower than that sought by the industry, the external part of the muscles may darken when exposed to chilling, giving the meat an undesirable visual appearance and thus compromising its sale (Bonin et al., 2014).

Conclusions

1. Beef carcasses with subcutaneous fat thickness greater than 6 mm accumulate more intramuscular fat.
2. The meat is tougher when the thickness of subcutaneous fat in the carcass is lower than 3 mm.
3. Adequate thickness of subcutaneous fat (3 to 6 mm) produces carcasses with intramuscular fat consistent with tenderness acceptable by consumers without harming the color of the meat.

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