Carcass characteristics and meat quality of Holstein bulls according to slaughter age and muscle type

Características de la canal y calidad de la carne de toros Holstein en función de la edad de sacrificio y tipo de músculo

Características de carcaça e qualidade da carne de touros da raça Holandês em função da idade de abate e tipo de músculo

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Abstract

Background: Among non-genetic factors, slaughter age is the most significant aspect influencing meat quality traits and quantity of beef. **Objective:** To compare the effects of slaughter age and muscle type on carcass traits and meat quality of Holstein bulls. **Methods:** A total of 30 Holstein Friesian bulls were slaughtered at different age, as follows: Young group (YG) at 18 months (n=14 animals); and Old group (OG) at 24 months of age (n=16 animals). Carcass and meat quality traits of *longissimus dorsi* (LD) and *gluteus medius* (GM) muscles were evaluated. **Results:** Carcass traits were not significantly affected over time. Although carcass fat measurements -such as marbling score, back fat thickness, European Beef Carcass Classification System (SEUROP) fatness score- increased numerically with greater slaughter age, only the increase in percentage of kidney, pelvic, and heart (KPH) fat contents were significant ($p<0.05$). Bulls slaughtered at 24 months had 13.4% greater ($p<0.01$) LD area than those in the YG group. Bulls in the OG group had significantly ($p<0.01$) higher slaughter weight as well as hot and cold carcass weights. However, percentages of hot and cold carcass dressing were not significantly affected by slaughter age. The L* (lightness), a* (redness), b* (yellowness), chroma (color intensity), and hue values of meat in the OG group did not differ from those in the YG group. However, L*, a* and chroma values of GM muscle were higher than those of LD muscle, while the pH_{24} value of GM muscle was significantly ($p<0.01$) higher than that of LD. **Conclusion:** It seems more advantageous to slaughter bulls at 24 months of age to get heavier, more marbled, and muscled carcasses better suited to current consumer expectations.

Keywords: *beef quality; carcass traits; cattle; color parameters; Holstein Friesian; non-casing components; slaughter age; slaughter characteristics; types of muscle.*

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Resumen

Antecedentes: Entre los factores no genéticos, la edad al sacrificio se destaca como el que más influye en la calidad de canal y cantidad de carne. **Objetivo:** Comparar los efectos de la edad de sacrificio y los tipos de músculo sobre las características de la canal y los atributos de calidad de la carne de toros Holstein. **Métodos:** Los toros fueron sacrificados a los 18 meses (grupo joven=YG) y 24 meses (grupo viejo=OG) de edad. Al final del período de ceba, se sacrificaron los 30 toros (YG=14 animales; OG=16 animales). Luego se evaluaron las características de la canal y calidad de la carne de los músculos *Longissimus dorsi* (LD) y *Gluteus medius* (GM). **Resultados:** Se encontró que los toros se pueden sacrificar a una edad más avanzada porque la edad al sacrificio no afectó significativamente las características de la canal. Aunque las mediciones de grasa de la canal (tales como puntuación de marmoleo, grosor de la grasa dorsal y puntuación de grasa del Sistema Europeo de Clasificación de Canales de Res -SEUROP) aumentaron numéricamente a mayor edad de sacrificio, solo el contenido graso en riñón, pelvis y corazón (KPH) aumentó significativamente ($p<0,05$). Los toros sacrificados a los 24 meses de edad tuvieron un área LD de 13,4% mayor ($p<0,01$) que los del grupo YG. Los toros en el grupo OG tuvieron mayor ($p<0,01$) peso al sacrificio y en canal caliente y fría. Sin embargo, los porcentajes de faenado caliente y frío de la canal no se vieron afectados significativamente por la edad de sacrificio. Los valores de L* (luminosidad), a* (rojez), b* (amarillez), croma (intensidad de color) y tonalidad de la carne de los toros en el grupo OG no difirieron significativamente de los del grupo YG. Sin embargo, los valores de L*, a* y croma del músculo GM fueron más altos que los del músculo LD, mientras que el valor de pH_{24} del músculo GM fue significativamente ($p<0,01$) más alto que el del músculo LD. **Conclusión:** Parece más ventajoso sacrificar toros a los 24 meses de edad para obtener canales no solo más pesadas sino también con mayor puntuación de marmoleo y más musculosas y, por lo tanto, más adecuadas a las expectativas actuales del consumidor.

Palabras clave: *calidad de la carne; características de la canal; características del sacrificio; componentes que no son de carcasa; edad de sacrificio; ganado; Holstein Friesian; parámetros de color; tipos de músculo.*

Resumo

Antecedentes: Entre os fatores não genéticos, a idade de abate é apontada como o fator mais significativo que influencia as propriedades de qualidade da carne e a quantidade de carne bovina. **Objetivo:** Comparar os efeitos da idade de abate e tipos de músculos nas características de carcaça e atributos de qualidade da carne de touros da raça Holstein Friesian. **Métodos:** Touros foram abatidos com 18 meses (grupo jovem=YG) e 24 meses (grupo velho=GO) de idade. No final do período de engorda, foram abatidos os 30 touros (YG=14 cabeças; OG=16 cabeças) que foram engordados numa quinta privada. Em seguida, foram avaliadas as características de carcaça e qualidade da carne dos músculos *Longissimus dorsi* (LD) e *Gluteus medius* (GM). **Resultados:** Foi determinado que os touros podem ser abatidos mais tarde porque suas características de carcaça não foram significativamente afetadas ao longo do tempo. Embora as medidas de gordura da carcaça, como escore de marmoreio, espessura de toucinho, o escore de gordura do European Beef Carcass Classification System (SEUROP) aumentou numericamente com o avanço da idade de abate, apenas o aumento da porcentagem de rim, pelve e coração (KPH) o teor de gordura foi estatisticamente significativo ($p<0,05$). Touros abatidos aos 24 meses de idade tiveram área LD 13,4% maior ($p<0,01$) do que os do grupo YG. Os touros Holstein Friesian no grupo OG tiveram peso de abate significativamente ($p<0,01$) maior, bem como pesos de carcaça quente e fria. No entanto, as porcentagens de rendimento de carcaça quente e fria não foram significativamente afetadas pela idade de abate. Os valores de L* (luminosidade), a* (vermelhidão), b* (amarelamento), croma (intensidade da cor) e matiz da carne de touros da raça Holstein Friesian no grupo OG não diferiram significativamente dos touros no YG grupo. No entanto, os valores de L*, a* e croma do músculo GM foram maiores do que os do músculo LD, enquanto o valor de pH_{24} do músculo GM foi significativamente ($p<0,01$) maior do que o do músculo LD. **Conclusões:** Parece mais vantajoso abater touros aos 24 meses de idade para obter carcaças não apenas mais pesadas, mas também com maior pontuação de marmoreio e mais musculosas e, portanto, mais adequadas às exigências atuais do consumidor.

Palavras-chave: *características de abate; características de carcaça; componentes não invólucros; gado; Holstein Friesian; idade de abate; parâmetros de cor; qualidade da carne bovina; tipos de músculo.*

Introduction

The physiochemical traits of meat determine its commercial value and acceptability by consumers (Belhaj *et al.*, 2021). Meat quality is usually defined as a measurement of traits or features that determine the consumer appreciation of texture, flavor, food safety, and the suitability of meat to be eaten fresh or stored for a reasonable period without deterioration (Elmasry *et al.*, 2012). Variations in carcass and beef quality traits can be attributed to intrinsic factors (e.g. breed, slaughter age, slaughter weight, sex) and extrinsic factors (diet, pre-slaughter handling practices, aging duration, and slaughtering procedure) (Bureš and Bartoň, 2012; Purwin *et al.*, 2016, Nogalski *et al.*, 2018, Clinquart *et al.*, 2022). In addition, the histochemical properties of muscles affect meat quality (Preziuso and Russo, 2004). Among the intrinsic factors, age at slaughter greatly influences carcass and beef quality (Guerrero *et al.*, 2013).

Beef production in Europe depends heavily on dairy cattle enterprises. Most beef in Europe is produced as a by-product from dairy farms, comprising two-thirds of European cattle (Greenwood, 2021). Holstein bull calves provide a significant part of the overall supply of beef around the world, including many European countries and the USA. Likewise, dairy cattle breeds in eastern Turkey contribute considerably to beef production in this region (Özdemir and Yanar, 2021). Holstein Friesian cattle reared on the elevated plains of eastern Turkey has a distinctive morphological structure. They have comparatively lower body weight and size than their counterparts raised in the lowland countries of Europe (Bayram *et al.*, 2004). Although body size of Holsteins reared in Turkey became relatively smaller, these animals are quite well adapted to the difficult environmental conditions of eastern Turkey due to their ability to adapt to a wide range of climatic conditions (Fanta, 2017).

There is scarce information about the effect of slaughter age on carcass traits and meat quality of Holstein cattle reared in the harsh climatic conditions of Eastern Turkey. Therefore, this study was undertaken to compare the effects of slaughter age and muscle type on carcass characteristics and meat quality of Holstein bulls.

Materials and Methods

Ethical considerations

Slaughtering and postslaughter procedures in the abattoir were carried out in line with the procedures for slaughtering and carcass preparation of the Turkish Standards Institute (TSI, 1987). In addition, the research project was approved by the Ethics and Animal Welfare Committee of the College of Agriculture at Atatürk University, Turkey.

Experimental design

A total of 30 Holstein Friesian males were fattened in a private farm located in the Erzurum Province, Eastern Turkey. A total mixed ration was offered *ad libitum* in group-feeding throughout the fattening period (210 days) (Figure 1). The ration consisted of 70% concentrate and 30% dry hay (on a dry matter basis). The chemical composition of the concentrate used was 88.0% dry matter, 16.1% crude protein, 8.5% crude ash, 2.3% ether extract, 41.5% neutral detergent fiber, and 19.8% acid detergent fiber. The hay contained 87.8% dry matter, 8.1% crude protein, 8.8% crude ash, 2.8% ether extract, 41.1% acid detergent fiber, and 61.6% neutral detergent fiber.

Figure 1. Cattle fed total mixed ration in group-feeding.

Prior to slaughter, bulls were allocated into two groups based on slaughter age. Then, the groups were named young group (YG) (average 18.0±1.4

months old; n=14) and old group (OG) (24.0±1.2 months old; n=16).

Non-carcass components and carcass traits

Immediately after slaughter, hide, head, feet, heart, liver, testis, tail, spleen, kidney, and lung weights were determined. Percentage of non-carcass components were calculated by dividing the weight of hide, head, feet, heart, liver, testes, tail, spleen, kidney, and lung by the hot carcass weight, which was recorded about 1 h *postmortem*; then, these values were multiplied by 100. Kidney, pelvic, and heart (KPH) fat were determined for each carcass, and percentage of KPH was calculated by dividing KPH fat weight by the hot carcass weight and then multiplied by 100. Meanwhile, carcass measures, such as thoracic depth, carcass length, length of the round, width of the round from the medial side, and width of the round were also recorded from the hot carcasses (Özlütürk *et al.*, 2008).

The SEUROP beef carcass grading system was used to visually assess the fatness score (degree of fat cover) and the conformation score of each carcass by a trained meat grader. After visual evaluation of the carcasses, the hot carcasses were split along the spine into two halves and chilled at 4 °C for 24 h in a commercial chiller. Then, cold carcass weights of the two halves of a carcass were determined. Losses in carcass weight were also determined by subtracting cold carcass weight from hot carcass weight. The weight difference was then divided by the hot carcass weight, and then multiplied by 100 to determine percentage of chill loss. Dressing percentage of the hot and cold carcasses were calculated as a ratio of hot or cold carcass weight to live body weight obtained at the slaughterhouse. After 24 h *postmortem*, the carcasses were ribbed at the 12-13 rib interface. Marbling score and fat depth at three equally spaced points over *Longissimus dorsi* (LD) muscle and area of LD muscle cross-section was determined at the ribbing site. The scale used to determine marbling score ranged from 1 to 6 (1: slight, 2: small, 3: modest, 4: moderate, 5: slightly abundant, 6: abundant) and official USDA marbling photos were used to evaluate color scores (Figure 2).

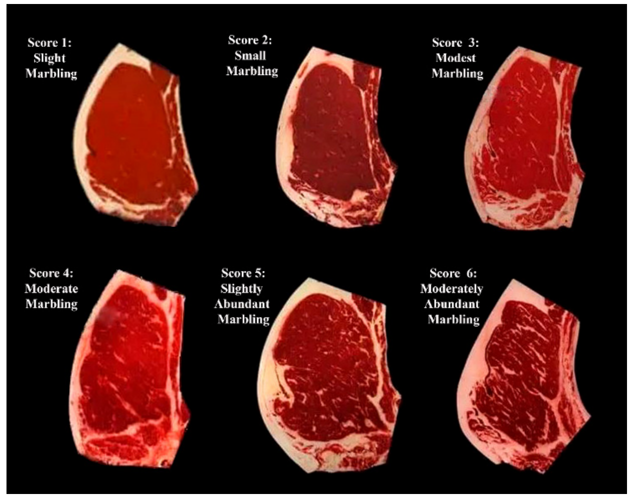

Figure 2. Official USDA marbling photos used to determine marbling score.

Meat color parameters and pH

Meat samples from the *gluteus medius* (GM) and the LD muscles were excised from the carcasses to determine objective meat color parameters. After pH measurements were performed on freshly cut surfaces of LD and GM muscles using a direct probe of a SCHOTT model pH meter (Schott, Lab Star pH, Mainz, Germany), meat color parameters [lightness (L*), redness (a*), yellowness (b*) values] in muscle samples of LD and GM were objectively measured using the Minolta Chroma meter CR-400 (Minolta, Osaka, Japan) after 30 min of exposure to the air (Figure 3). The hue of the tissue and the chroma were calculated as $\tan^{-1}(b^*/a^*)$ and $\sqrt{(a^{*2}+b^{*2})}$ respectively. Finally, hue was determined by multiplying $\tan^{-1}(b^*/a^*)$ by (180/3.14).

Statistical analysis

The Shapiro-Wilk normality test in SPSS Statistics 20 (IBM, Chicago, IL, USA. 2011) was used to analyze normality of the data. Since data had normal distribution, the SPSS Independent Samples T Test procedure was used for statistical analysis of slaughter and carcass traits data. Data from meat color parameters were statistically compared using a mathematical model that included slaughter age and muscle as main effects. The interaction between slaughter age (YG, OG) and muscle (LD, GM) was excluded from the statistical model since it was found not significant in the preliminary statistical analysis. The Duncan Multiple Comparison Test was used for subclass mean comparisons when the F test for main effects were significant (Montgomery, 2013).

Figure 3. Minolta Chroma meter CR-400 used in the study.

Results

Least square means and standard errors for slaughter traits are presented in Table 1. Slaughter weight of bulls in the YG and OG groups were 500.90±48.00 and 587.70±36.50 Kg, respectively. While hot and cold carcass weights of bulls in the YG group were 273.64±31.02 and 269.62±30.88 Kg, respectively, values of the OG group were 323.09±26.57 and 318.20±25.95, respectively. Percentage of hot and cold carcass dressing ranged from 54.60±1.40 to 53.80±1.40 in the YG group and from 54.90±1.60 to 54.10±1.50 in the OG group, respectively. Slaughter age groups differed significantly in slaughter weight, hot and cold carcass weights ($p<0.01$) as well as percentage of chilling loss ($p<0.05$) (Table 1). In contrast, hot and cold carcass dressing percentages were not significantly affected by slaughtering age.

The least squares means and standard errors from carcass traits are given in Table 2. While SEUROP fatness and SEUROP conformation scores in the YG group were 3.82±1.97 and 11.01±2.09, respectively, for the OG they were 4.27±1.45 and 10.64±2.01, respectively. The LD area of bulls in the YG and OG groups were 73.55±5.76 and 83.42±5.54, respectively. Marbling scores and back fat thickness of carcasses increased from 1.64±0.51 to 1.91±0.44, and from 4.04±1.72 to 4.79±1.47 with increasing slaughter age, respectively. Percentage of kidney fat and KPH were 0.09±0.03 and 0.74±0.25 in the YG group and 0.11±0.02 and 0.97±0.20 in the OG group, respectively. All carcass traits, except for LD area and percentage of kidney fat, were not significantly affected by slaughter age. Differences in LD area ($p<0.01$), KPH ($p<0.05$) between slaughter age groups were statistically significant.

Table 1. Traits of Holstein Friesian bulls slaughtered at two ages.

Slaughter trait	Slaughter age		Significance
	Young group (n=14)	Old group (n=16)	
	X±SE	X±SE	
Slaughter weight	500.90±48.00	587.70±36.50	**
Hot carcass weight	273.64±31.02	323.09±26.57	**
Cold carcass weight	269.62±30.88	318.20±25.95	**
Hot carcass dressing (%)	54.60±1.40	54.90±1.60	NS
Cold carcass dressing (%)	53.80±1.40	54.10±1.50	NS
Chilling loss (Kg)	4.02±0.93	4.89±1.02	*
Chilling loss (%)	1.46±0.33	1.52±0.25	NS

*: $p<0.05$; **: $p<0.01$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error.

Table 3 presents the non-carcass components data. Proportions of weights of hide, head, fore-hind shanks, and liver to the hot carcass weight of bulls in YG and OG groups were determined as 7.95±0.36 and 7.45±0.34; 3.72±0.18 and 3.57±0.13; 2.01±0.18 and 1.99±0.14; 1.60±0.40 and 1.32±0.25, respectively. In addition, percentages of testis, tail, lung, spleen, heart, and kidney of bulls in the YG and OG groups were 0.17±0.03 and 0.16±0.02; 0.24±0.03 and 0.23±0.02; 0.96±0.08 and 0.85±0.05; 0.18±0.02 and 0.17±0.01; 0.46±0.03 and 0.43±0.02, 0.89±0.09 and 0.84±0.03, respectively. While age at slaughter had a significant impact on the percentage of hide, heart ($p<0.01$), liver, and testis ($p<0.05$), the rest of non-carcass components did not differ by slaughter age.

Table 2. Carcass traits of Holstein bulls slaughtered at two ages.

Carcass trait	Slaughter age		Significance
	Young group (n=14)	**Old group (n=16)**	
	X±SE	**X±SE**	
SEUROP fatness score	3.82±1.97	4.27±1.45	NS
SEUROP conformation score	11.01±2.09	10.64±2.01	NS
LD area (cm^2)	73.55±5.76	83.42±5.54	**
Marbling score	1.64±0.51	1.91±0.44	NS
Back fat thickness (mm)	4.04±1.72	4.79±1.47	NS
Fat thickness/LD area	4.80±2.48	6.51±1.75	NS
LD area/100 Kg carcass weight	26.06±2.35	27.43±1.94	NS
Kidney fat (%)	0.09±0.03	0.11±0.02	NS
KPH (%)	0.74±0.25	0.97±0.20	*

*: $p<0.05$; **: $p<0.01$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error; SEUROP: European Beef Carcass Classification System.

Table 3. Non-carcass components of Holstein bulls slaughtered at two ages.

Non-carcass components (%)	Slaughter age		Significance
	Young group (n=14)	**Old group (n=16)**	
	X±SE	**X±SE**	
Hide	7.95±0.36	7.45±0.34	**
Head	3.72±0.18	3.57±0.13	NS
Fore-hind shanks	2.01±0.18	1.99±0.14	NS
Liver	1.60±0.40	1.32±0.25	*
Testis	0.17±0.03	0.16±0.02	*
Tail	0.24±0.03	0.23±0.02	NS
Lung	0.96±0.08	0.85±0.05	NS
Spleen	0.18±0.02	0.17±0.01	NS
Heart	0.46±0.03	0.43±0.02	**
Kidney	0.89±0.09	0.84±0.03	NS

*: $p<0.05$; **: $p<0.01$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error.

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Least square means and standard errors for carcass measurements are shown in Table 4. Thoracic carcass depth in the YG and OG groups were 45.4±0.8 and 49.4±0.3 cm, while carcass lengths were 144.7±1.6 and 152.2±1.0 cm, respectively. Length of the round of bulls in the YG and OG groups were 76.4±1.2 and 82.0±0.6, respectively. Width of the round from medial side and width of the round rose from 41.4±1.0 to 43.5±0.4 and from 21.9±0.4 to 22.7±0.5, respectively, with increasing slaughter age. All carcass measurements that excluded the width of the round from the medial side as well as the width of the round were significantly ($p<0.01$) affected by slaughter age.

In Table 5, least square means, and standard errors of the color parameters and pH_{24} of GM and LD muscles are presented. The pH values of GM and LD muscles measured at 24 h *postmortem* was 5.48±0.01 and 5.66±0.0, respectively; and 5.60±0.03 and 5.54±0.02 for carcasses in the YG and OG groups, respectively. None of the color parameters (L*, a*, b*, chroma and hue) together with pH_{24} value of meat were affected by slaughter age. However, muscle type had a significant ($p<0.01$) effect on L*, a*, b*, chroma and hue as well as pH_{24} values. Meat color parameters, such as L*, a*, b*, chroma, and hue values of GM muscle were 31.26±0.28, 15.03±0.24, 5.83±0.12, 16.13±0.33 and 21.18±0.32, respectively; while for the LD muscle they were 29.39±0.28, 13.56±0.24, 5.47±0.12, 14.62±0.33 and 23.75±0.32, respectively.

Table 4. Carcass measurements of Holstein bulls slaughtered at two ages.

Carcass measurements (cm)	Slaughter age		Significance
	Young group (n=14)	**Old group (n=16)**	
	X±SE	**X±SE**	
Thoracic depth	45.4±0.8	49.4±0.3	**
Carcass length	144.7±1.6	152.2±1.0	**
Length of the round	76.4±1.2	82.0±0.6	**
Width of the round from medial side	41.4±1.0	43.5±0.4	NS
Width of the round	21.9±0.4	22.7±0.5	NS

**: $p<0.01$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error.

Table 5. Color parameters and pH_{24} value of the *gluteus medius* (GM) and *longissimus dorsi* (LD) muscles of Holstein bulls slaughtered at two ages.

Measurements	Slaughter age		Muscle		Significance	
	Young group (n=14)	**Old group (n=16)**	***Gluteus medius* (n=30)**	***Longissimus dorsi* (n=30)**	**Slaughter age**	**Muscle type**
	X±SE	**X±SE**	**X±SE**	**X±SE**		
pH_{24}	5.60±0.03	5.54±0.02	5.48±0.01	5.66±0.01	NS	**
			Color parameters			
L*	30.42±0.40	30.24±0.37	31.26±0.28	29.39±0.28	NS	**
a*	13.89±0.39	14.7±0.32	15.03±0.24	13.56±0.24	NS	**
b*	5.48±0.19	5.82±0.17	5.83±0.12	5.47±0.12	NS	NS
Chroma	14.94±0.42	15.82±0.40	16.13±0.33	14.62±0.33	NS	**
Hue	22.29±0.39	22.65±0.37	21.18±0.32	23.75±0.32	NS	**

**: $p<0.01$; NS: Non-significant ($p>0.05$); X: Least square mean; SE: Standard error; L*: Lightness; scale 0 (black) to 100 (white); a*: Redness; + a* (red) to – a* (green); b*: Yellowness; + b* (yellow) to – b* (blue).

Discussion

Beef producers in Turkey are paid based on carcass weight and dressing percentage of the cattle. Therefore, cattle breeders want to know the association between potential carcass weights and dressing percentage of their animals slaughtered at various ages to maximize profit. Additionally, carcass dressing is the most important component of carcass quality (Ulutaş *et al.*, 2021). In the present study, slaughter age was a significant ($p<0.01$) source of variation for live weight at slaughter along with hot and cold carcass weights of Holstein bulls. Hot and cold carcass weight, as well as slaughter weight of animals in the OG group, respectively, were 15.9, 18.07 and 18.01% heavier than those of the YG group (Table 1). Furthermore, the values of the slaughter traits increased with greater age at slaughter. Similar findings were reported by Mojto *et al.* (2009), Bureš and Bartoň (2012), Marti *et al.* (2013), and Aydin *et al.* (2013). Both hot and cold dressing percentages improved with increasing slaughter age; however, differences in carcass dressing of bulls in the OG and YG groups were not statistically significant.

The LD area was strongly associated with live body weight, carcass weight as well as carcass muscularity. Significant positive correlation between meat yield and rib eye area were also confirmed by Tait *et al.* (2005) and Musa *et al.* (2021). Furthermore, the amount of intramuscular fat in LD muscle is also an important factor to determine carcass quality. In the present study, age at slaughter had a significant ($p<0.01$) effect on the cross-sectional area of LD muscle, and it increased with slaughter age (Table 1). The LD area in the OG group was 13.4% higher than that of animals in the YG group, indicating a considerable increase in muscularity in the OG group compared to younger bulls. This finding agrees with studies conducted by Aksoy *et al.* (2006) and Nogalski *et al.* (2018).

Carcass fat traits, such as marbling score, back fat thickness, SEUROP fatness score, percentages of kidney fat tended to increase with higher slaughter age (Table 2). Although differences in carcass fat parameters were not statistically significant, older bulls produced fattier carcasses. Consistent with the present results, Du Plessis and Hoffman (2007), Warren *et al.* (2008), Marti *et al.* (2013), Nogalski *et al.* (2014), and Momot *et al.* (2020) observed that high slaughter age is associated with higher carcass fat content. Furthermore, in the present study older animals had better conformation scores ($p<0.05$) than bulls in the YG group (Table 2). This result could be attributed to increased carcass fat parameters in the OG group and it is consistent with findings by Warren *et al.* (2008), Aydin *et al.* (2013), and Momot *et al.* (2020).

Although all non-carcass components of the OG group were lower than those of the YG group, differences in the proportion of hide, liver, testis ($p<0.05$) and heart ($p<0.01$) to slaughter weight were statistically significant in favor of younger bulls (Table 3). This finding agrees with the result of Aksoy *et al.* (2006), who reported that percentage of non-carcass components decreases with advancing slaughter age.

The increase in slaughter age led to significant increase in carcass measurements, such as thoracic depth, carcass length, and length of the round (Table 4). In agreement with previous studies (Aksoy *et al.*, 2006; Du Plessis and Hoffman, 2007), carcass measurements increased with advancing slaughter age.

Color affects meat visual evaluation and consumer appreciation as well as preference. Furthermore, meat discoloration is considered as an indicator of freshness and wholesomeness; therefore, any deviation from the bright cherry-red color of beef negatively affects the purchase decision of buyers. Age at slaughter is among the main factors affecting meat color attributes (Canto *et al.*, 2016). In the present study, L* (lightness), a* (redness), b* (yellowness), chroma (color intensity), and hue values of meat in the OG group did not differ significantly than those of YG group. Meat pH_{24} values also ranged from 5.48 to 5.66, confirming its high eating quality (Pogorzelska-Przybyłek *et al.*, 2018). Meat color parameters are closely associated with meat pH. Factors leading to pre-slaughter stress as well as excitation are mainly responsible for increased pH and darker meat.

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Therefore, transport and pre-slaughter have to be carried out appropriately to prevent undesirable discoloration of beef. In the present study, pH_{24} of OG and YG meat did not differ significantly and were within desirable limits. This could be attributed to adequate pre-slaughter conditions. Therefore, the unimportant differences in meat pH_{24} observed could result in trivial differences between the OG and YG groups in terms of color parameters. These findings are also supported by results of Nogalski *et al.* (2018), and Pogorzelska-Przybyłek *et al.* (2018). On the other hand, Marti *et al.* (2013), and Kopuzlu *et al.* (2018) reported increasing pH_{24} as slaughter age advances, and the increasing pH_{24} values led to significant changes in meat color.

In the present study, the significant ($p<0.01$) differences in pH_{24} between LD and GM muscles could be due to differences in fiber type of both muscles as indicated by Mojto *et al.* (2009) and Anderson *et al.* (2012). The L*, a* and chroma values of GM were higher than those of LD muscle. The differences in color could be attributed to the lower pH_{24} of GM muscle. This effect of muscle on color parameters is also in agreement with findings by Preziuso and Russo (2004), and Bureš and Bartoň (2012).

In conclusion, our results show that Holstein Friesian bulls can be slaughtered at later age (24 months) since their carcass traits are not adversely affected over time. Additionally, it seems more advantageous to slaughter bulls at 24 months of age to get carcasses not only heavier but also have higher marbling score and more muscled and thus better suited to current consumer expectations.

Declarations

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Conflicts of interest

The authors declare that they have no conflicts of interest regarding the work presented in this report.

Author contributions

AD, MY, RA, and RK designed and supervised the study. AD, VFÖ, ŞŞO, and RK collected the data. RA made the statistical analysis. The manuscript was written by MY and VFÖ. All authors contributed to the critical revision of the manuscript. The final version of the manuscript was approved by all authors.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

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