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Influence of dietary energy concentration and body weight at slaughter on carcass tissue composition and beef cuts of modern type Fleckvieh (German Simmental) bulls

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ABSTRACT

A feeding and slaughter experiment was conducted to evaluate the carcass tissue composition and meat quality of growing modern type Fleckvieh (German Simmental) bulls. For the study, 72 bulls were customary reared and for the fattening period allocated to a normal energy and a high energy treatment group with 11.6 and 12.4 MJ ME/kg DM, respectively. Bulls were slaughtered in a serial slaughter trial with final live weights of 120, 200, 400, 600, and 780 kg. The weights of carcasses, carcass quarters, beef cuts and their tissues (muscle, tendon, fat and bone) as well as meat quality traits were recorded. Results showed that carcass fat increased during growth primarily at the expense of bone and subsidiary muscle tissue, while the tendon content remained constant. Meat quality traits like IMF, meat color and tenderness were superior in high weight groups. Feeding high energy rations did not lead to increased fat accretion, but increased daily gain during certain stages of the fattening period.

1. Introduction

Studies on growth and tissue development of cattle (Augustini, Branscheid, Schwarz, & Kirchgeßner, 1992; Berg & Butterfield, 1976) indicated that the percentage of carcass meat and the proportion of beef cuts change during growth. Furthermore, the carcass tissue composition is subject to change, as each tissue reaches its growth maximum at a different point of maturity. Bone, as an early developing tissue, grows especially during fetal development and the first months of life. Extensive muscle growth is associated with increasing activity of the young animals, while accretion of fat tissue provides energy stores during later stages of development.

The Fleckvieh (German Simmental) breed is a common dual-purpose cattle breed in southern Germany and provides high milk and meat yields simultaneously. Fleckvieh is described as a late maturing cattle breed which can be fattened intensively to high final live weights and features high protein accretion (Augustini et al., 1992). Late maturing cattle breeds are associated with a slower physiological development in relation to their body weights and ages and possess a higher growth potential and slower fat accretion compared to early maturing cattle breeds (Irshad et al., 2013). Moreover, van der Westhuizen (2013) stated that late maturity leads to an increased growth of leaner carcasses because “Later maturing cattle will generally grow faster and will generally be better converters of high energy feed to carcass weight” (Van der Westhuizen, 2013). Hence, carcass traits of late maturing Fleckvieh bulls differ from those of early maturing Hereford cattle and the Holstein-Friesiean dairy breed as described by Keane (2011). Furthermore, the performance potential of late maturing Fleckvieh fattening bulls has been improved by selective breeding during the past decades, which may result in changes of fattening and slaughter traits of bulls fed with low and high concentrate rations, respectively.

The objective of this study was to specify the effects of dietary energy concentration and body weight at slaughter on carcass composition, carcass quarters, beef cuts and their tissue compositions as well as on meat quality of modern type Fleckvieh bulls.

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Table 1
Composition, crude nutrient and energy contents of feedstuffs fed during calf rearing

Feedstuff	Composition		Crude nutrients					
	While milk feeding %DM	After weaning %DM	DM g/kg	CA g/kg DM	CP g/kg DM	CF g/kg DM	aNDFom g/kg DM	ME MJ/kg DM
Calf milk replacer (120 g/L)	5 L/d	–	961	69	210	191	0	16.6
Maize silage	–	63.6%	443	29	78	43	392	11.6
Hay	30.0%	3.7%	852	61	140	20	629	8.5
Molasses	14.3%	1.9%	775	209	108	0	0	10.9
Barley	17.7%	1.2%	879	23	98	20	154	13.0
Maize grain	11.1%	7.1%	888	14	98	42	82	13.3
Rapeseed meal	13.4%	14.2%	889	90	360	45	363	11.6
Pressed beet pulp	11.1%	6.2%	902	80	96	7	418	11.6
Soybean oil	0.3%	0.8%	999	0	0	999	0	30.6
Minerals, 26% Ca, 2% P	1.7%	1.1%	981	981	0	0	0	0
Calcium Carbonate	0.4%	0.3%	997	997	0	0	0	0
Brewer's yeast	–	110 g/d	928	59	280	25	431	12.4

2. Methods

2.1. Calf rearing

The experiment was conducted at the Bavarian State Research Center for Agriculture (LfL) according to European guidelines for animal experiments (Council Directive 2010/63/EU, 2010) and was approved by the ethics committee of the Ethics of Animal Experiments of LfL. For the study, 72 male Fleckvieh calves (German Simmental; age: 42d ± 9, body weight (BW) 80 kg ± 6) were randomly acquired from cattle farms in Bavaria, Southern Germany. The calves were randomly assigned to deep litter calf pens and fed with restricted amounts of milk replacer and ad libitum total mixed rations (TMR) according to Table 1 over a period of 6 weeks. The TMR for the period after weaning (8 weeks) was adjusted weekly and supplemented with brewer's yeast, 110 g per calf and day. The feed intake of each animal group was recorded daily and individual milk replacer intake was recorded by automatic calf feeders. Calves' BW was determined with a calf scale every second week.

2.2. Fattening period

For the fattening period, starting with an average BW of 225 kg ± 29 and age of 154d ± 15, the bulls were randomly assigned to six beef pens housing 12 animals per pen. The pens were equipped with straw litter on sloped floors, automatic manure scrapers and automatic feed intake monitoring systems. The individual feed intake was recorded daily and BW was determined using a cattle scale in four-week intervals. Three pens each were allocated to a normal energy (NE) and a high energy (HE) treatment group with 11.6 and 12.4 MJ ME/kg DM, respectively. Crude protein contents per kg DM remained constant in both diets, while the HE treatment group was fed lower amounts of maize silage and more feedstuffs with higher energy density than the NE animal group. The compositions of NE and HE TMRs are illustrated in Table 2.

2.3. Feed analysis

The individual feed components were sampled and analyzed individually, while concentrates and TMRs were sampled weekly and pooled for a four week period. The analysis was performed using methods of VDLUFA (2012) for dry matter (DM, method 3.1), crude ash (CA, method 8.1), crude protein (CP, method 4.1.2), sugar (method 7.1.1) and neutral detergent fiber (aNDFom, method 6.5.1) determination. Additionally, by methods of the Commission Regulation EC No 152/2009, 2009, the content of crude fat (CF, method 152-H) and starch (method 152-L) was determined. The DM of maize silages was corrected for losses by oven drying according to Weißbach and Kuhla (1995) and the content of metabolisable energy (ME) was calculated from the individual analyses (DLG, 2011; GfE, 2008). The crude nutrient and energy content of the TMRs was calculated by their compositions and the crude nutrient and energy contents of the individual feed components.

2.4. Slaughtering and meat cutting

During the feeding trial, 5 target final live weights were set for slaughtering animals from both feeding groups: 120 kg (4 + 4 animals), 200 kg (5 + 5 animals), 400 kg (9 + 9 animals), 600 kg (9 + 9 animals), and 780 kg (9 + 9 animals), respectively. The bulls were separated from the group 20 h prior to slaughter, weighed and fasted from the TMR by feeding a hay and water diet for ad libitum intake in an isolation box. Slaughtering and meat cutting took place at the LfL Research Abattoir in Grub, Germany. The bulls were transported to the abattoir (distance 500 m), inspected by a veterinarian (ante-mortem inspection), weighed and held in lairage with free access to water until slaughter. Slaughtering was carried out in compliance with the Council Regulation EC No 1099/2009, 2009. The bull's final live weights were

Table 2
Composition, crude nutrient and energy contents of feedstuffs fed for the fattening period.

Feedstuff	Composition		Crude nutrients					
	Normal energy %DM	High energy %DM	DM g/kg	CA g/kg DM	CP g/kg DM	CF g/kg DM	aNDFom g/kg DM	ME MJ/kg DM
Maize silage	80.0%	40.0%	355	31	77	34	336	11.8
Wheat	0.5%	15.5%	888	21	169	16	132	13.3
Maize grain	–	20.6%	889	13	91	41	94	13.3
Rapeseed meal	16.4%	16.7%	891	85	380	39	337	11.7
Pressed beet pulp	0.9%	5.5%	893	96	89	4	408	11.5
Feed grade urea 46,5% N	0.5%	–	990	0	2906	0	0	0
Minerals 26% Ca, 2% P	0.8%	0.8%	981	981	0	0	0	0
Calcium Carbonate, cattle salt	0.8%	0.8%	994	994	0	0	0	0

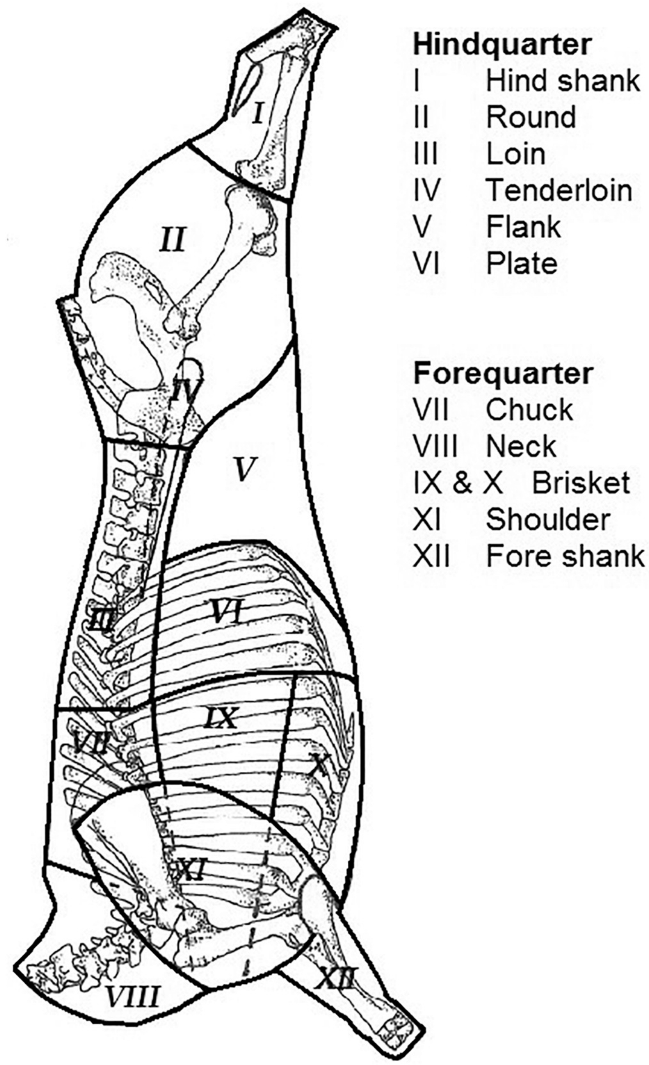

Fig. 1. Beef cuts according to DLG cutting methods (Figure modified from DLG, 1985).

determined after stunning with a cattle gun and prior to bleeding. Dehiding, evisceration, carcass halving and trimming were carried out according to European standards (Commission Regulation EC No 1249/2008, 2008). Post-mortem inspection was performed by a veterinarian during the slaughtering process. Dressed carcasses (carcasses without inner organs, hanging tender, suet and body cavity fat) were weighed and chilled for 20 h at 4 °C. After chilling, the left and right side of each carcass were weighed as cold carcass weights and the right side of the carcass was dissected. To this effect, the carcass was quartered between the 8th and 9th rib, cut according to DLG cutting methods (Fig. 1; DLG, 1985) and each cut was manually dissected to muscle, tendon, fat and bone tissues. Each cut as well as the tissues of each cut were weighed separately.

2.5. Rib eye area and meat quality analysis

A sample of the Longissimus thoracis (LT) muscle (9th and 10th rib cut) was used for meat quality analysis. Muscle pH was measured using a portable pH meter (testo 205, Testo SE & Co. KGaA, Germany) 1 h, 24 h and 14 days after slaughtering. The rib eye area of the 9th rib was measured by digital image analysis and intramuscular fat (IMF) content was measured using petroleum ether in a Soxhlet extraction apparatus. Meat color was measured in CIELAB color space (L*: lightness, a*: redness, b*: yellowness), using a portable spectrophotometer (CM-508i, Minolta Camera CO., LTD., Japan). Ageing loss was recorded after storing the muscle sample from the 10th rib for 14d at 4 °C, cooking loss was determined after heating the 2.5 cm thick, stored sample in 70 °C warm water up to a meat core temperature of 70 °C. The shear force was measured after storing the cooked sample for 24 h at 4 °C, using the Warner-Bratzler method (2519-1kN, Instron GmbH, Germany).

2.6. Statistical analysis

Statistical analysis was performed using the Proc Mixed procedure of SAS (Version 9.4, SAS Institut, Cary, NC, USA) and the Kenward-Roger method to provide corrected degrees of freedom. The analysis included a two-way ANOVA with interaction (feed energy, weight group, feed energy × weight group). Differences between groups were tested using the PDIFF option with effects stated as significant when $p < .05$. Results are shown as LS Means (LSM) and standard error of mean (SEM).

3. Results and discussion

3.1. Daily feed, energy and nutrient intake

As a consequence of feeding varying energy concentrations during the fattening period, HE treated bulls showed in all stages of the finishing period a higher daily DM, sugar, starch and energy intake than the NE animal group, while NE fed bulls showed a higher daily aNDFom intake (Table 3). Higher feed intake in the HE treatment group was most likely a result of increased concentrates proportion of the diet. Similar conclusions were drawn by Steen and Kilpatrick (2000), which fed varying amounts of concentrates to Simmental crossbred steers. Although crude protein contents of the NE and HE TMRs were identical, crude protein intake differed between the treatment groups because of the higher daily DM intake of HE fed bulls. However, crude protein intake of bulls in both treatment groups exceeded the bull's crude

Table 3
Daily feed, nutrient, energy intake and weight gain of bulls in normal and high energy treatment groups in different weight ranges.

Feed intake/fattening performance	Weight range								SEM	p-value		
	80-120 kg	120-200 kg	200-400 kg		400-600 kg		600-780 kg			Feed	Weight	Feed × weight
	$n = 72$	$n = 64$	NE $n = 27$	HE n = 27	NE n = 18	HE n = 18	NE $n = 9$	HE n = 9				
DM (kg/d)	1.92	4.38	7.03^{A}	7.75^{B}	9.47^{A}	10.66^{B}	10.72^{A}	11.35^{B}	0.09	< 0.0001	< 0.0001	< 0.0001
CP (g/d)	321	647	1001^{A}	1107^{B}	1372^{A}	1546^{B}	1538^{A}	1665^{B}	11.91	< 0.0001	< 0.0001	< 0.0001
aNDFom (g/d)	450	1464	2274^{A}	1973^{B}	3116^{A}	2701^{B}	3526^{A}	2759^{B}	28.87	< 0.0001	< 0.0001	< 0.0001
Starch (g/d)	349	1245	2233^{A}	3276^{B}	2802^{A}	4419^{B}	3208^{A}	4769^{B}	36.68	< 0.0001	< 0.0001	< 0.0001
Sugar (g/d)	358	229	208^{A}	286^{B}	257^{A}	357^{B}	292^{A}	398^{B}	4.20	< 0.0001	< 0.0001	< 0.0001
ME (MJ/d)	24.6	51.4	82.1^{A}	96.1^{B}	110.1^{A}	132.3^{B}	124.3^{A}	141.7^{B}	1.02	< 0.0001	< 0.0001	< 0.0001
Daily weight gain (g)	980	1452	1717^{A}	1841^{B}	1753^{A}	1910^{B}	1500	1521	27.07	0.0139	< 0.0001	0.0407

Means within a weight range sharing the same superscript are not significantly different.

protein requirements (GfE, 1995) and therefore did not limit cattle growth.

3.2. Fattening performance

Feeding varying amounts of concentrates alters the daily weight gain, as was previously described by Slabbert, Campher, Shelby, Leeuw, and Kühn (1992) and Steen and Kilpatrick (2000). Further studies with Fleckvieh bulls fed with high energy diets found daily live weight gains of 1210 g/d for the fattening period in a weight range from 200 to 650 kg (Schwarz, Kirchgeßner, Augustini, & Branscheid, 1992) and peak live weight gain of 1536 g/d in a weight range of 205-363 kg (Schwarz & Kirchgessner, 1990). In the current study, the high energy ration led to average daily weight gains of 1699 and 1792 g/d for the NE and HE treatment group, respectively ($p < .1$). Peak live weight gains, with significantly higher gains of the HE treatment group, were reached in between 400 and 600 kg with 1753 and 1910 g/d in NE and HE treatment group, respectively (Table 3). Hence, bulls fed with high energy rations reached the target weight in shorter time.

While the target weights in the present study were kept comparable for NE and HE treatment groups, the slaughter ages of bulls in weight groups 600 and 780 kg differed between treatment groups (Table 4). The average slaughter age of HE bulls at 600 kg was 9 days less than those of NE bulls at the same weight. Likewise, HE bulls with final live weights of 780 kg were slaughtered 21 days earlier ($p < .05$) than NE bulls with same final weights. Comparison to former studies indicated an approximately 500 g higher daily weight gain of HE fed modern type Fleckvieh bulls than high energy fed bulls of past decades (Dannenberger, Nuernberg, Nuernberg, & Ender, 2006; Schwarz et al., 1992). Thus, present-day Fleckvieh bulls grow faster and reach final live weights of 600 kg approximately 130 days earlier than past decade bulls of the same breed when fed with high concentrates rations. The following results illustrate how the accelerated growth rates affected slaughter traits and carcass composition of modern type Fleckvieh bulls.

3.3. Dressing percentage and carcass tissues

The present data showed no significant effects of dietary energy concentration on dressing percentage, carcass composition and meat quality traits of NE and HE treatment groups. Hence, the combined results of both animal groups are shown.

With increasing body weight the dressing percentage increased from 52.2% to 59.7% ($p < .05$) in bulls with 120 kg and 780 kg final weights, respectively (Table 5). Comparison with previous studies showed that the dressing percentages of growing bulls in the present study were approximately 2% lower than in past decades Fleckvieh bulls with 650 kg final weight (Otto et al., 1994), but 3–4% higher than present Simmental bulls, steers and heifers (Coyne, Evans, & Berry, 2019; Sami, Augustini, & Schwarz, 2004; Terler, Velik, Kitzer, & Kaufmann, 2016). Hence, as a late maturing breed, modern type Fleckvieh converted feed energy efficiently into carcass growth.

Comparing the lowest and highest weight groups with 120 and 780 kg, carcass muscle percentage decreased by 4% ($p < .05$) while percentage of fat tissue increased by 13.6% ($p < .05$; Table 5). During the growth period, the percentage of bone tissue in the chilled carcasses decreased from 23.1% in 120 kg bulls to 13.2% in 780 kg bulls ($p < .05$). However, percentage of tendon did not vary between weight groups 120 and 780 kg with 6.0% and 5.9%, respectively. These changes in carcass tissue composition of growing Fleckvieh bulls are in line to results of Augustini et al. (1992) and Keane (2011) which concluded that growth alters the carcass composition of beef cattle. However, present data could not confirm former studies by Augustini et al. (1992), who observed differences in muscle and fat deposition between growing Fleckvieh bulls of a restricted and ad libitum feeding group.

In comparison, early maturing Hereford bulls featured lower dressing percentage (Bartoň, Řehák, Teslík, Bureš, & Zahrádková, 2006; Manninen, Honkavaara, Jauhiainen, Nykänen, & Heikkilä, 2011; Pesonen et al., 2013) while studies comparing Hereford and Simmental breeds indicate higher carcass fat proportion in Hereford and higher meat proportion in Simmental cattle (Bartoň et al., 2006; Mandell, Gullett, Wilton, Allen, & Kemp, 1998). The same effect could be observed by comparison with high yielding dairy cattle breeds as Holstein Friesian. This breed showed lower dressing percentage (Geuder, Pickl, Scheidler, Schuster, & Götz, 2012; Keane, 2011; Pfuhl et al., 2007) and carcass muscle tissue (Geuder et al., 2012; Keane, 2011), but higher carcass fat tissue percentage (Geuder et al., 2012; Keane, 2011) than Fleckvieh bulls. Overall, our data prove that late maturity leads to carcasses with a relatively high amount of muscle but low amount of fat, even in high weight groups.

3.4. Carcass quarters and tissues

Proportions of the carcass quarters remained constant throughout final live weights 120 and 200 kg, while the amount of the forequarter increased significantly at the expense of hindquarter portions in higher weight groups (Table 6). These observations, as well as the non-significant effect of the feed energy concentration on the amount of carcass quarters correspond to data reported from Augustini et al. (1992).

The majority of both carcass quarters consisted of muscle tissue, which decreased ($p < .05$) in the course of growth, particularly in the hindquarter, while tendon content decreased significantly in the forequarter and increased in the hindquarter. Furthermore, the percentage of bone tissue in the fore- and hindquarter decreased ($p < .05$) during growth by 11.6 and 8.8%, respectively, whereas the average amount of fat in the carcass quarters increased ($p < .05$) constantly up to 16.9% in the forequarter and 15.8% in the hindquarter. These observations are consistent with the ad libitum feed intake group of Augustini et al. (1992), which also showed higher fat accretion than bulls in the restricted feeding group. The shifts in quarter and tissue distribution characterize slow but progressive maturity of the fast growing bulls. Amounts of carcass quarters changed slightly, so valuable cuts of the hindquarter persisted in high final weights, as described in the next section.

Table 4
Animal performance of bulls in different treatment of energy density and slaughter groups.

Animal performance	Slaughter group								SEM	p-value		
	120 kg	200 kg	400 kg		600 kg		780 kg			Feed	Weight	Feed × weight
	n = 8	n = 10	NE n = 9	HE n = 9	NE n = 9	HE n = 9	NE n = 9	HE n = 9				
Slaughter age (d)	94	147	271	271	375	366	502[A]	481[B]	5.50	0.1744	< 0.0001	0.5561
Final live weight (kg)	121	200	399	401	595	595	777	784	4.05	0.6334	< 0.0001	0.9597
Warm carcass weight (kg)	63	105	228	226	345	352	469	462	2.84	0.9257	< 0.0001	0.3701
Cold carcass weight (kg)	61	102	224	220	339	346	463	456	2.74	0.9357	< 0.0001	0.2304

Means within a slaughter group with different superscripts differ significantly.

Table 5
Average dressing percentage and carcass tissue composition of bulls in different slaughter groups.

Carcass	Slaughter group					SEM	p-value		
	120 kg n = 8	200 kg n = 10	400 kg n = 18	600 kg n = 18	780 kg n = 18		Feed	Weight	Feed × weight
Dressing percentage	52.2^{A}	52.7^{A}	56.7^{B}	58.5^{C}	59.7^{D}	0.44	0.4784	< 0.0001	0.0510
Muscle	67.5^{A}	67.8^{A}	67.2^{A}	65.3^{B}	63.5^{C}	0.52	0.6566	< 0.0001	0.7231
Tendon	6.0^{AB}	5.9^{B}	6.4^{A}	6.1^{AB}	5.9^{B}	0.15	0.2388	0.0683	0.5784
Fat	2.7^{A}	6.0^{B}	9.1^{C}	12.7^{D}	16.3^{E}	0.56	0.9888	< 0.0001	0.6179
Bone	23.1^{A}	19.6^{B}	16.5^{C}	15.0^{D}	13.2^{E}	0.22	0.8211	< 0.0001	0.4754

Means within a row sharing the same superscript are not significantly different.

3.5. Beef cuts and tissues

The following percentages of cuts and tissue composition of individual cuts are displayed in Table 7 and agree widely with data reported from Augustini et al. (1992) and Dannenberger et al. (2006). The share of cuts of the forequarter increased during growth, except for the front shanks. Fore and hind shank shares, as well as the round decreased in higher weight groups ($p < .05$). The percentage of muscle tissue in the individual cuts of beef decreased ($p < .05$) during growth except for neck, chuck and shanks. The greatest decrease of muscle tissue could be observed in the plate and flank, where muscle percentages decreased by 21.8 and 23.8%, respectively. Likewise, the percentage of bone tissue in all bone containing cuts decreased ($p < .05$) on average by 10% between 120 and 780 kg. The abatement of muscle and bone tissue is associated with an increasing proportion of fat tissue in all cuts ($p < .05$). Especially brisket, plate and flank showed high fat depositions of 24.7, 33.0 and 30.7%, respectively. Even the amount of tendons per cut changed during growth. Fore and hind shanks as well as loin and round showed increasing amounts of tendon tissue, while the tendon percentages of neck, brisket, plate and flank decreased in higher weight groups ($p < .05$). The growth of forequarter cuts is connected with progressive maturing of the bulls, but the late maturity of the breed slows down this process. Hence, valuable hindquarter cuts as loin and tenderloin showed the same proportions, even in high weight groups. As a consequence, the lean meat yield increased, because fat accretion increased only slowly while the amount of bone tissue decreased.

Significant differences between NE and HE feeding groups could be observed for the following particular cuts and their tissues. The neck percentage of HE bulls in weight group 400 kg was 0.6% higher ($p < .05$) than the NE treatment group. A reverse effect was detected in the 600 kg weight group, where the NE animals had 0.5% higher ($p < .05$) neck cut percentage, which is in agreement with data reported from Augustini et al. (1992). Another difference between both feeding groups became apparent for shoulder percentage in the 600 kg weight group, where HE fed bulls showed 0.7% higher ($p < .05$) shoulder percentage. Furthermore, the plate muscle percentage of the HE bulls in weight group 780 kg was 4% higher ($p < .05$) than those of the NE treatment group at the same final weight. Shoulder and loin of NE 400 kg bulls showed 1.5% and 1%, respectively, higher ($p < .05$) tendon percentage than the HE animal group. The fat and bone percentage of individual cuts showed no difference between treatment groups. Differences between feeding groups occurred mostly in forequarter cuts of high weight groups, which indicates that HE fed bulls matured slightly faster than bulls of the NE treatment group.

Data of Dannenberger et al. (2006) indicate significant higher neck, round and sirloin percentage in German Simmental compared to German Holstein bulls. Comparing studies which used the same cutting methods on Holstein-Friesian and Hereford carcasses, Holstein-Friesian showed higher loin, tenderloin and round percentage while subcutaneous fat yield of the round was superior in early maturing Hereford cattle (Huuskonen, Pesonen, Kämäräinen, & Kauppinen, 2013; Manninen et al., 2011; Pesonen et al., 2013). Comparison of dressing percentage and carcass composition with international studies that did not operate according to European Union standards is difficult, because carcass dressing procedures may differ between the countries and carcass cutting methods vary throughout all countries and regions.

3.6. Rib eye area and meat quality traits

Rib eye area and meat quality traits of growing modern type Fleckvieh bulls are displayed in Table 8. The rib eye area as well as the IMF content increased ($p < .05$) during growth up to 87cm^2 and 3.3%, respectively. Comparison to former studies (Geuder et al., 2012; Sami et al., 2004) indicated a larger rib eye area of present bulls. The IMF content increased during the last decades (Schwarz & Kirchgessner, 1991), which is in agreement with data of Nuernberg et al. (2005) and Geuder et al. (2012). Meat color changed significantly during growth. The meat darkened, while redness intensified and yellowness decreased to 3.3 in 400 kg weight group and increased again in higher weight groups. The meat lightness widely corresponds to former studies (Nuernberg et al., 2005; Sami et al., 2004; Schwarz & Kirchgessner,

Table 6
Average percentages of carcass quarters and quarter tissues of bulls in different slaughter groups.

Carcass quarters		Slaughter group					SEM	*p*-value		
		120 kg n = 8	200 kg n = 10	400 kg *n* = 18	600 kg n = 18	780 kg n = 18		Feed	Weight	Feed × weight
Forequarter	Proportion	43.8^{A}	43.3^{A}	45.4^{B}	46.5^{C}	47.4^{D}	0.25	0.8573	< 0.0001	0.7913
	Muscle	64.8^{A}	64.7^{AB}	65.4^{A}	64.9^{A}	63.1^{B}	0.54	0.7447	0.0166	0.9688
	Tendon	6.0^{A}	5.9^{A}	6.1^{A}	5.2^{B}	5.3^{B}	0.18	0.4936	0.0001	0.2320
	Fat	3.1^{A}	7.1^{B}	9.9^{C}	13.3^{D}	16.9^{E}	0.55	0.8456	< 0.0001	0.7521
	Bone	25.7^{A}	21.9^{B}	18.2^{C}	16.2^{D}	14.1^{E}	0.25	0.8636	< 0.0001	0.5842
Hindquarter	Proportion	56.2^{A}	56.7^{A}	54.6^{B}	53.5^{C}	52.5^{D}	0.25	0.7366	< 0.0001	0.7916
	Muscle	70.0^{A}	70.5^{A}	69.1^{A}	66.2^{B}	64.4^{C}	0.55	0.6595	< 0.0001	0.5576
	Tendon	6.1^{A}	6.0^{A}	6.7^{B}	6.9^{B}	6.6^{B}	0.16	0.1721	0.0007	0.9614
	Fat	2.4^{A}	5.2^{B}	8.6^{C}	12.3^{D}	15.8^{E}	0.60	0.8867	< 0.0001	0.5160
	Bone	21.2^{A}	17.9^{B}	15.2^{C}	14.0^{D}	12.4^{E}	0.23	0.5490	< 0.0001	0.4392

Means within a row sharing the same superscript are not significantly different.

Table 7
Average percentages of beef cuts and tissue composition of cuts of bulls in different slaughter groups.

Beef cuts		Slaughter group					SEM	p-value		
		120 kg n = 8	200 kg n = 10	400 kg n = 18	600 kg n = 18	780 kg n = 18		Feed	Weight	Feed × weight
Neck	Proportion	7.2^{A}	6.8^{A}	7.8^{B}	7.8^{B}	8.1^{B}	0.15	0.9428	< 0.0001	0.0326
	Muscle	66.8^{A}	69.1^{B}	73.2^{C}	75.6^{D}	74.2^{CD}	0.63	0.2846	< 0.0001	0.6483
	Tendon	4.9^{A}	4.1^{AB}	3.6^{B}	2.6^{C}	2.8^{C}	0.28	0.7939	< 0.0001	0.1529
	Fat	3.3^{A}	6.4^{B}	7.4^{B}	9.0^{C}	11.7^{D}	0.54	0.4089	< 0.0001	0.8127
	Bone	24.8^{A}	20.0^{B}	15.3^{C}	12.4^{D}	11.0^{E}	0.46	0.9024	< 0.0001	0.6136
Chuck	Proportion	9.3^{A}	8.8^{A}	9.8^{B}	10.5^{C}	10.9^{D}	0.16	0.6468	< 0.0001	0.4763
	Muscle	68.2	69.7	68.8	69.2	68.1	0.61	0.9393	0.3650	0.8239
	Tendon	4.5^{A}	4.6^{A}	5.4^{B}	4.4^{A}	4.3^{A}	0.22	0.0380	0.0015	0.8108
	Fat	2.4^{A}	4.5^{B}	7.6^{C}	9.9^{D}	13.5^{E}	0.55	0.8910	< 0.0001	0.8083
	Bone	24.4^{A}	20.6^{B}	17.7^{C}	16.0^{D}	13.4^{E}	0.47	0.5051	< 0.0001	0.5922
Shoulder	Proportion	13.7^{AB}	13.3^{A}	14.0^{B}	14.5^{C}	14.4^{C}	0.15	0.7863	< 0.0001	0.0579
	Muscle	70.6^{A}	68.6^{AB}	69.2^{AB}	68.2^{B}	66.1^{C}	0.61	0.3798	< 0.0001	0.9806
	Tendon	6.6	6.5	7.4	6.9	7.3	0.36	0.3569	0.2756	0.0206
	Fat	2.6^{A}	7.0^{B}	8.7^{C}	12.1^{D}	14.9^{E}	0.62	0.2989	< 0.0001	0.7465
	Bone	20.1^{A}	18.0^{B}	14.6^{C}	12.7^{D}	11.6^{E}	0.24	0.4394	< 0.0001	0.2563
Brisket	Proportion	8.8^{A}	10.2^{B}	10.5^{BC}	10.6^{C}	11.2^{D}	0.16	0.4213	< 0.0001	0.2861
	Muscle	63.3^{A}	61.4^{A}	58.2^{B}	54.3^{C}	51.2^{D}	0.82	0.6709	< 0.0001	0.6352
	Tendon	4.8^{A}	4.4^{A}	4.5^{A}	2.8^{B}	2.8^{B}	0.36	0.0605	< 0.0001	0.0732
	Fat	5.9^{A}	12.9^{B}	18.3^{C}	25.0^{D}	30.6^{E}	0.93	0.4867	< 0.0001	0.4755
	Bone	25.0^{A}	20.5^{B}	18.5^{C}	17.4^{D}	14.8^{E}	0.35	0.3571	< 0.0001	0.8667
Fore shank	Proportion	4.6^{A}	4.1^{B}	3.2^{C}	2.9^{D}	2.6^{E}	0.05	0.2959	< 0.0001	0.7501
	Muscle	40.7	42.3	42.8	42.5	42.1	0.69	0.5604	0.3826	0.8479
	Tendon	11.0^{A}	12.8^{AB}	14.0^{BC}	14.8^{C}	16.3^{D}	0.56	0.2026	< 0.0001	0.8896
	Fat	0.0^{A}	0.2^{A}	0.4^{A}	1.4^{B}	2.4^{C}	0.29	0.7590	< 0.0001	0.9208
	Bone	47.7^{A}	43.6^{B}	42.2^{B}	40.5^{C}	38.6^{D}	0.65	0.7468	< 0.0001	0.7870
Loin	Proportion	7.9^{A}	8.0^{A}	8.1^{AB}	8.3^{B}	8.1^{AB}	0.12	0.8930	0.1015	0.8857
	Muscle	64.7^{AB}	65.7^{A}	65.6^{A}	63.9^{B}	62.7^{B}	0.65	0.9742	0.0022	0.9734
	Tendon	4.3^{A}	3.9^{A}	6.5^{B}	6.2^{B}	6.1^{B}	0.33	0.6956	< 0.0001	0.1515
	Fat	1.7^{A}	4.7^{B}	6.9^{C}	9.9^{D}	13.9^{E}	0.58	0.5780	< 0.0001	0.4892
	Bone	28.5^{A}	25.1^{B}	20.2^{C}	19.2^{C}	16.5^{D}	0.59	0.4194	< 0.0001	0.6383
Tenderloin	Proportion	2.1^{A}	2.3^{B}	2.2^{BC}	2.1^{AC}	2.1^{A}	0.04	0.7084	0.0022	0.9728
	Muscle	90.8^{A}	86.9^{B}	85.7^{B}	82.5^{C}	80.6^{D}	0.77	0.8082	< 0.0001	0.7338
	Tendon	4.0^{A}	5.0^{B}	4.5^{AB}	3.8^{A}	4.0^{A}	0.29	0.2224	0.0426	0.4537
	Fat	4.3^{A}	7.6^{B}	9.4^{B}	13.1^{C}	14.7^{C}	0.71	0.5446	< 0.0001	0.3892
	Bone	-	-	-	-	-	-	-	-	-
Plate	Proportion	3.9^{A}	5.0^{B}	6.0^{C}	6.5^{D}	7.2^{E}	0.16	0.6291	< 0.0001	0.5411
	Muscle	73.8^{A}	71.9^{A}	64.8^{B}	57.1^{C}	52.0^{D}	1.20	0.8204	< 0.0001	0.1278
	Tendon	8.9^{AB}	9.6^{A}	7.7^{B}	4.8^{C}	4.6^{C}	0.57	0.7573	< 0.0001	0.5698
	Fat	1.7^{A}	6.1^{A}	16.8^{B}	28.1^{C}	34.7^{D}	1.36	0.7783	< 0.0001	0.1523
	Bone	14.5^{A}	11.6^{B}	10.1^{C}	9.4^{C}	8.2^{D}	0.44	0.3505	< 0.0001	0.9345
Flank	Proportion	3.0^{A}	3.3^{AB}	3.6^{B}	4.2^{C}	4.3^{C}	0.16	0.9061	< 0.0001	0.9863
	Muscle	76.1^{A}	68.5^{B}	62.0^{C}	55.4^{D}	52.3^{D}	1.32	0.2247	< 0.0001	0.4275
	Tendon	19.1^{A}	15.3^{B}	14.5^{B}	13.6^{BC}	12.1^{C}	0.79	0.6192	< 0.0001	0.6126
	Fat	4.2^{A}	15.7^{B}	23.0^{C}	30.3^{D}	34.9^{E}	1.55	0.4572	< 0.0001	0.6098
	Bone	-	-	-	-	-	-	-	-	-
Round	Proportion	31.3^{A}	30.9^{A}	29.2^{B}	27.2^{C}	26.4^{D}	0.19	0.3449	< 0.0001	0.1451
	Muscle	76.6^{A}	76.8^{A}	75.6^{A}	73.7^{B}	72.8^{B}	0.48	0.4641	< 0.0001	0.8470
	Tendon	3.1^{A}	2.9^{A}	4.0^{B}	4.9^{C}	4.7^{C}	0.22	0.1709	< 0.0001	0.7325
	Fat	2.9^{A}	5.1^{B}	7.1^{C}	8.5^{D}	10.8^{E}	0.50	0.9113	< 0.0001	0.7968
	Bone	17.3^{A}	15.2^{B}	13.3^{C}	12.9^{C}	11.7^{D}	0.19	0.5767	< 0.0001	0.2428
Hind shank	Proportion	7.8^{A}	7.0^{B}	5.3^{C}	4.9^{D}	4.3^{E}	0.10	0.2301	< 0.0001	0.3698
	Muscle	39.4^{A}	42.6^{BC}	40.9^{AD}	42.9^{C}	41.4^{BD}	0.54	0.2200	0.0004	0.7864
	Tendon	13.6^{A}	15.3^{AB}	16.1^{BC}	17.3^{CD}	18.1^{D}	0.63	0.4213	0.0001	0.3043
	Fat	0.0^{A}	0.9^{AB}	1.4^{B}	3.5^{C}	5.5^{D}	0.46	0.7306	< 0.0001	0.7989
	Bone	46.2^{A}	40.5^{B}	40.9^{B}	35.5^{C}	34.2^{C}	0.59	0.5791	< 0.0001	0.7223

Means within a row sharing the same superscript are not significantly different.

1991), but was lower than described by Terler, Velik, Kitzer, & Kaufmann, 2016. Meat redness and yellowness was consistent with data reported from Geuder et al. (2012), which processed the meat sample in the same way as in the present study, but lower than described by Sami et al. (2004) and Terler, Velik, Kitzer, & Kaufmann, 2016. Differences in meat color can occur through meat processing practices such as storage time and cooling and thereby pH value, but color is also influenced by time in lairage, nutrition, cattle breed and gender (Murray, 1989; Page, Wulf, & Schwotzer, 2001). The meat pH decreased within 24 h post mortem to an average of 5.5 and remained constant during 14d of cold storage. PH values 1 h and 24 h post mortem were in agreement with data reported from Geuder et al. (2012) and pH after 14d of storage consented with Sami et al. (2004). An average ageing loss of 5% was measured after 14d cold storage, which was higher than described in previous studies (Geuder et al., 2012; Sami et al., 2004). Cooking loss increased significantly in high weight groups and was comparable to data reported from Terler, Velik, Kitzer, & Kaufmann, 2016, but greater than described by Sami et al. (2004) and Geuder et al. (2012). Since IMF content in those studies was at a similar level, cooking loss seems to be independent of muscle IMF content. Former studies indicated that cooking loss can be altered by using variations of cooking or grilling methods and temperatures (Obuz, Dikeman, Grobbel, Stephens, & Loughin, 2004; Yancey, Apple, & Wharton, 2016). Concerning meat tenderness, high shear forces were measured in low weight groups,

Table 8
Rib eye area and meat quality traits of bulls in different slaughter groups.

Rib eye area and meat quality traits	Slaughter group					SEM	p-value		
	120 kg n = 8	200 kg n = 10	400 kg n = 18	600 kg *n* = 18	780 kg n = 18		Feed	Weight	Feed × weight
Rib eye area (cm^2)	20.7^{A}	30.2^{B}	53.8^{C}	74.2^{D}	87.0^{E}	2.31	0.6361	< 0.0001	0.5515
pH, 1 h	6.8	6.8	6.8	6.8	6.8	0.05	0.2869	0.9418	0.1543
pH, 24 h	5.6^{A}	5.6^{A}	5.5^{B}	5.4^{B}	5.4^{B}	0.02	0.2659	0.4179	0.6458
pH, 14d	5.6	5.6	5.6	5.5	5.5	0.02	0.4962	0.4537	0.4183
IMF (%)	0.5^{A}	0.7^{A}	1.3^{B}	2.4^{C}	3.3^{D}	0.20	0.4108	< 0.0001	0.7271
Ageing loss, 14d (%)	4.9^{AB}	5.8^{A}	4.6^{B}	4.8^{B}	5.1^{AB}	0.31	0.2410	0.0775	0.5646
Cooking loss (%)	26.0^{A}	27.4^{A}	29.7^{B}	30.6^{B}	30.7^{B}	0.76	0.3539	0.0002	0.9576
Shear force (N)	61.9^{A}	86.5^{B}	49.2^{C}	42.1^{C}	46.0^{C}	3.79	0.7912	< 0.0001	0.4233
	42.2^{A}	42.0^{A}	37.2^{B}	36.9^{B}	34.6^{C}	0.56	0.4147	< 0.0001	0.1774
L*	5.8^{A}	4.6^{A}	8.9^{B}	11.0^{C}	13.2^{D}	0.49	0.6723	< 0.0001	0.8162
a*	4.5^{A}	3.6^{AB}	3.3^{B}	4.6^{A}	4.2^{A}	0.37	0.6269	0.0341	0.2603
b*									

Means within a row sharing the same superscript are not significantly different.

while 600 kg and 780 kg weight groups showed shear forces of 42.1 N and 46.0 N, respectively. Shear forces of animals in high weight groups were lower compared to former studies using the same cooking method, temperature and cattle breed (Geuder et al., 2012; Sami et al., 2004; Schwarz & Kirchgessner, 1991; Terler, Velik, Kitzer, & Kaufmann, 2016).

Regarding differences in cattle breeds, Holstein cattle used in studies by Geuder et al. (2012) showed smaller rib eye area, but higher IMF content. Differences in meat pH and meat lightness could not be observed, but meat tenderness was superior in Fleckvieh compared to Holstein cattle. The early maturing Hereford breed featured comparable meat pH, meat lightness and rib eye area, but higher IMF content and shear force (Papaleo Mazzucco et al., 2016; Pesonen et al., 2013). In summary, Longissimus thoracis of modern type Fleckvieh bulls showed larger rib eye area, but similar IMF content and meat lightness as previous studies on Fleckvieh bulls. Meat quality traits were characterized by higher ageing and cooking loss, but better tenderness compared to previous studies. Fattening Fleckvieh bulls to high final live weights of 780 kg had only a limited effect on IMF, but increased rib eye area and intensified meat color at consistently good tenderness.

4. Conclusion

Comparison with former studies indicates that modern type Fleckvieh bulls grow faster than bulls of past decades and the present study shows that feeding high energy rations shortens the fattening period for a high target weight as 780 kg. Since late maturing cattle breeds are efficient in exploiting high energy diets, only minor effects of the dietary energy concentration on carcass weights and the tissue compositions of carcass, quarters and cuts in NE and HE treatment groups were observed. The characteristics of a late maturing cattle breed became obvious during growth, when bulls produced large, lean carcasses with high muscle and low fat content. Percentage of fat in the carcasses increased primarily at the expense of bone and subsidiary muscle tissue, while the tendon content remained unchanged. Meat quality traits like IMF, meat color and tenderness increased in high final weight groups. Hence, fattening Fleckvieh bulls to high final weights as 780 kg can be recommended. In summary, modern type Fleckvieh bulls meet the needs of meat markets which target high production rates of lean beef.

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Declaration of Competing Interest

None.

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