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Hereditary and environmental effects on the quality of beef

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Results of studies on beef production are shown based on fattening and feeding trials with bulls and heifers conducted in the last two decades by the former Bavarian Institute of Animal Production, Grub (near Munich), Germany. The examinations on meat quality were done by the former Federal Institute on Meat Science, Kulmbach, (northern Bavaria), Germany. Also the genetic parametres (variation, heritabilities, genetic correlations) of various meat quality traits are discussed based on records from the two Bavarian progeny test stations. Fattening trials and the test stations records supplied information about the meat quality of the Bavarian dual-purpose breeds and the most important European beef breeds and their crossbreds. The trials also revealed the effect on meat quality of different forages, feeding regimen, slaughter maturity, feeding intensity, category (sex) and castration age. Moreover, some trials showed the effect of varying age at slaughter on beef quality, specially on its tenderness.

KEY WORDS: beef / cattle / crossing / fattening / meat quality

In Bavaria, southeast of Germany, about half the farmers' income is derived from cattle industry, *i.e.* selling milk and beef. The self-sufficiency degree in milk and beef is about 180% and 230%, respectively. Over half the produced beef is sold outside

Bavaria, chiefly in Italy and other mediterranean countries. In most parts of Bavaria there are favourite natural conditions for grassland and dairy farming, and in arable regions for production of energy-reach maize silage for fattening bulls. These attributes, together with the relatively small mean farm size are the main reasons why in Bavaria the dual-purpose German Simmental *(Fleckvieh)* cattle are kept, accounting for 80% of all cows. In the last decades the breed has mainly been selected for milk which caused losses in muscularity. The second cattle breed is *Braunvieh* (12%) spread in the southwest of Bavaria. Through crossing with Brown Swiss from the USA the breed has greatly changed towards a dairy-purpose breed.

1. Investigations and methods for evaluating the quality of meat

The decreasing carcass quality of Simmental cattle (muscularity, lean content) gave rise to two bigger investigations aiming at examining six European beef breeds for suitability for commercial crossing with *Braunvieh* and G. Simmental. The investigations were done by the former Bavarian Institute of Animal Production (BIAP) in Grub in cooperation with state farms and breeding societies. As the fattening trials with bulls and heifers differed with regard to diet composition, feeding intensity and slaughter age, beside the effects of breed and sex (category) also the influence of slaughter age and of various environmental factors on meat quality could be examined. Apart from crossing, also fattening trials with purebred bulls of various beef breeds and of the endangered Bavarian dual-purpose breeds were conducted. In addition, some special trials were carried out to get information about the effects on meat quality of different forages and animals' age varying to a greater extent.

All bulls were intensively fattened with *ad lib*. maize silage plus grain (cereal or maize) and soya meal, *i.e.* in the same way as in specialized Bavarian fattening farms. The heifers were kept indoors the whole time or were for one or two seasons fed on grass pasture. Indoors the heifers got mainly grass, grass silage and hay, and in winter also some grain or grass cobs. To get comparable experimental units, the animals were divided into groups according to breed, sire, age and live body weight. For statistical evaluation in the crossing trials the effects of sires were considered as random within breed. Therefore F-value for breed = DQ-breed/DQ sires (within breed). In other trials the sire variation (fixed effect) was eliminated before the differences between means were tested for significance.

Beside the carcasses from trials, also the bull carcasses from the progeny test stations Westerschondorf (since 1990) and Schwarzenau (since 2001) have routinely been examined in Grub for some beef quality traits. These bulls were also fed maize silage and concentrate up to a final age of 450 days.

At the end of the trials or the testing period the animals were fasted for 24 h and slaughtered in the experimental slaughter house in Grub. The carcasses from the trials were examined for meat quality by the former German Federal Institute for Meat Science (FIMS), Kulmbach, and those from the progeny testing stations by the BIAP in Grub. All determinations were done on *m. longissimus dorsi* muscle. The simple quality criteria were applied according to the following procedure still being in use.

One day after slaughter a two-rib-section (ribs 9 and 10) is taken and the pH_{24} value, as indicator of DFD beef, and the MINOLTA-reflexion values – brightness, redness and yellowness are measured. Then the two-rib-section is deboned and one of the two muscle discs is cut to pieces, minced and then used for determining the intramuscular fat (IMF) content by the NIR-method. However, the used standard curves are fixed on chemically determined values. The other muscle disc is packed in plastic bag under moderate vacuum and aged for 13 days at 3°C. The disc is then unpacked and grilled until 70°C core temperature. Then small meat cylinders are punched out to measure shear force (maximum force) and shear energy (force × way) with eight-fold repetition.

At the FIMR Kulmbach also taste scoring was carried out by a panel of six trained persons. A 6-point scale was used to evaluate tenderness, texture, juiciness and flavour (6 is always best). For this a further rib steak was taken and prepared in the same way as the muscle disc for determining shear force and shear energy. Furthermore, at the FIMS, Kulmbach, determined was the content and solubility of the connective tissue with the amino acid hydroxyproline that is only found in the connective tissue of muscles and always in the same proportion. Beyond that also histological and further chemical or physical investigations were alternatively performed.

2. Importance of the meat quality criteria

Tenderness is generally considered the most important property of beef. It depends mainly on the presence of connective tissue, but more on its structure and solubility than on its content. Juiciness ranks second, while third is flavour which can be improved by adding fat or spices. As shown in Figure 1 (based upon data from a bull fattening trial with Bavarian dual-purpose breeds), the values for tenderness (sens.) and shear force are closely related to juiciness, flavour and IMF content. This means, that a tough beef is mostly also dryer and less aromatic. The correlation of juiciness with tenderness is partly caused by different grill losses. Tenderness is also affected by the IMF content, because fat is deposited in the strings and tracts of connective tissue, so that this is less firm and easier to break up. While the juiciness is strongly reduced by higher grill losses, the drip losses show the relation neither to the several times higher grill losses nor to other eating quality criteria. This is due to the different origin of water: at aging, the unbound water in capillaries and in the free cell room is lost. The bound water is hold tightly in the filament structure of the muscle cells and exudes at grilling or cooking of beef. It should also be noticed that flavour correlates with tenderness (sens.) and shear force much closer than with fat content, which accounts for 14% ($14=r^2\times100$) of the flavour point variation. In another trial conducted on crossbreds with intensive beef breeds this value was only 4%. These loose relations can be explained by the relatively small IMF content in the dual-purpose and beef breeds and the fact, that beside triglycerides some further flavour substances are involved leading to the special beef

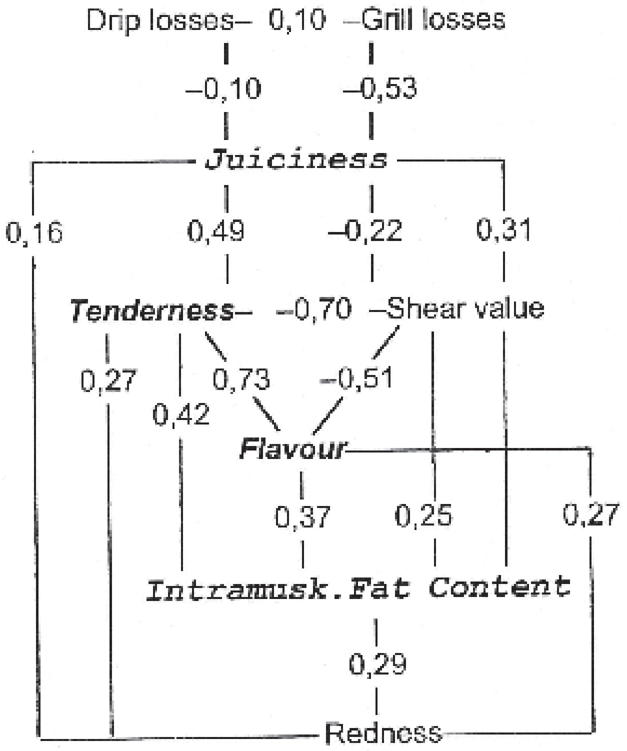

Fig. 1. Correlations between criteria of meat quality from a bull fattening trial with Bavarian breeds.

flavour. At lower IMF content the triglyceride flavour is masked by the beef flavour. In the USA much higher correlations were found, but with Anguses and Herefords, the breeds with the highest IMF content. Redness finally correlates positively with flavour and tenderness (sens.) and negatively with shear force, whereas the relations to brightness are converse. However, brighter beef is generally preferred, especially in mediterranean countries.

3. Results of breed comparisons

3.1. Crossing trial with *Braunvieh*

The first investigations on beef quality were made in a trial with *Braunvieh* (1984-1987) for commercial crossing. The animals for fattening were sired by 5 bulls – *Braunvieh* (control), Simmental, Blond d'Aquitaine (Blond), Limousine and Piedmontese – mated to *Braunvieh* cows. The bulls tested for beef quality were intensively fattened on maize silage (whole plant, chaffed) and all the same amount of concentrates. The bulls were divided in two similar groups slaughtered at the age of 470 and 520 days. As the number of bulls was limited and the interactions with the effect "slaughter age" appeared not significant, the animals of the two age levels were pooled. In this case the bulls were compared at the same feeding intensity and slaughter age. But the late maturing crossbreds of Blond and Piedmontese had not reached the optimum slaughter maturity, whereas *Braunvieh*, at any rate overstrained due to the high feeding intensity, was slaughtered somewhat too late (Tab. 1).

Braunvieh showed 3.4% IMF content, *i.e*. significantly more than the other genotypes, which was partly caused by the more advanced maturity. The higher fat content

Table 1. Meat quality traits in purebred *Braunvieh* (BV) and crossbred bulls. Slaughter ages pooled [Augustini et al., FIMS Kulmbach 1992]

Trait	Pure *Braunvieh*[1] (n=33)	Simmental × BV (n=34)	Blond × BV (n=35)	Limousine × BV (n=38)	Piemontese × BV (n=37)
Shear force (kg)	4.33	-0.25	-0.52	-0.29	-0.15
Connective tissue (%)	2.23	0.25	-0.04	-0.05	-0.30**
Solubility of connec. tiss. (%)	17.32	1.03	0.70	1.17	0.33
Tenderness[2] (p)	3.88	0.17	0.42	0.32	0.12
IMF content (%)	3.4	2.6*	1.9**	2.4**	2.2**
Flavour[2] (p)	4.02	-0.20	-0.04	-0.27	-0.05
Drip losses (%)	1.54	0.16	0.46	0.09	0.31
Grill losses (%)	19.04	-1.16	1.25	-0.86	-0.04
Juiciness[2] (p)	4.11	-0.08	0.04	0.08	-0.02
Brightness (L)	35.8	-0.58	0.96	0.40	-1.00
Redness (a)	13.8	-0.28	-0.56	-0.69	-0.04

[1]Means share of Brown Swiss = ca. 2/3.
[2]6-point scale, 6 = the best.
*P<5%; **P<1%.

could also be the main reason for the better flavour. But for the most important traits, *i.e.* shear force, tenderness (sens.) and grill losses, the sire breed Blond appeared best (despite of its low IMF content), followed by Limousine, Simmental, Piedmontese and *Braunvieh* sire breeds. The offspring by Simmental sires performed well, despite of the higher content of connective tissue that was found lowest in Piedmontese progeny, in which the genetic disposition for double muscling might be expressed. Generally, it is to point out that the differences between the genetic groups appeared relatively small and were not always in accordance with the results for other breed comparisons. But this is less surprising in light of the wide inter-individual differences, the small number of sires per breed and the possibility of existing specific combination effects.

3.2. Crossing trial with German Simmental

In the crossing trial with German Simmental, running in three parts from 1992 to

2001, beside breeds tested with *Braunvieh*, also Charolaise, German Angus and White-Blue Belgian (WB) breeds were examined. The G. Angus, which came into being mainly in the year1960, consists by 2/3 of Aberdeen Angus and 1/3 of German dual- purpose breeds. In the trial half the bulls were red and the other half were black (from German Black-and-White). Random samples of 10 bulls per breed were taken, which were only performance-tested. In the trial part 1 and 2 the same Simmental test bulls were used. The bulls were weighed every 4 weeks and fed maize silage and concentrate. Due to the different muscle growth predisposition, three feeding intensity levels were set by applying differentiated amount of concentrate. Each genotype was tested at two intensity levels, except the WB crosses, which were fattened in the test station together with Simmental progeny. To meet the varying maturity age, different slaughter age levels were fixed for the subclasses "breed × intensity level". The maturity age of the genotypes was assessed by measuring the body weight and recording the daily gains. Thus, the bulls could be slaughtered about the optimum maturity stage (Tab. 2).

The second column of Table 2 contains the means for Simmental crossbreds for the three trial parts. The double muscled breeds – Piedmontese and WB crossbreds – were found best in shear force and tenderness (sens.), especially WB, by 1/3 superior to Simmental. Then followed Charolaise, Limousine, G. Angus, Blond and Simmental crossbreds. The superiorities to Simmental might be caused principally by the higher solubility of connective tissue. The highest IMF content was found in G. Angus, followed by Simmental and Charolaise crossbred bulls. The IMF content of Blond, Piedmontese and Limousine crossbred bulls was similar and markedly lower, while that of WB crossbreds was by far the lowest. There were only small inter-genotype differences in water losses and in muscle juiciness. Only WB bulls showed greater water losses, nevertheless in juiciness they proceeded nearly as well as Simmentals. The crossbreds with beef breeds showed also higher values for brightness and apart from Limousine, also for redness. The highest values were found in WB sires' offspring, whereas in brightness Charolaise sires were found the second. The value for redness, which depends also on age, was lowest in Limousine and second lowest in Simmental crossbred bulls.

3.3. Fattening trial with Bavarian dual-purpose breeds

A bull fattening trial should show, how the endangered Bavarian dual-purpose breeds – Pinzgauer, Original (O.) *Braunvieh* and *Murnau-Werdenfelser* – come off in beef characteristics, especially in beef quality traits, in comparison with the main breed Simmental. As no greater differences had been observed in the optimum slaughter age in the progeny test station, the four breeds were slaughtered at the same age of 500 days (Tab. 3).

This trial revealed astonishing facts, but not for experienced butchers, which have always pointed out that the beef from Pinzgau cattle is more tender than that of other Austrian or Bavarian breeds. All the beef quality criteria used, principally the tenderness, showed the Pinzgauer bulls to be the best. Shear force and tenderness (sens.)

Table 2. Meat quality traits in purebred Bavarian Simmental (S) and Bavarian Simmental crossbred bulls (1991-2001)
Random samples: 10 sires (test bulls) per breed mated to Simmental cows. Intensity levels: m – medium, h – high, vh – very high (Rosenthal-Herzog, PWS, 1997: Final report of part 1+2)

Trait	Part 1-3 ∅ group Simmental (mean)	Trial part 1, h + vh: Charolais x Simmental (n=6)	Trial part 1, h + vh: Blond d'Aquitaine x Simmental (n=7)	Trial part 1, h + vh: Limousine x Simmental (n=5)	Trial part 2, h + vh: Piemontese x Simmental (n=7)	Trial part 2, m + h: German Angus[1] x Simmental (n=9)	Trial part 3, vh: White-Blue Belgian x Simmental (n=3)
Shear force (kg)	5.56	-0.89	-0.27	-0.61	-1.01	-0.21	-1.66
Tenderness[2] (p)	2.24	0.30	0.01	0.14	0.86	0.47	1.16
Connective tissue (%)	2.30	-0.08	-0.18	-0.21	-0.14	-0.04	–
Solubility of connective tissue (%)	11.66	-0.42	-0.19	-0.24	-1.15	-0.64	–
IMF content (%)	1.71	-0.27	-0.19	-0.21	-0.30	0.47	-0.91
Flavour[2] (p)	2.69	0.07	-0.11	0.01	0.10	0.47	-0.30
Drip losses (%)	1.17	0.37	0.27	0.15	0.71	0.17	0.61
Grill losses (%)	17.11	0.16	0.10	0.21	0.71	-0.47	2.30
Juiciness[2] (p)	2.94	0.08	0.10	0.04	0.17	0.09	-0.06
Brightness (L*)	38.61	1.66	0.65	0.68	0.74	0.65	2.30
Redness (a*)	16.18	0.39	0.21	-0.21	1.74	0.82	2.00

[1] Mean share of Aberdeen Angus = ca. 3/4
[2] 6-point scale, 6 = the best

Table 3. Meat quality traits in bulls of Bavarian dual-purpose cattle breeds. Participating institutions: FIMS Kulmbach, TU Weihenstephan, BIAP Grub [Augustini et al., FIMS Kulmbach 1998]

Trait	Simmental (n=24)	Pinzgauer[1] (n=27)	Original Braunvieh (n=19)	Murnau-Werdenf. (n=27)
Final weight (kg)	627	631	559	589
Fat class[2] (p)	2.85	2.95	2.60	2.79
Shear force (kg)	6.22	4.72*	5.99	6.39
Tenderness[3] (p)	3.32	4.33*	3.40	3.06
IMF content (%)	2.03	2.51	1.98	1.85
Flavour[3] (p)	3.33	4.04*	3.30	3.41
Drip losses (%)	0.88	0.66	1.23	1.05
Grill losses (%)	19.2	16.1*	18.2	18.3
Juiciness[3] (p)	3.63	4.16*	3.94	3.79
Redness (a)	17.0	18.4*	17.3	17.4

[1]*P<5%, in comparison with Simmental.
[2]5-point scale.
[3]6-point scale, 6 = the best.

were by -1.50 kg and +1.01J (or relatively by -1/4 and +1/3) better, respectively, than in Simmentals. The values of flavour (+0.71 p), grill losses (-3.1) and juiciness (+0.53) appeared also markedly better. Simmental, O. *Braunvieh* and *Murnau-Werdenfelser* bulls showed similar results with, however, slight advantages in favour of O. *Braunvieh*.

3.4. Breed comparison at the progeny test station

At the station Westerschondorf also *Gelbvieh* ("Yellow cattle") and crosses Blond × *Braunvieh* were tested. The number of *Gelbvieh* is continually decreasing. Today the breed can only be met in northwest Bavaria, in the arable region around Würzburg. Due to the good results of Blond in the crossing trial with *Braunvieh*, the former was dominant in commercial crossings with *Braunvieh* from 1987 to 2002. However, Blond breed was recently replaced by WB, since their crosses with *Braunvieh* are sold for higher prices to Italy where they are used for baby beef production.

Also at the test station the Pinzgauer bulls showed the best results in beef quality ranking foremost in shear force and shear energy as well as in IMF content (together with *Braunvieh*), drip losses and redness (Tab. 4). In shear force *Gelbvieh* was the second and Blond × *Braunvieh* the third. Then followed Simmental, *Murnau-Werdenfelser* (a local breed near Garmisch-Partenkirchen) and *Braunvieh* (high share of Brown Swiss blood), which had also here similar values. In water losses, particular in the sum of the two values, the inter-genotype differences appeared negligible.

3.5. Fattening trial with five beef breeds

In a bull fattening trial the beef breeds Simmental polled (p), Charolaise, G. Angus

Table 4. Meat quality traits in bulls of various dual-purpose breeds tested at the Westerschondorf station [Kögel *et al.*, BIAP Grub 2003]

Trait	Simmental (n=1394)	*Braunvieh*[1] (n=157)	Blond x *Braunvieh* (n=122)	Yellow Cattle (n=24)	Pinzgauer (n=45)	*Hinterwälder* (n=27)
Shear force (kg)	3.44	3.55	3.24**	3.19	3.06**	3.32
Shear energy (0.01 J)	29.4	30.0	28.0	26.9	26.2*	29.0
Drip losses (%)	3.16	3.02	3.48**	3.61	2.87**	3.12
Grill losses (%)	27.7	27.6	28.5*	27.0	28.7	28.7
IMF content (%)	2.05	2.59**	1.92	2.05	2.59**	1.98
Brightness (L)	35.7	36.5**	36.8**	36.6	34.9	36.1
Redness (a)	13.5	12.6**	12.5**	13.4	14.2	13.5

[1]Mean share of Brown Swiss = ca. 2/3.
*P<5%; **P<1%.

and the robust breeds Galloway and Highland were tested for fattening ability, slaughter value and principally for meat quality. Only two offspring per sire were tested. The Simmentals (p) were from a state-owned experimental herd which has been used in the last four decades mainly for selecting polled Simmental cattle. Half the bulls of G. Angus were red and the other half were black. The Simmental (p), Charolaise and G. Angus bulls were kept in mixed groups at the test station Westerschondorf and fed identically as the Simmental progeny. Half the bulls of the robust breeds was kept indoors (open east front) in littered boxes. The other bulls were the whole time fed on pasture, in the winter they were additionally offered grass silage and hay in a shelter.

Simmental (p), Charolaise and G. Angus bulls were slaughtered at the age of 18 months, and the robust breeds 7,5 months later, *i.e.* at 25,5 months of age (Tab. 5). Ranging the breeds according to two tenderness traits, the G. Angus bulls appeared best, followed by Charolaise and Highland, and Simmental (p) and Galloway, the latter two occurring equal. However, the question remains how far the results of the robust breeds are influenced by the higher age and different feeding. G. Angus had the highest IMF content (3.74%), followed by Simmental (p), Charolaise, Galloway and Highland. Nearly the same ranking was shown for grill losses, juiciness and flavour. It is, however, surprising that samples from Charolaises, despite of their lower IMF content (by 1/3), were better assessed for flavour than those of G. Angus bulls. It should also be mentioned that Charolaises showed the brightest beef.

4. Comparison of bulls and heifers

To recognize the genetic inter-sex differences, bulls and heifers are to be fed with

Table 5. Meat quality traits in bulls of various beef breeds

Trait	Simmental pooled (n=14)	Charolais (n=9)	German Angus (n=9)	Galloway (n=20)	Highland (n=17)
Purchase age (days)	8.7	85	99	83	8.7
Final age (months)	17.4	18.9	18.5	24.9	26.1
Final weight (kg)	668	745	622	515	489
Daily gains since birth (g)	1189	1228	1040	642	578
Fat class (1-5)[1] (p)	2.77	2.65	3.25	2.09	2.16
IMF content (%)	2.83	2.52	3.74	2.41	2.23
Flavour[2] (p)	3.98	4.30	4.00	3.58	3.15
Shear force (kg)	5.83	4.54	4.15	5.31	5.57
Tenderness[2] (p)	4.04	4.57	4.86	3.47	4.04
Grill losses (%)	18.2	17.2	16.9	18.6	21.3
Juiciness[2] (p)	4.13	4.13	4.22	3.99	3.66
Brightness (L)	38.5	41.0	38.5	38.8	37.3
Redness (a)	16.6	16.7	17.6	18.8	18.7

[1]5-point scale.
[2]6-point scale, 6 = the best.

the same feedstuffs up to the fatness degree which is common in practice. The feeding intensity must be so adapted, that in each sex the same portion (for instance 80%) of the maximum muscle growth is utilized. There is no doubt, that in this case heifer beef would get higher evaluation than bull beef. This is mainly the consequence of a finer structure of connective tissue and a higher IMF content.

But the bull and heifer carcasses offered at the markets are produced under different conditions. For economical reasons Simmental bulls should be fattened intensively*, i.e.* in arable regions where maize silages of high quality can be produced. Because the specialized heifer fattening is not economical, the heifer carcasses are only by-products of milk production. Therefore, they are usually fed with grass and grass products with mean daily gain of 750-800 g and are mated earliest at the age of 16 months, but frequently at the age of over 20 months. Heifers which not become pregnant or are for other reasons not suited for the replacement of the herd are culled and slaughtered.

To compare beef from bulls and heifers offered at the market the results of fattening trials of the *Braunvieh* crossing trial are presented in Table 6. The bulls were fed with maize silage and concentrate, the heifers with grass, grass silage, hay and grass cobs. Half the heifers were on pasture for two seasons. The heifers were slaughtered at the mean age of 18.9 months, *i.e.* 2.6 months later than the bulls, similarly as in practice. The heifers showed a higher IMF content than bulls, nevertheless their score for flavour was markedly lower. In juiciness, tenderness (sens.) and shear force the results of the two sexes were similar. It can be concluded that at the markets the meat quality of heifers and bulls is similar. However, it seems more likely that heifer beef

Table 6. Meat quality traits in bulls and heifers. Crossing trial with *Braunvieh*; different feeding and slaughter age [Augustini et al., FIMS Kulmbach 1992]

Trait	Bulls (n=187)	Heifers (n=105)	Difference heifers - bulls
Final age (months)	16.3	18.9	2.6
Daily gain since birth (g)	1150	814	-336
Kidney fat/carcass weight (%)	2.8	4.5	1.7
Shear force (kg)	4.13	4.19	0.06
Tenderness[1] (p)	4.02	4.13	0.11
Solubility connect. tissue (%)	18.0	13.5	-4.5
IMF content (%)	2.44	2.94	0.50
Flavour[1] (p)	3.85	3.25	-0.60
Juiciness[1] (p)	4.14	4.03	-0.11
Brightness (L)	34.9	33.8	-1.1

[1]6-point scale, 6 = the best.

is somewhat less valuable. In light of the fact that heifers are generally fatter, a lower price for heifer carcasses is certainly justified.

5. Impact of castration age

The objective of this trial was to clarify whether a higher castration age and there with a longer utilizing of the genetic performance potential alters the meat quality. In eight purchase waves a total of 240 Simmental bull calves were purchased. Thirty calves/wave, sired always by the same six bulls, were assigned to five castration ages (1 calf per sire). The ages were stepped by a two-month interval and ranged between 5.5 and 13.5 months. The castrates were fed grass and grass silage, and in the winter 0.5-1.5 kg cereals/animal/day. Half the castrated males (4 purchase waves) were on pasture over one season. The castrates were slaughtered at the age of 22 months (Tab. 7).

Castrated males of five castration ages showed nearly the same fattening performance and slaughter indicators. In meat quality only shear value and shear energy were related to castration age. From the age of 3.5 to 5.5 months the values of these criteria remained on the same level, and then they rose to the highest age (13.6 months) continuously from 3.79 to 4.16 (kg) and from 34.9 to 39.4 (0.01 J). Thus an increase of meat firmness should be expected when the castration is postponed from the age of 5.5 to 7.5 months, which is not compensated during the following fattening period of 14.5 months. These results speak for a low castration age, as also follows from the aspects of animal keeping and protection.

6. Genetic parametres of beef quality traits

Table 7. Impact of castration age on meat quality in Simmental castrated males [Kögel *et al.*, ITZ Grub, März 2005]

Item	Castration age (months)[1]					Limit difference <5%
	3.5	5.5	7.5	9.5	11.5	
Number of animals (n)	41	42	43	44	42	
Purchase age (days)	49	41	39	35	33	2.77
Castration live weight (kg)	135	188	230	275	342	12.80
Final age (days)	673	669	669	668	665	9.50
Final weight (kg)	628	624	621	609	614	12.80
Daily gain since purchase (g)	850	863	865	857	874	29.40
IMF content (%)	3.27	3.22	2.93	2.96	3.19	0.44
Shear force (kg)	3.79	3.79	4.00	4.04	4.16	0.46
Shear energy (0.01 J)	35.5	34.9	37.8	37.4	39.4	4.60
Drip losses (%)	3.6	3.7	3.4	3.5	3.5	0.55
Grill losses (%)	28.0	27.9	29.9	27.5	28.6	1.34
Brightness (L)	35.9	36.3	36.1	36.1	36.1	0.77
Redness (a)	14.3	14.1	13.8	14.0	14.0	0.58
Yellowness (b)	3.5	3.6	3.3	3.0	3.5	0.60

[1]No significant differences between castration ages.

To improve quality parametres through selection their values must be considerably different in selected animals and progeny groups and a greater share of this variation must be determined by genetic factors. Moreover, the single criterion should not be closely negatively correlated with any other meat quality trait (e.g. fattening or carcass indicators) which are successfully selected for. To recognize the extent to which the criteria meet these requirements, an investigation was performed based of 3400 bulls of 425 progeny groups from the test station. Table 8 shows that variation in traits considered was wide enough. The heritabilities were as high as those for net daily gain and higher than with EUROP-classes and the estimated lean meat content (Tab. 9). The heritabilities of shear force and IMF content were about 0.50 and 0.70, respectively, and that for grill losses appeared the lowest (0.20). The coefficient of genetic correlation between shear force and shear energy was as high as 0.80, but speaks nevertheless for using both criteria in selection. Genetic improvement in these two traits had an favourable effect on IMF content and grill losses and led to a darker beef. Also higher IMF contents were found related to a decline in water losses. Generally, the correlation coefficients estimated among the beef quality traits (selection criteria) appeared either favourable or near zero. It would not, therefore, cause any problems to combine them into one selection trait.

The genetic correlations of the meat quality traits with other selection criteria indicate, that the values of shear force and shear energy rose up with the EUROP-

Table 8. Means and their standard deviations (SD) for meat quality traits in Simmental bulls [Kögel et al., ITZ Grub, April 2005]

Trait	Number of animals	Number of sires	Bulls mean	Bulls SD	Variation within sires SD	Variation within sires from - to
Shear force (kg)	3401	426	3.63	1.06	0.69	2.0-5.9
Shear energy (0.01 J)	3363	422	31.6	10.5	6.98	16.4-54.6
IMF content (%)	3424	426	2.11	0.81	0.47	1.2-4.1
Drip losses (%)	3283	423	3.14	1.37	0.91	1.4-9.8
Grill losses (%)	3369	423	28.4	2.98	1.61	23.0-32.8
Brightness (L)	2459	337	36.6	2.26	1.52	31.5-39.6
Redness (a)	2459	337	12.9	1.75	1.19	10.0-16.8
Yellowness (b)	2457	337	4.02	1.61	1.13	0.4-7.8

[1] Since 1996 from progeny test station Westerschondorf, since 2001 also from Schwarzenau.

Table 9. Heritabilities (h^2) and genetic correlations for meat quality traits in Bavarian Simmentals. Data from the two Bavarian progeny test stations [Kögel et al., ITZ Grub, April 2005]

Trait	Shear force	Shear energy	IMF content	Drip losses	Grill losses	Brightness	Redness	Yellowness
Heritability	0.48	0.45	0.68	0.83	0.20	0.50	0.49	0.49
Shear force (kg)	1	0.79	-0.07	0.02	0.24	0.43	-0.09	-0.10
Shear energy (J)		1	-0.10	-0.02	0.29	-0.15	0.02	-0.07
IMF content (%)			1	-0.08	-0.13	0.09	0.36	0.33
Drip losses (%)				1	-0.02	-0.08	0.10	0.01
Grill losses (%)					1	0.36	0.23	0.29
Brightness (L)						1	-0.25	0.45
Redness (a)							1	0.19

Number of bulls: 3280-3400, 2460 including MINOLTA colour criteria.
Number of sires: 423-426, 337 including colour criteria.

classification and the muscling score (Tab. 10). An increase in carcass fattness was related to rise in IMF content and redness of meat and with fall of brightness and water losses. These relations are in accordance with the fact that the beef from dairy breeds (Jersey and Holstein Friesian) is generally very tasty. Moreover, it is to point out that the IMF content depends on the fat proportion of the whole carcass, but the relation is not close enough (*r*=0.50) to exclude any selection for IMF content. From the genetic correlations it can also be deduced, how the beef quality will develop in FV when, as consequence of the one-sided selection for milk, further losses in muscling and lean meat content occur. As the correlations reveal, this leads to increased tenderness, fat IMFcontent and redness and to reduced water losses. Thus, also without a selection for beef quality an improvement in these criteria is to be expected.

Table 10. Genetic correlations of meat quality traits with fattening, conformation and fat class in Bavarian Simmentals based upon the records from two Bavarian progeny test stations [Kögel et al., ITZ Grub, April 2005]

Trait	Shear force	Shear energy	IMF content	Drip losses	Grill losses	Brightness	Redness	Yellowness
Daily gain (g)	-0.05	-0.00	-0.02	0.06	-0.06	0.08	0.05	0.11
Net daily gain (g)	-0.06	-0.17	-0.07	0.05	0.05	0.04	0.18	0.17
EUROP[1] (p)	0.21	0.25	0.03	-0.13	0.01	-0.13	0.01	-0.04
Muscling[2] 1-9 (p)	0.18	0.20	0.02	-0.04	-0.01	-0.03	0.03	0.07
Circ. of round/half length (%)	-0.05	-0.03	-0.08	0.05	0.17	0.02	0.03	0.02
Fat class[3] (p)	-0.15	-0.00	0.45	0.07	-0.39	-0.11	0.08	-0.06
Kidney fat/carcass half (%)	-0.02	0.05	0.51	-0.10	-0.36	-0.22	0.20	-0.01
Fatty tissue (estimated) (%)	-0.05	-0.02	0.43	-0.12	-0.25	-0.06	0.15	0.03
Muscle tissue (estimated) (%)	0.07	0.03	-0.49	0.14	0.28	0.05	-0.09	0.00

Number of bulls: 3280-3400, 2460 including MINOLTA colour criteria.
Number of sires: 423-426, 337 including colour criteria.
[1]5-point scale, E = 5.
[2]9-point scale, 9 = the best.
[3]5-point scale.

Finally, it is to conclude that selection for meat quality would have some success. As by an increasing muscularity the beef quality is affected negatively, a selection for beef quality would have sense principally in beef breeds. Regarding the IMF content newer microbiological methods could eventually be used. The selection for beef quality is less important in dairy and dual-purpose breeds, as the selection for milk leads to advantages in beef quality. But in spite of this could a direct selection for better beef accelerate and improve the breeds reputation.

7. Impact of environmental factors on beef quality

7.1. Forages

In a fattening trial with 90 Simmental heifers the effect of grass silage, meadow hay and maize silage on beef quality was investigated. The animals were bought in three wells at the age of 5 to 7 weeks, then kept under identical conditions, uniformly fed up to the age of one year, and next divided into three similar groups assigned to the following diets:

– group 1 – grass silage *ad libitum* + 1.5 kg cereal grain;
– group 2 – meadow hay *ad libitum* + 2.0 kg cereal grain;
– group 3 – maize silage restricted + 0.8 kg soybean meal.

The diets were adjusted to uniform daily gain, the overall mean of which was 740 g (Tab. 11). After a 6-month feeding with differentiated diets the heifers were slaughtered at the age of 18 months, reaching a similar final live weight of 465 kg. Group 3 was found best in all meat quality traits. Group 1 (grass silage) appeared similar in shear force and was only slightly worse than group 3 in meat flavour and juiciness. Group 2 (hay) was worse in all traits, particularly in tenderness (sens.) and shear force, the latter being by 0.75 kg higher than in the other two groups. Though the hay-fed group was highest evaluated in carcass fat classes, it had the lowest IMF content. But this had only a slight effect on the quality criteria as could be revealed by a calculation with constant fat content. Beside, it is to assume that the IMF content is also affected by feeding. So, maize starch leads to a higher level of propionic acid in the rumen, which is then effectively utilized for fat synthesis. From these it can be concluded that heifers (or castrated males) fed on pasture for improving beef quality in the last period before slaughtering should be fed on maize silage and grain or at least with a higher proportion of grain, specially maize grain. With this it is also possible to reduce the undesired yellow hue of carcass fat. On such yellow-coloured carcasses price reductions are partly imposed. In the trial, heifers were fed on pasture and then, before slaughtering, for a different time on nearly carotene-free maize silage and grain. It took 3 to 4 months until the yellowness was reduced by half, so that the carcasses were accepted without any price reduction [Kögel *et al*. 1997].

7.2. Fattening regimen

In the *Braunvieh* crossing trial 112 young heifers were bought, reared together and

Table 11. Impact of feeding with different forages over the last six months of the trial upon meat quality traits in Simmental heifers [Kögel et al., BIAP Grub/FIAS Kulmbach 1998]

Trait	Grass silage +1.5 kg grain (n=33)	Hay +2.0 kg grain (n=26)	Maize silage +0.8 kg soybean meal (n=23)
Final age (months)	18.2	18.2	18.2
Final weight (kg)	463	460	467
Daily gain since week 6 (g)	741	741	745
Fat class[1] (p)	2.66	2.71	2.66
Shear force (kg)	5.34	6.10	5.38
Tenderness[2] (p)	3.65	3.37	3.90
Texture[2] (p)	3.81	3.62[a]	4.08[b]
IMF fat content (%)	2.05	1.67[a]	2.16[b]
Flavour[2] (p)	3.80	3.56	3.89
Drip losses (%)	1.21	1.29	0.94[b]
Juiciness[2] (p)	3.99	3.78	4.07
Redness (a)	16.8	15.6[a]	17.3b

[1]5-point scale.
[2]6-point scale, 6 = the best.
[ab]Within rows means bearing different superscripts differ significantly at P<5%.

then allotted to two different feeding regimens (tab.12):

– group 1 – fattening indoors – higher intensity, fed grass products incl. grass cobs;
– group 2 – fattening on pasture (two seasons), lower intensity, fed grass silage and hay.

The heifers from group 2 gained daily slightly over 700 g while those from group 1 – 900 g daily. After an 8-month longer fattening the former reached final weight of 530 kg that was about 80 kg more than in group 1. Heifers from group 1 (mostly di-

Table 12. Impact of two fattening regimens on meat quality in 112 heifers from the crossing trial with *Braunvieh* [Augustini et al., FIM 8 Kulmbach 1992]

Trait	Indoors (n=55)	Pasture[1] (n=50)	Difference pasture - indoors
Final age (months)	14.9	22.8	7.9**
Final weight (kg)	450	530	80**
Daily gain (since birth) (g)	915	713	-202**
Kidney fat/carcass weight (%)	4.9	4.0	-0.9**
Shear force (kg)	3.89	4.37	0.48
Tenderness[2] (p)	4.33	4.05	-0.28
Solubility of conn. tissue (%)	16.8	10.2	-6.6**
IMF fat content (%)	3.06	2.82	-0.24 **
Flavour[2] (p)	3.57	2.93	-0.64 **
Juiciness[2] (p)	4.03	4.03	0.00
Brightness (L)	36.2	31.3	-4.9**

[1]Two seasons on pasture.
[2]6-point scale, 6 = the best.
**P<1 %.

rectly kept off pasture) were less fatty and quality of their meat was worse than in the indoor group. The reason for the worse valued flavour, by 0.64 p., is higher animals' age, smaller IMF content and the "grassy" flavour often found in heifers. The strongly reduced solubility of the connective tissue (-6.6 % abs.) might be the main reason for the higher values of tenderness (sens.) and shear force. This shows that the slaughter age is a dominant factor affecting meat quality also in heifers. This effect might be greater than is generally assumed.

7.3. Degree of maturity

To get knowledge about the age at which fattened cattle of different genotypes are ready (mature) for slaughter, in the *Braunvieh* crossing trial used were bulls divided into two equal groups, slaughtered at the age of 470 and 520 days (15.5 and 17.1 months, respectively). As both groups were fed equally, the results can inform, whether through a longer finishing period, leading to higher IMF content, the beef quality could be improved (Tab. 13). As expected, the bulls slaughtered at later age (by 50 days) showed more IMF (by +0.40 pp), but simultaneously their meat was slightly less flavourful. The effect of higher IMF content was obviously altered by the negative effect of higher slaughter age also visible in declines of juiciness, brightness and solubility of connective tissue. Surprisingly, the age at slaughter did not affect the tenderness of meat: the beef of the older bulls was found only slightly less tender and its shear force was even slightly smaller than in younger bulls. Thus, through fattening up to a higher degree of maturity no improvement in the beef eating quality can be expected. It is more likely, however, that the quality and specially the sensoric beef properties, are somewhat lower.

7.4. Fattening intensity

In the Simmental crossing trial the bulls were tested at high and very high fattening

Table 13. Impact of two slaughter age levels on meat quality in 187 bulls from the crossing trial with *Braunvieh* [Augustini *et al.*, FIMS Kulmbach 1992]

Trait	Slaughter age		
	15.5 months	17.1 months	difference: 1.6 months
Final weight (kg)	583	633	50**
Fatclass[1] (p)	2.88	3.03	0.15
Shear force (kg)	4.05	3.99	-0.06
Tenderness[2] (p)	4.17	4.10	-0.07
Solubility of conn. tissue (%)	19.1	16.8	-2.3 **
IMF fat content (%)	2.24	2.63	0.39**
Flavour[2] (p)	3.89	3.81	-0.08
Juiciness[2] (p)	4.17	4.11	-0.06
Brightness (L)	35.5	34.2	-1.3 **

[1] 5-point scale.
[2] 6-point scale, 6 = the best.
**P<1%.

intensity level, while the G. Anguses at level medium and high. Table 14 shows, with the Simmental control, the impact of fattening intensity on beef quality. To reach the same degree of fatness the less intensively fattened bulls were slaughtered 1.5 and 1.7 months later, respectively. Though the fat classes were somewhat lower, the fat contents were slightly higher, by 0.3 and by 0.2 pp, respectively. This is in accordance with the general observation that at higher ages relatively more fat is stored in the muscles. But again, despite of the slightly higher IMF content, the flavour was evaluated as markedly weaker, and in trial part 2 also juiciness. In both parts the solubility of connective tissue was – due to the older age – lower by 0.7 pp. It is worth to pay a special attention to the tenderness traits: in trial part 1 the older bulls were scored lower than the younger bulls, and in trial part 2 – contrary to the expectation – higher than the younger, more intensively fed bulls. It can generally be concluded that there is a close relation between slaughter age and beef quality, but with the exception of beef tenderness. At higher slaughter age levels, the correlations with tenderness (sens.) and shear force are

Table 14. Impact of different fattening intensity (with adapted final age) on meat quality in Simmental bulls used as control breed in the Simmental crossing trial [Roswitha Herzog FIMS Kulmbach, 1997: Final report of trial part 1 + 2]

Trait	Trial part 1			Trial part 2		
	fattening intensity					
	very high (n=30)	high (n=36)	high – very high	high (n=22)	medium (n=24)	medium – high
Final age (months)	14.6	16.1	1.5	16.0	17.7	1.7
Final weight (g)	597	616	19	618	660	42
Daily gain (g)	1294	1212	-82	1195	1155	-40
Fatclass[1] (1-5)	3.01	2.90	-0.11	2.96	2.80	-0.16
Shear force (kg)	6.32	6.38	0.06	4.81	4.65	-0.16
Tenderness[2] (p)	3.84	3.16	-0.68	2.99	3.25	0.26
Solubility of conn. tissue (%)	22.8	22.1	-0.7	22.2	21.5	-0.7
IMF content (%)	1.56	1.83	0.27	1.66	1.82	0.16
Flavour[2] (p)	4.05	3.79	-0.26	3.67	3.32	-0.35
Juiciness[2] (p)	4.11	4.11	0.00	4.03	3.79	-0.24
Brightness (L)	39.7	39.7	0.0	38.4	38.3	-0.01

[1]5-point scale.
[2]6-point scale, 6 = the best.

loosened and turn to near zero. Therefore, an increase of feeding intensity is generally not a promising way for improving the eating quality of beef.

8. Impact of slaughter age on meat quality

It is known that beef, specially that from bulls, becomes firmer with increasing age. For this responsible are mainly structural changes in connective tissue, which consists nearly solely of collagen. The molecules of this structure protein are composed of three protein chains, between which and also between the molecules an increasing number of cross-links are erected with growing age. Through this the meat becomes tougher and coarser. It was assumed that the beef is continually getting firmer with increasing age. This is a main reason, why the meat marketing companies have requested higher fattening intensities, so that the bulls are ready for slaughter at lower ages.

8.1. Investigations of the ALPEN-ADRIA

Some years ago the Association ALPEN-ADRIA working group performed two investigations to clarify the relations between slaughter age and the most important criteria used to characterize the meat attributes. In the first investigation with bulls, heifers and cows the meat samples were taken in Styria (Austria) from three commercial slaughter houses. Because of the small number of investigated bulls (n=27) and the unexpected results, a second investigation was arranged in which only meat samples of bulls were taken from a slaughter house in Bavaria. In these two investigations participated the

Agricultural College Hatzendorf (Styria), the University of Padua (Italy), the BIAP Grub (Germany) and FIMS in Kulmbach (Germany). Here only the results of bulls are shown, in both cases allocated to 4 slaughter age groups (Tab. 15).

The values for tenderness (sens.) and shear force were found conform to one another. In the first investigation these values were markedly worse from group 1 to group 2, from group 2 to group 3 only slightly, and in group 4 the meat was again more tender. In the second investigation the turn to a more tender meat appeared markedly

Table 15. Impact of slaughter age on tenderness (sens.) and shear force of beef

Age group	First investigation*				Second investigation*			
	number of animals	age (months)	tenderness (p)	shear force (kg)	number of animals	age (months)	tenderness (p)	shear force (kg)
1	7	14.3	3.73	4.44	15	16.8	3.58	5.26
2	7	16.1	3.37	5.21	15	18.8	3.76	5.10
3	6	19.5	3.36	5.59	14	20.7	4.04	4.77
4	7	23.3	3.60	4.74	16	23.0	3.88	4.87

*Each figure is the mean from two results of the Padua University or FIMS Kulmbach and BIAP Grub.

earlier – already from group 1 to group 2 the values improved slightly, from group 2 to group 3 much markedly, and in group 4, at the age of 23 months, the turning point to an again tougher meat was already crossed. Similar relations showed the values recorded for heifers.

8.2. Impact of six age levels on meat quality

As the topic "slaughter age" is of great importance for the Bavarian beef industry, another trial was devoted to the influence of six slaughter age levels on meat quality. The trial was performed at the progeny test station Westerschondorf. The age intervals differed by three months and ranged between 9 and 24 months. The total of 72 bull calves were purchased, 12 per age level, sired in each level by the same 6 bulls. By means of a strongly differentiated feeding regimen, adapted to age levels as strictly as possible, the bull groups were slaughtered at almost the same rate of fatness. The bulls of the two highest age levels were fed by a mixture of maize silage and chopped straw plus soybean meal, whereas the two groups of the lowest levels were offered maize silage *ad libitum* supplemented with high amount of concentrate. In this trial investigated was *longissimus dorsi* (LD) muscle and shoulder and round of beef cuts.

Fatness criteria revealed only small differences between the six slaughter maturity ages (Tab. 16). In addition to that, in the analyses of variance the meat quality criteria were corrected for the same fat content. The values for shear force and shear energy in the three locations showed nearly the same trend. They rose up to the age of about 18 months, then remained unchanged, and at the age of about 21 months they rose again. These trends are in accordance with those found in the crossing trials with *Braunvieh* and Simmental and also with the results of the two investigations of ALPEN-ADRIA. In all five cases, the meat growed firmer with ascending age, but somewhere between 16 and 20 months of age these correlations get looser until they reached zero or even the negative values.

An interruption in the course of increasing meat firmness has been shown also by other authors. Shear forces (LD muscle) from trials with at least three slaughter age levels were taken, adapted to a mean force of 5.0 kg and then connected with lines (Fig. 2). Involved were different breeds and cattle categories, mostly Hereford and Angus

Table 16. Impact of slaughter age of Simmental bulls on firmness of beef from three locations. Similar slaughter maturities by decreasing fattening intensities with given slaughter age. Data are corrected for intramuscular fat content [Kögel et al. ITZ, April 2005]

Trait, location	Slaughter age (months)					
	9 (n=11)	12 (n=10)	15 (n=11)	18 (n=11)	21 (n=8)	24 (n=10)
Shear force (kg)						
m. long. dorsi	4.35	3.74*	4.30	3.85*	3.94*	4.66
shoulder	3.63	4.44*	4.70*	5.13*	5.13*	5.58*
round of beef	3.61	3.73	4.24*	4.60*	4.51*	4.33*
mean	3.87	3.97	4.41	4.52	4.53*	4.86*
Shear energy (1/100 J)						
m. long. dorsi	38.3	29.6*	38.8	35.7	37.5	43.5*
shoulder	33.8	40.8*	46.8*	53.9*	52.6*	55.2*
round of beef	29.9	30.4	36.9*	48.8*	47.8*	44.6*
mean	34.0	33.6	40.8*	46.1*	45.9*	47.8*

*P<5 %.

castrated males. In addition to this the cattle were differently fed and maintained. Altogether, the course of shear forces passes through a wide decline, that ranges roughly from 14 to 21 months of age. After that, as can be seen with cows, the meat firmness increases again.

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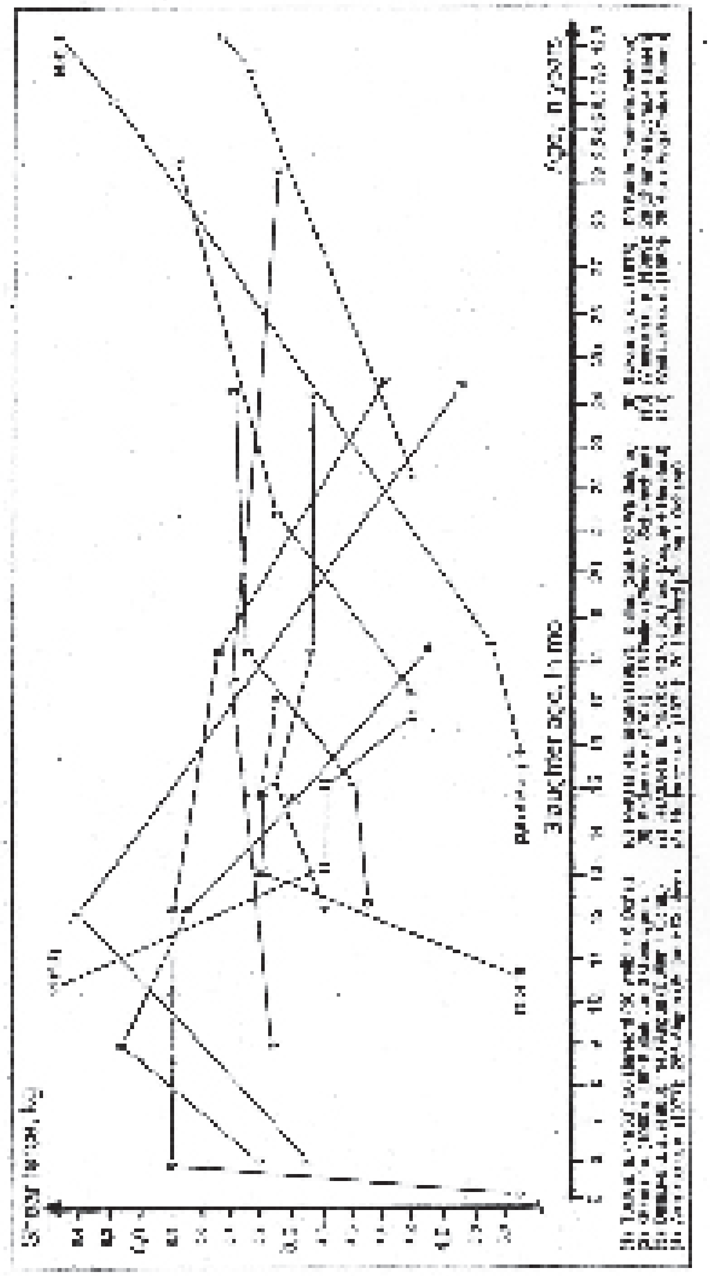

Fig. 2. Shear force values as related to slaughter age (adjusted to the mean of 5.0) given by different authors.

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