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Fattening heifers on Alpine pastures
Implications for productivity and meat quality

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Abstract

So far, in Austria, beef cattle were raised mostly in barn because of the harsh weather conditions of the Eastern Alps. With the current economical and cultural context, trends to raise beef cattle on pasture during the grazing season are rising. Implications of turning beef cattle on pasture remain unclear regarding animal performances and quality of the meat produced. This study aimed at acknowledging whether raising beef cattle on pasture provided as good performances and meat quality as the current practices in barn. Heifers Charolais x Simmental of about 300 kg live weight were either fattened on pasture and finished in barn or solely raised in barn on a grass silage-based diet with low amounts of concentrates. All animals were slaughtered at 550 kg live weight and meat quality (composition, shear force, water holding capacity, meat and fat colour) was assessed. Results showed that fattening on pasture was as suitable as raising in barn regarding growth performance and slaughter characteristics. Meat quality was within desirable thresholds but fat colour was more red and more yellow in grazing animals. Meat from grazing animals was leaner without consequence on shear force. Fatty acid profile was in favour of pasture raising regarding human health recommendations (higher proportion of unsaturated fatty acids like C18:3).

Zusammenfassung

Kalbinnen der Kreuzung Fleckvieh x Charolais wurden mit 300 kg Lebendgewicht zwei Fütterungsregime zugeordnet, um Unterschiede in der Mastleistung, Schlachtleistung und Fleischqualität zu untersuchen. Die Fütterungsverfahren waren (1) Weidemast auf Kurzrasenweide mit Stallendmast beziehungsweise (2) Stallmast mit Grassilage und moderaten Kraftfuttergaben. Die Schlachtung erfolgte bei 550 kg Lebendgewicht. Der Fütterungsvergleich zeigte, dass hinsichtlich Tageszunahme und Schlachtleistungsmerkmale die Weidemast auf Kurzrasenweide mindestens ebenso geeignet war wie eine Grassilage-betonte Stallmast. Die Fleischqualitätsbestimmung (Nährstoffgehalt, Zartheit, Wasserverbindungsvermögen, Fleisch- und Fettfarbe) ergab keine nennenswerte Unterschiede zwischen den beiden Fütterungsregimes. Lediglich bei der Fettfarbe wurde ein signifikant stärkerer Gelbton für die Weidegruppe ermittelt. Fleisch der Weidegruppe war fettarmer, jedoch ohne negativen Folgen für die Zartheit (Scherkraft). Alle untersuchten Fleischqualitäts-Merkmale lagen innerhalb des als optimal definierten Referenzbereichs. Signifikante Unterschiede wurden im Fettsäurengehalt ermittelt mit entsprechend besseren Fettsäurenwerten in der Weidegruppe (höherer Gehalt an mehrfach ungesättigten Fettsäuren wie C18:3).

List of abbreviations

ADG: average daily gain
ATP: adenosine triphosphate
CIE: commission internationale de l´éclairage (international commission on illumination)
CLA: conjugated linoleic acids
DFD: dark, firm and dry meat
DHA: docosahexaenoic acid
DM: dry matter
DPA: docosapentaenoic acid
EPA: eicosapentaenoic acid
FAME: fatty acid methyl esther
FAO: Food and Agriculture Organisation
IMF: intramuscular fat
ISO: international standard organisation
LW: live weight
MUFA: monounsaturated fatty acids
p.m.: post mortem
pH_u: ultimate pH (at 48 h post mortem)
PSE: pale, soft and exudative meat
PUFA: polyunsaturated fatty acids
SEM: standard error of the mean
SFA: saturated fatty acids
WHC: water holding capacity

Table of contents

1 Introduction

1.1 Context

In the Eastern Alps, difficult weather conditions (average temperature 6.7°C and 969 mm rainfall per year in Ennstal -Landesstatistik Steiermark, 2010) motivate farmers to keep beef and dairy cows in barn and to use farm grasslands as meadows rather than as pastures. In the current economical context, farmers in difficult agricultural areas like Alpine regions often have another job besides farming to ensure a minimum income. Therefore, agricultural practices which are less cost- and labour-demanding like rearing on continuous pasture (Durgiai, 1996; Durgiai and Müller, 2004; Steinwidder *et al*., 2010) become more attractive. Furthermore, consumer demand for products of extensive agriculture is rising and quality programs which specify use of pastures are successful (organic production, quality labels). Other arguments for use of grasslands as pastures refer to summer tourism and biodiversity matters (Crook and Jones, 1999; Buchgraber and Gindl, 2004; Maurer *et al*., 2006; Niedrist *et al*., 2008). Yet, pasture rearing could have consequences on growth performance, slaughter performance and further on nutritional and eating quality of the meat (Realini *et al*., 2003; Keane and Moloney, 2009; Daley *et al*., 2010). The aim of this study is to enlighten the possible opportunities and threats of pasture fattening in the Eastern Alps regarding growth performance, slaughter characteristics and meat quality traits.
This study is the second half of a research project that started in 2008. The first half of the project (Friedrich, 2010) consisted in comparing fattening on pasture to fattening in barn. Charolais x Simmental heifers of 300 kg live weight were fattened on short grass continuous pasture and finished in barn in case they did not reach 550 kg at the end of the grazing season. Growth rate, slaughter characteristics and meat quality were compared to a common fattening in barn. In barn, animals were fed grass and maize silage *ad libitum* (DM ratio 70:30) plus 2 kg concentrates daily.

1.2 Literature review

1.2.1 Pasture management for consistent grass quality supply in Alpine regions

Currently, four types of cattle pasture management are practiced on European grassland. The least labour- and material-demanding management is extensive grazing. The herd remains on a single pasture during the whole grazing season. However, with this type of pasture management grass supply and animal performances are inconsistent (Buchgraber and Gindl, 2004). A second way of maintaining animals on pasture is to move fences daily to continuously provide fresh grass to the herd. This allows a good valorisation of grass with uniform grazing over the entire pasture, but the work load is significant. Pastures can also be divided into smaller paddocks by permanent fences. Cattle will graze for a few days and then be moved to the next paddock. However, the grass quality is variable in this system and a rather large surface is necessary (Buchgraber and Gindl, 2004). The latter system has both the advantages of an extensive pasture management and pasture rotation as described above. The principle of continuous grazing on short grass is to adapt the size of the pasture in such a way that sward height remains at a constant height between 5 and 7 cm (Bavarian State Research Center for Agriculture, 2010). On the area not used for grazing, grass has to be mown and eventually used for making grass silage. This way, grass remains in the vegetative stage and nutritive quality is optimum. Experiments conducted in Alpine regions showed that continuous grazing on short grass was suitable for beef production (Häusler *et al*., 2008; Friedrich, 2010).

1.2.2 Growth performance of beef cattle

Growth consists of development and maturation of different tissues in the animal. All tissues do not develop at the same rate: the nervous system is the first to develop followed by bones, then muscles and thereafter fat (Dudouet, 2004). As a consequence, beef meat production after weaning is often divided in two phases: a fattening period during which bones and muscles develop while the animal grows, most often followed by a finishing period during which muscularity and fatness are improved. The growth performance is defined by the rate at which tissue is deposited and, consequently, the rate at which live weight increases (daily weight gain) as well as the amount of feed needed for each kg of live weight gain (feed conversion ratio). As mentioned by Perry and Thompson (2005), differences in growth performance between two groups of animals reflect the effects of the combination of nutritional, management and environmental factors while differences between individual animals in one group reflect differences in genetic potential for growth.

Animal-intrinsic determinants of growth performance

As described by Geay and Robelin (1979), potential daily weight gain and feed efficiency are influenced by genetic factors. A breed is classified early or late maturing according to the rate of development and maturation of the different tissues. Early maturing breeds reach puberty at a younger age than late maturing breeds. Consequently, muscle development is completed earlier and fat deposition occurs at a younger age in early maturing cattle. According to Geay and Robelin (1979), dairy breeds (Holstein), smaller meat breeds (Limousin) and early maturing meat breeds (Angus, Hereford) have a lower potential daily weight gain than large meat breeds (Rouge des Prés, Charolais). The same authors noted that meat breeds were also more efficient than dairy breeds in transforming feed intake into live weight and energy intake into protein while dairy breeds gained more fat. In contrast, Dufey et al. (2002) found no difference in daily weight gains and feed conversion between Angus (early maturing breed) and Charolais (late maturing breed) bulls when slaughtered at the same fatness score and Albertí et al. (2008) even obtained better live weight gains for Angus bulls than Charolais bulls. However, in the two articles previously cited, differences could be related to different age and weight at slaughter between breed groups as explained later. At last, genetic differences in growth potential also appear at the individual level within breeds. Potential daily weight gain is also largely influenced by gender. According to the review of Field (1971), bulls have a 15 to 17 % higher growth rate and 13 % higher feed efficiency than steers. In feedlots, heifers and steers had similar growth rates in the study of Hedrick (1969) whilst steers gained weight faster than heifers in the study of Steen (1995). The latter also showed that bulls had a higher increase in lean gain in response to an increase in feed intake than had steers and heifers. This implies that bulls are more efficient to produce meat on a high energy diet than steers and heifers. Consequently, steers and heifers will be more suitable for extensive managements than for feedlot-like rearing. At last, age and weight are the third determinant of growth rate potential. Theoretically, live weight follows a sigmoid curve over time while live weight gain follows a parabolic curve with the highest point (maximal rate of live weight gain) reached at puberty (Dudouet, 2004). Hence, the average lifelong-growth rate is also determined by the age and weight at slaughter.

Influence of the diet on growth performance

Hygiene, housing, climate, physical activity and diet are environmental factors that have an influence on daily weight gain and feed conversion ratio. This study will focus on the influence of the diet. As mentioned above, age, gender and breed are factors of variation of growth performance. However, diet is able to enhance or reversely moderate these effects. In the studies

of Field (1971) and Nuernberg *et al*. (2005), gender- and breed-related differences in growth rate were largest on the most energy-rich diet. In contrast, Arthaud *et al*. (1977) obtained larger differences between Angus steers and bulls on a low energy diet than on a high energy diet. The results of Arthaud *et al*. (1977) were probably contrasting because they used an early maturing breed with a moderate growth potential. Therefore, diet effect should be corrected for age, breed type and gender.

In a majority of articles, grazing animals had a lower daily weight gain than indoor-fed animals (Steen *et al*., 2003, Nuernberg *et al*., 2005, Keane and Moloney, 2009). However, differences were most often related to differences in daily energy intake. In the studies of Steen *et al*. (2003), Nuernberg *et al*. (2005) and Keane and Moloney (2009), the indoor-fed animals were given high amounts of concentrates (9 to 11 kg d^{-1}). In contrast, when intensively fed heifers (95 % concentrates and 5% straw) were restricted at 70 % of their *ad libitum* intake, they showed same live weight gains as solely grazing heifers (Steen *et al*., 2003). Furthermore, in the study of Noci *et al*. (2005), Charolais crossbred heifers fed grass silage *ad libitum* plus 3 kg concentrates daily had similar live weight gains than heifers grazing a perennial ryegrass sward. Friedrich (2010) also found that weight gains of heifers were similar whether they were fed a grass silage-based diet *ad libitum* or were grazing a continuous short grass pasture with a finishing period on the same diet as the indoor-fed group. In contrast to results previously cited, French *et al*. (2000a) obtained same live weight gains whether crossbred steers were intensively fed (8 kg concentrates daily) or solely grazing. Several experimental designs and results are presented in Table 1 and show that although diets may be similar among studies, results differ. Contrasting results can probably be attributed to differences in genetics and in energy content of the diets, information that is most often omitted in articles. Furthermore, animal health can be questioned at feeding levels as high as 8 kg concentrates daily with only 0.5 kg fodder (Velik, personal communication).

Table 1. Growth performance of heifers and steers of meat type breeds slaughtered at about 550 kg live weight

Authors	Breed	Gender	Starting weight (kg)	Duration experiment	Weight at slaughter (kg)	Days on pasture	Daily feed intake (DM)		CP fodder (g kg^{-1} DM)	ADG (g d^{-1})
							F	C		
French *et al*., 2000	Crossbred meat breed	Steers	504	85 days	600[1]	0	GS 5.8 kg	3.6 kg	149	1146[a,1]
					600[1]	0	Hay 0.8 kg	8 kg	ND	1091[a,1]
					593[1]	85 days	Grazed grass 4.7 kg	5 kg	224	1091[a,1]
					600[1]	85 days	Grazed grass 7.5 kg	2.5 kg	224	1127[a,1]
					589[1]	85 days	Grazed grass 12.6 kg	0	224	1073[a,1]
Steen *et al*., 2003	Crossbred meat breed	Steers	403	127 days	561	0	Straw 0.45 kg	8.55 kg	37	1245[a]
			406		565	0	Straw 0.40 kg	7.60 kg	37	1253[a]
			406		531	0	Straw 0.35 kg	6.65 kg	37	986[b]
			406		529	127 days	Grazed grass	0	236	969[b]
Noci *et al*., 2005	Crossbred Charolais	Heifers	332	158 days	488	0	GS 4.1 kg	3.55 kg	177	959[a]
					477	Last 118 days	GS 4.21 kg[2]	3.29 kg[2]	177	876[a]
					488	Last 59 days	GS 4.5 kg[2]	2.81 kg[2]	177	900[a]
					495	158 days	Grazed grass	0	134	996[a]
Friedrich, 2010	Crossbred Charolais	Heifers	283	360 days	546	0	GS 4.6 kg + MS 2 kg[3]	2 kg[3]	GS: 138; MS: 90	1083[a]
			289	376 days	552	First 182 days	GS 5.5 kg + MS 2.2 kg[3]	2 kg[3]	GS: 138; MS: 90	1131[a]
Keane and Moloney, 2009	Crossbred Angus or Belgian Blue	Steers	434	94 days	501	94 days	Grazed grass	0	ND	714[5]
			431	94 days	576	0	GS 1 kg	9.7 kg	162	1539[5]
			437	189 days	626	First 94 days	GS 1 kg[4]	10.2 kg[4]	162[4]	999[5]
			434	189 days	658	0	GS 1 kg	11.3 kg	162	1186[5]

ADG: average daily gain; C: concentrates; CP: crude protein; DM: dry matter; F: fodder; GS: grass silage; MS: maize silage; ND: not determined:
[1] Results calculated from the carcass weight and carcass daily gains with 55 % dressing percentage as estimated by the authors.
[2] Data only for the first part of the experiment because they were solely grazing once on pasture.
[3] Data from 183rd day of the experiment onwards.
[4] Data only for the last 94 days because the animals were on pasture during the first 94 days of the experiment.
[5] Authors did not indicate the significant differences but they found a significant diet effect and no duration effect.
[a, b] Different letters within ADG of one article indicate significant differences as indicated by authors (p-value<0.05).

1.2.3 Slaughter performance of beef cattle

As not all parts of beef cattle are valuable, the live weight is not sufficient to predict the value of the slaughtered animal. After slaughter of bovine, skin, head, feet and organs are removed. The remaining carcass is composed of muscles, fat and bones in different proportions. During cooling, the carcass looses water by evaporation. The cold carcass weight represents about 98% of the warm carcass weight (Warriss, 2010). The ratio between carcass weight and live weight is known as killing-out percentage or dressing percentage. The carcass muscularity and fatness are assessed using standardised methods such as the European Beef Carcass Classification in which carcass conformation is graded with letters E, U, R, O, P, and carcass fatness is scored on a scale from 1 to 5.

Influence of animal-intrinsic factors on slaughter performance

As breed, gender and age influence live weight and physiological maturity (chapter I.2.2), they also influence carcass classification and fatness. Furthermore, carcass weight is not only dependent on live weight but also on genetics as shown by a study of Robelin *et al*. (1978, in Geay and Robelin, 1979) on 80 Limousin and 69 Charolais bulls. Although Charolais bulls were heavier at slaughter, carcass weights of Limousin and Charolais were similar. Hence, Limousin bulls had a larger dressing percentage than Charolais.

Diet influence on slaughter performance

Dressing percentage was not influenced by the diet in the study of Steen *et al*. (2003) with crossbred Charolais heifers fed either a concentrate-based diet or solely on pasture. Similarly, dressing percentage of crossbred steers was not influenced by the diet in the study of Keane and Moloney (2009); although live weight gains and carcass weights were significantly different between groups in both studies. Friedrich (2010) obtained similar growth performances and similar slaughter performances whether heifers were fed indoor on a grass silage-based diet or were grazing during fattening and finished on a grass silage-based diet. In contrast, Noci *et al*. (2005) found a quadratic decrease in dressing percentage with the length of the stay on pasture (0, 59, 118 or 158 days). Dressing percentage values were the most similar for animals fed grass silage (0 days on pasture) and animals solely grazing (158 days on pasture), while animals that combined indoor fattening and pasture finishing (59 and 118 days on pasture) had lower dressing percentages.

Carcass conformation is often similar between grazing and concentrate-fed animals (Vestergaard, 2000; Steen *et al*., 2003; Keane and Moloney, 2009) although Realini *et al.* (2003) mentioned a lower carcass conformation with grazing animals. However, authors often mention grazing animals to have lower fatness scores (Realini *et al.*, 2003; Steen *et al*., 2003; Keane and Moloney, 2009), most likely due to the lower growth rate of grazing animals. Friedrich (2010) who obtained similar growth rates for the grazing group and the grass silage-fed group also obtained similar carcass conformation and fatness scores. To ensure good carcass fatness to animals fattened on pasture, a finishing period on concentrates is advisable (Kerth *et al*., 2007).

As mentioned earlier, the yield of bones, muscles and fat can differ between carcasses. In the study of Steen *et al*. (2003), heifers fed a concentrate-based diet had a higher marbling score, a thicker subcutaneous fat depth and a higher carcass fatness score than grazing heifers. Consequently, lean and bone proportions were larger for grazing heifers. As carcass composition could have been influenced by the higher growth rate of the concentrate-fed group, results were also compared for an adjusted live weight gain. Thereafter, no significant difference remained but for the proportion of bones in the carcass.

1.2.4 Beef meat quality characteristics

The international standard organisation (ISO) defines quality as something that "represents the totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs" (ISO 5492:1992 quoted by Issanchou, 1996). Food products quality concept for the consumer relies on product safety regarding food born diseases, acceptable palatability and respect of ethical concerns. In addition, the food industry has its own concerns about meat quality for processing classified under technological quality.

Measuring meat quality

According to Warriss (1996, in Warriss, 2010) meat quality can be measured by assessing:

– Meat yield and composition: muscle size, shape and ratio fat to lean

– Appearance: texture, colour and amount of marbling

– Technological characteristics: chemical composition and water holding capacity

– Palatability: texture, juiciness, tenderness and flavour determine the eating quality

– Wholesomeness: chemical and microbiological safety, defined by regulations to prevent food born diseases

– Ethical quality: acceptable animal husbandry is of interest for concerned consumers

There are some standards, particularly for safety and animal husbandry, and aspects on which more variability is possible. This study will focus on the latter. Meat yield, composition and technological characteristics are assessed objectively through instrumental measurements. In contrast, palatability and appearance can either be assessed by a panel or instrumentally measured. Instrumental measurements have the interest to be easier and cheaper to implement and also more repeatable than panel tasting (Platter *et al*., 2003). However, instrumental measurements are not yet able to explain the whole range of what human senses can assess and do not provide information such as consumers' preference. Furthermore, all meat quality characteristics do not have the same importance for consumers. Meat colour and fatness determines the purchase or refusal by the customer; hence, it is of utmost importance for the retailer; followed by meat tenderness and flavour. Although it is an important quality attribute, tenderness is also one of the most variable attributes on the meat market (Tarant, 1998). As underlined by Destefanis *et al*. (2008), tenderness depends on many animal-intrinsic and extrinsic factors and their interaction. Meat tenderness is assessed by panel ratings but instrumental measurements are also used. The most widely used is the Warner-Bratlzer shear force test (Culioli *et al*., 1995, in Destefanis *et al*. 2008). Destefanis *et al*. (2008) found a correlation coefficient of –0.72 between consumer panel rating of tenderness and Warner-Bratlzer shear force value. The shear force value explained 52% of meat tenderness variability (R^2 value) assessed by a consumer panel of 220 people.

Influence of pre-slaughter and post mortem handling on meat quality characteristics

Meat quality can be strongly negatively affected by pre- and post-slaughter handling. After death, the blood stream ceases and muscles do not receive any oxygen or glucose supply. Thereafter, muscle cells synthesise ATP from glycogen through anaerobic glycolysis. This reaction produces lactic acid which accumulates in the muscle since there is no more blood stream; as a consequence, muscle pH decreases. According to Dransfield (1994b, in Warriss, 2010) this process takes 15 to 36 h in cattle. Acidification stops when glycogen is no more available or when the pH is too low to allow this enzymatic process to occur. This specific pH value is referred to as ultimate pH (pH_u). Meat pH influences the structure of muscle constituents. When the muscle pH reaches 5.3 to 5.5, myofibrillar proteins reach their isoelectrical point (Warriss, 2010). Then, myofibrillar proteins are no more electrically charged and are prone to loose bound water resulting in poor water holding capacity (WHC) of the meat cuts. Also meat colour can look paler by rearrangement of myofilaments by meat

acidification. ATP maintains muscle relaxation but as soon as ATP level falls below 5.5 mmol kg^{-1}, actin and myosin filaments associate to form actomyosin (Warriss, 2010). This phenomenon is known as rigor mortis and happens in 24 h *post mortem* (*p.m.*) in cattle (Warriss, 2010). If long term stress occurs before slaughter, levels of ATP and glycogen in the muscles at death are depleted. This shortens the process of rigor mortis and limits acidification of the meat. This phenomenon is called alkaline rigor and produces dark, firm and dry (DFD) meat. Rigor mortis sets the attachment of actin to myosin so by definition it sets the muscle sarcomeres length and thus participates to determination of meat toughness or tenderness (Warris, 2010; Herring *et al.*, 1965). After slaughter and cooling, meat maturation begins. Maturation was shown to reduce shear force value of the meat (Revilla and Vivar-Quintana, 2006; Vieira *et al*., 2007). During the days following slaughter, proteolytic enzymes (mainly calpains) break down myofibrils and this makes the muscle more flexible. If the meat pH is too low, calpains are denatured and tenderisation does not occur which results in high shear force values. Furthermore, when animals are stressed before slaughter, adrenaline is released which enhances calpastatin production. Calpastatin is an endogenous protein which inhibits calpain activity and thus, is opposed to tenderisation process. Calpastatin levels are also influenced by genetic factors. Warriss (2010) quoted a study of Casas *et al.* (2006) which demonstrated that level of endogenous calpastatin was genetically programmed which induces some cattle breeds may produce tougher meet than others. When animals undergo acute stress at the time of slaughter, acidification of the meat can occur faster than normal and in this case a low pH is reached when the carcass is still hot. This causes denaturation of muscle proteins and results in pale, soft and exudative (PSE) meat but occurs scarcely in cattle (Branscheid *et al*., 2007).

Immediately after dressing, carcasses are hanged in a cold room to prevent spoilage. The way of hanging the carcass determines muscle stretching or contraction and therefore influences further meat tenderness (Thompson, 2002). Cooling time is also important and depends on the muscle considered (external muscles will cool first), on the thickness of subcutaneous fat and on the air temperature. Cooling reduces enzyme activity and slows down the drop in pH. When cooling happens too fast, calcium ions are released from the sarcomeres and activate the enzyme ATPase which results in extreme shortening of sarcomeres. This phenomenon is called cold shortening and produces tough meat but happens less in cattle which large carcasses cool down slowly. Several handling techniques have been developed to control pH decrease, cooling speed and rigor mortis onset time. The rate of carcass cooling must be in adequacy to muscle pH to obtain tender meat: when the carcass temperature is higher than

35°C, pH should be above 6 whilst when the carcass temperature falls below 12°C, pH should be less than 6 (Meat Standard Australia in Thompson, 2002).

Animal-intrinsic influence on meat quality

Although pre- and post-slaughter handling is critical for meat quality, there are also animal factors influencing meat quality characteristics. Studies about the influence of sex, breed, age, growth rate and carcass classification on meat quality resulted in controversial conclusions. Results of Arthaud *et al*. (1977), Crouse *et al*. (1985) and French *et al.* (2000b) showed that steers had intrinsically a better meat quality profile than bulls for similar husbandry practices. Although results are variable, steers tend to have better water holding capacity, more marbling, lower shear value and better panel score for tenderness, lower myoglobin content and less dark meat, and a finer lean texture than bulls. Furthermore, Prost *et al*. (1975) quoted a study of Field *et al*. (1966) who obtained no difference in meat tenderness between heifers, steers and bulls up to 399 days old but heifers and steers had better scores than bulls when older than 500 days. Prost *et al*. (1975) mentioned those results contrasted with the results of Koger *et al*. (1960) and Zinn *et al*. (1970) who found no difference between bulls and heifers in meat tenderness. Therefore, differences between genders are not always perceived and are mostly visible at maturity. Prost *et al*. (1975) also showed that differences were dependent on the muscle considered. Maturity also influences myoglobin content so that meat becomes darker when the animal is older (Arthaud *et al*., 1977). At last, maturity influences fat deposit location because internal fat develops first while IMF develops at last (Dudouet, 2004). According to the study of Perry and Thompson (2005), there is no relationship between the mean average daily gain in a group of animals and overall meat palatability when adjusted to the same age at slaughter. Yet, within one group, animals which showed better individual daily gain also had improved meat palatability for reasons that remain unclear. However, effects varied according to the breed, the muscle considered and the test used to assess meat palatability (panel, compression or shear force). Oury *et al*. (2006) further found that if slaughtered at the same age, Charolais heifers with the heaviest live weight and therefore highest life long-average weight gain also had the best meat quality. At last, genetics which influence growth rate, age at maturity, potential meat production will further influence meat quality characteristics.

Dietary effects on meat quality traits

As mentioned in chapters I.2.2 and I.2.3, diet influences growth rate and carcass composition. Therefore, diet influences meat quality characteristics inherent to growth rate and carcass composition mentioned before. Furthermore, diet has a direct influence on meat quality characteristics as detailed below.

Water holding capacity

As described previously, WHC of the meat is related to meat pH. WHC depends on the muscle considered (Crouse *et al*., 1984). Razminowicz *et al*. (2006) and Realini *et al*. (2003) found no difference in pH of *musculus longissimus dorsi* respectively at 24 h *p.m.* and after purchase at the retailer. Similarly, Friedrich (2010) found neither a dietary effect nor a meat ageing effect on WHC. Moreover, Razminowicz *et al*. (2006) found no difference in WHC of grilled meat although production systems, age and degree of finishing of animals were different. Therefore, nutritional interventions seem to have less influence than pre- and post-slaughter handling on WHC of meat.

Meat composition

Feeding intensity affected meat composition in the study of Sami *et al*. (2004). Bulls were fed for 100 or 138 days either *ad libitum* or restricted maize silage with concentrates. Differences in weight gains appeared between the two groups and *m. longissimus dorsi* from bulls with the higher feeding level had lower moisture content and higher fat content than in the restricted group. However, feeding intensity had no effect on protein content. Furthermore, length of time on feed had no effect on fat, moisture and protein content. In contrast, when animals had similar live weight gains, there was no effect of the type of diet on meat composition (French *et al*., 2000b; Steen *et al*., 2003; Noci *et al*., 2005; Friedrich, 2010). Therefore, meat moisture, protein and fat content depended on the energy level of the diet but not on the type of diet under investigation.

Marbling

Intramuscular fat (IMF) is the last type of fat to deposit after subcutaneous fat and intermuscular fat. As both other types of fat, it is influenced by the animal weight gain and maturity. Pasture grazing animals showed lower levels of IMF than concentrate-fed animal in the studies of Steen *et al*. (2003) and Oury *et al*. (2006). However, when animal weight gains were similar, meat marbling was also similar (French *et al*., 2000b; Steen *et al*., 2003;

Friedrich, 2010). Hence, as for meat composition, marbling seems to depend more on the energy level of the diet than on the type of diet.

Meat fatty acid profile

The Food and Agriculture Organisation (FAO) recommends an increased consumption of n-3 fatty acids to compensate for the high n-6 intake in our modern regimen. It also recommends exchange of saturated fatty acids (SFA) for mono- and polyunsaturated fatty acids (MUFA and PUFA) to prevent coronary and heart diseases (FAO, 2008). In several studies, cattle fed grass-based diets had enhanced proportion of PUFA in meat when compared to silage- or concentrate-based fed animals (French *et al*., 2000a; Steen *et al*., 2003; Noci *et al*., 2005). Noci *et al*. (2005) found a linear increase in PUFA content of the meat with days on pasture. Furthermore, Duckett *et al.* (1993) found a quadratic decrease in PUFA and linear increase in SFA with days on a maize silage finishing diet after fattening on pasture. The PUFA content of the meat increased at the expense of SFA in the study of Noci *et al*. (2005) and French *et al*. (2000a) whilst in Steen *et al*. (2003), MUFA content but not SFA content tended to decrease while PUFA increased. The n-6:n-3 ratio decreased linearly with the number of days spent on pasture before slaughter (Noci *et al*., 2005) due to increased proportion of n-3 while the proportion of n-6 remained unchanged (French *et al*., 2000a; Noci *et al*., 2005) or decreased (Steen *et al*., 2003). Furthermore, conjugated linoleic acid content was enhanced in the meat of animals fed grass-based diets (French *et al*., 2000a; Noci *et al*., 2005). Differences in meat fatty acid profile were observed both when the grass was offered fresh on pasture or as a silage. Indeed, if fatty acid composition depends on the intrinsic plant characteristics, it is further modified by lipid oxidation during the ensiling and wilting processes (Dewhurst *et al*., 2003). As a conclusion, the consulted literature provided arguments in favour of meat from grass-fed and specially grazing animals regarding recommendations of the FAO (2008) about fatty acids in our modern regimen. As the ratio of unsaturated fatty acid increases, the oxidative stability of the meat is reduced, resulting in undesirable odours and colours (Berges, 1999). Hence, there could be concerns about shelf life of meat from grass-fed animals, richer in unsaturated fatty acids. As demonstrated by Cabell and Ellis (1942) and Hakkarainen and Pehrson (1987), fresh grass and grass silage contain more antioxidative vitamin E (α-tocopherol) than corn, wheat and hay. Hence, while the PUFA content of grass-fed animals increases, the vitamin E content of the muscle increases, preventing oxidative damage on the meat (O´Sullivan *et al*., 2002).

Meat and fat colour

As described in the previous paragraph, oxidative stability of the meat in not impaired when animals are grazing. Nevertheless, there is evidence that pasture grazing influences colour of both meat and fat but results from the consulted literature varied. In the study of French *et al*. (2000b), steers had different scores of subcutaneous fat colour whether they were fed for 85 days different levels of concentrates or solely grazing. The proportion of concentrates in the diet was inversely and linearly related to the subcutaneous fat yellowness (R^2 = 52%) and to the kidney and channel fat yellowness (R^2 = 69%). Friedrich (2010) and Realini *et al*. (2003) also found that fat from grazing animals was yellower. It was also showed that grazing animals had a darker meat than concentrate-fed animals at the same age (Crouse *et al*., 1984; Realini *et al*., 2003). In contrast, French *et al*. (2000b) and Friedrich (2010) found no difference in meat darkness, but French *et al*. (2000b) obtained more yellow meat when a higher proportion of grass than concentrates was present in the diet. Oury *et al*. (2006) found no difference in the colour of *m. rectus abdominis* whether Charolais heifers were finished 163 days on maize silage with concentrates or on pasture with additional concentrates. Therefore, authors agree that grazing animals have yellower fat; however effects of grazing on meat colour remains uncertain. Increased fat yellowness is most likely due to higher concentration of carotenoids in fresh grass than in silages and concentrates (Realini *et al*., 2004; Nozière *et al*., 2006).

Tenderness and shear force

In the study of Friedrich (2010), grazing did not influence meat tenderness (shear force); only ageing time lowered shear force value. Furthermore, French *et al*. (2000b) showed that although the diet had an influence on meat tenderness in the days following slaughter, differences were not anymore significant when meat was aged. In contrast, Razminowicz *et al*. (2006) found that pasture-derived meat of steers and heifers was more tender than conventionally reared heifers and bulls. However, due to the diversity of meat origins, influence of handling of animals and carcasses could have biased the results. Furthermore, although Razminowicz *et al*. (2006) found no relationship between IMF content of the meat and shear force, they noticed shear force values were variable within the same slice. Furthermore, Razminowicz *et al*. (2006) found higher Warner-Bratzler shear force values when meat contained less than 1.5% IMF; hence, 1.5% IMF seemed to be the minimum threshold for acceptability. For pork meat, Fortin *et al*. (2005) found a significant (*p*-value<0.05) linear relationship between IMF and respectively shear force, softness,

tenderness, juiciness and flavour intensity with Pearson correlation coefficients of -0.41, -0.32, -0.31, -0.27 and 0.24, respectively. Fortin *et al*. (2005) also confirmed the minimum level of 1.5 % IMF for acceptable palatability.

1.2.5 Conclusions of the literature study

Diet effect on growth performance, slaughter characteristics and meat quality should be compared for animals at similar age, breed and gender to reduce animal-intrinsic variations within production traits. Animals solely allowed pasture grazing showed lower daily weight gains than animals intensively fed concentrate-based diets, although some authors described similar weight gains for grazing and indoor-fed animals. Furthermore, grazing animals have leaner carcasses and a higher proportion of bones. As the lower fatness score of grazing animals was related to a reduced weight gain, a finishing period in barn is advisable in order to improve carcass fatness. Meat water holding capacity and tenderness are not influenced by the type of diet, although the diet should be rich enough to ensure an IMF higher than 1.5%, minimum required for acceptable tenderness. Meat composition and IMF depend more on the energy level of the diet than on the type of diet. In contrast, fatty acid profile, fat colour and vitamin E content of the meat are directly dependent on the type of diet. Results about meat composition in fatty acids were in favour of grazing animals regarding human health recommendations.

1.3 Research questions

The literature study revealed the expectable differences in animal performance and meat quality induced by feeding practices as well as animal-intrinsic covariates. However, conclusions need to be confirmed in the present context. In the Eastern Alps, animals raised for beef production are often:

- From Simmental dairy cows crossbred with meat type bulls;
- Heifers or steers, slaughtered between 500 and 650 kg;
- Raised in barn and fed mainly grass silage with some additional hay or maize silage and supplemented with low quantities of concentrates.

After the literature study, it remains unclear whether fattening heifers on pasture and finishing in barn will allow the same animal performances and meat quality as raising solely in barn on a grass silage-based diet with low amounts of concentrates. Therefore, the research questions are:

1. Are growth and slaughter performances on pasture similar to current performances in barn?
2. Are meat quality traits different whether animals are fed from pasture or as in current practices?
3. Is meat fatty acid profile improved regarding health recommendations when animals are grazing?

2 Animals, materials and methods

2.1 Animals

Twenty crossbred Charolais x Simmental heifers of 300 kg (± 50 kg) live weight were purchased at the beginning of April 2009 from the Carinthian animals and meat trading organisation (Bäuerlichen Vermarktungsgemeinschaft Kärntner Fleisch). From the day of purchase, animals were kept in a barn for three weeks and fed *ad libitum* grass silage and hay. The experiment began on April, 27th. On that day, animals were distributed over two groups of ten animals so that average live weight and age were similar in both groups. One group was assigned to pasture rearing (Pasture group) and turned out to pasture on the same day. The other group was assigned to barn rearing (Indoor group) and divided in two blocks of five animals.

2.2 Diets

The experiment was set up as described in Figure 1.

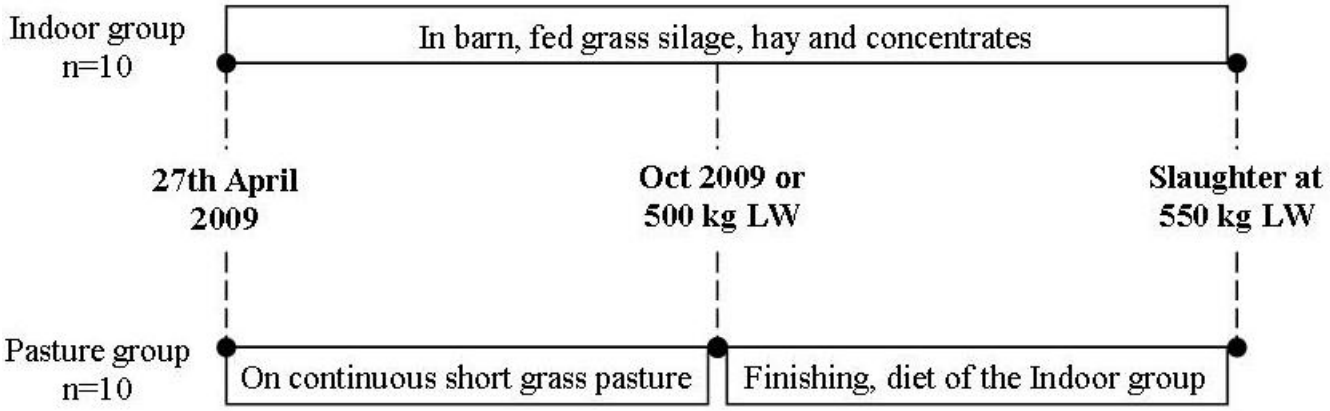

Figure 1. Scheme of the experimental set up (LW: live weight)

The Indoor group was fed grass silage (700 g kg^{-1} DM) and hay (300 g kg^{-1} DM) *ad libitum* (5-10% feed residues). In addition, each animal received daily 2 kg concentrates, which was a mash based mixture of 300 g kg^{-1} wheat, 300 g kg^{-1} barley, 250 g kg^{-1} corn and 150 g kg^{-1} rapeseed meal, and separately 30 g minerals and 30 g salt. The Pasture group was not supplemented during the entire grazing season but was offered minerals and salt. Heifers on pasture received anthelmintics twice during the grazing period and once at the beginning of the barn period. The botanical composition of the pasture was assessed both in 2006 and 2007 and is presented in the appendix A. Pasture composition was in average (presented as percentage of the area):

– Grass (55-80%): *Dactylis glomerata*, *Agrostis capillaris*, *Poa pratensis*, *Festuca pratensis* and *Alopecurus pratensis* as main species

– Leguminous (23-50%): *Trifolium repens*

– Aromatic herbs (16-24%): *Taraxacum officinale* as main species

Continuous grazing on short grass was chosen as pasture management for its convenience and its efficiency for feeding beef cattle (see chapter I.2.1). From 500 kg live weight onwards and latest at the end of October, animals were housed for a finishing period on the same diet as the Indoor group. When animals were about 550 kg live weight, they were fasted overnight and slaughtered at the facilities of the Agricultural Research and Educational Centre of Raumberg-Gumpenstein.

2.3 Measurements

2.3.1 Growth and feed

Concentrates and fodder were analysed monthly for nutrient composition using the methods described by ALVA (1983) and VDLUFA (1976). Dry matter content of hay and concentrates were analysed weekly and dry matter content of grass silage and feed residues were analysed daily (working days only). Animals from both groups were weighed weekly and individual daily feed intake was recorded using electronic Calan doors (American Calan, USA). Feed intake was not recorded for animals on pasture.

2.3.2 Slaughter characteristics

Animals were stunned by percussion stunning using a captive bolt. Blood was collected to be weighed. Thereafter, skin, feet, head, tongue, liver, spleen, kidneys, kidney fat, heart, lungs, diaphragm and tail were separated and weighed. The carcass was then divided in two parts and each half hung by the Achilles tendon. The carcass was immediately placed in a cooling room at 2°C and 70% humidity and equipped with a ventilation system. Carcass classification and fatness score were assessed from the right half carcass, according to the European classification system. Length of the right half carcass from the first vertebra to the cranial edge of the pelvis bone was measured. Thereafter, each half of the carcass was weighed warm and pH was measured one hour *p.m.* in the *m. longissimus dorsi* and the *m. semimembranosus*. At 48 h *p.m.*, pH was measured again and cold carcass was weighed. Seven days after slaughter, the right half carcass was carved and cuts were weighed.

2.3.3 Meat quality

Meat quality characteristics were assessed from the *m. longissimus dorsi* between the 8th and the 11th ribs of the right half carcass as described in Figure 2. Cuts were vacuum packed and stored in the dark at 2°C. Pictures of the different measurements are presented in appendix.

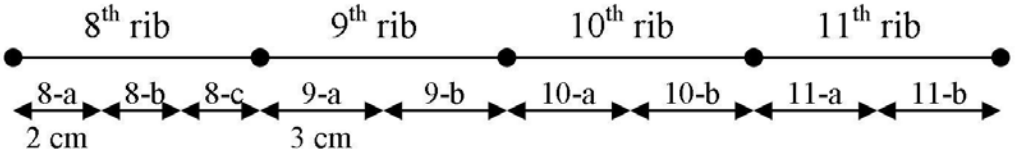

Figure 2. Scheme of the meat sampling locations and measurements for meat quality analysis.
8-a: Marbling, muscle size, meat composition and fatty acid analysis at 7 days p.m.
8-b: Drip loss and cooking loss at 7 days p.m.
8-c: Cooking loss at 7 days p.m.
9-a: Colour and raw meat shear force at 7 days p.m.
9-b: Grill loss and grilled meat shear force at 7 days p.m.
10-a: Colour and raw meat shear force at 14 days p.m.
10-b: Grill loss and grilled meat shear force at 14 days p.m.
11-a: Colour and raw meat shear force at 21 days p.m.
11-b: Grill loss and grilled meat shear force at 21 days p.m.

Marbling and muscle size

A picture was taken at 7 days *p.m.* of the full rib cut with bones. The bones remained so the shape of the *m. longissimus dorsi* was not altered. IMF percentage and size of the *m. longissimus dorsi* were obtained from an analysis of the picture using the software PicEdCora version 9.

Fatty acid analysis and meat composition

From the cut used for marbling and muscle size, the *m. longissimus dorsi* was removed and homogenised in a mixer. Dry matter, crude fat, crude protein (Kjeldahl method) and ash content were assessed on fresh meat according to Handbuch der Lebensmittelchemie (1968). Extraction of intramuscular fat for fatty acid analyses was carried out according to Folch *et al*. (1957) with slight modifications undertaken by the Bavarian State Research Center for Agriculture, division "Qualitätssicherung und Untersuchungswesen". The concentration of individual fatty acids from intramuscular fat was determined as their methyl esthers (FAME) by gas liquid chromatography using the trimethylsulfonium hydroxide (TMSH) derivatisation method as described by the Deutsche Gesellschaft für Fettwissenschaften (DGF, 2006). The gas chromatograph was a Varian 3900 instrument fitted with a 100 m x 0.25 mm open tubular Supelco Fused Silica SP 2380 column and helium was the carrier gas. A standard mix

Supelco 37 Component FAME Mix (Sigma-Aldrich Handels Gmbh, Austria) was used as a reference. Temperatures of injection and flame ionization detector were respectively 250°C and 260°C. Threshold for detection was 0.0075 % of the FAME.

Colour

A luminometer Codec 400 (Phyma, Austria) and its software were used to measure lightness, redness and yellowness of fat and meat according to the CIE L*a*b* colour space. For L*-lightness, values could range from zero (black) to 100 (diffuse white). For a*-redness, values could range from -60 (green colour) to +60 (red colour) and zero stood for a grey colour. For b*-yellowness, values could range from -60 (blue colour) to +60 (yellow colour) and zero stood for a grey colour. At day 7, 14 and 21, meat colour and subcutaneous fat colour were assessed from one cut for each animal as presented in Figure 2. The colour was assessed on at least five points of the *m. longissimus dorsi* (or the subcutaneous fat for fat colour measurement) and the average value was recorded. For meat colour, measurements were repeated after one hour oxidation at room temperature.

Water holding capacity

Drip loss was measured at 7 days *p.m*. The cut of *m. longissimus dorsi* was weighed, hanged on a spit and left in a plastic box at 2°C. After 48 h, the cut was weighed again and the difference in weight was recorded as drip loss.

Cooking loss was assessed at 7 days *p.m.* both from a fresh cut of the *m. longissimus dorsi* and from the cut used for the 48 h-drip loss measurement. The meat was cooked for 50 min in a plastic bag immersed in a 70°C-warm water bath (Grant, Germany), then cooled down for 40 min in cold water and weighed.

Grill loss was assessed at 7, 14 and 21 days *p.m*. Each cut was grilled in an aluminium foil to an internal temperature of 60°C, in a Silex grill (Silex Ltd, England) which double plates were heated at 200°C. Warm weight was measured immediately after cooking and weighing was repeated when the meat had cooled down to room temperature.

Shear force

Shear force was assessed using an Instron 3365 machine (Instron, Germany) equipped with a Warner-Bratzler sharing device as presented in the appendix B. Measurements were done on raw and grilled meat at 7, 14 and 21 days *p.m.* with the samples previously used for colour and grill loss. At least 12 cores (1.27 cm diameter) were cut from each steak parallel to the

direction of the muscle fibres and cut by the Warner-Bratzler sharing device at a speed of 150 mm min^{-1}. Shear force was recorded by an Instron Serie IX Automated Materials Testing System software for Windows.

2.4 Statistical analysis

Statistical analysis was performed using SAS 9.2. (SAS Institute Inc., Cary, NC). Data were analysed separately for growth, slaughter and meat quality characteristics. In the mixed models, animals were nested within treatment groups because one single treatment was applied on each animal. Correction for the small sample size was made as described by Kenward and Roger (1997). Compound symmetry and autoregressive covariance structures were tested using both the finite-sample corrected Akaike Information Criteria (AICC) and the Schwarz´s Bayesian Information (BIC) according to Wand and Goonewardene (2004). For all models, the Tukey procedure was used to test significance of the difference between least square means.

Growth performance

Data were all from repeated measurements and therefore analysed with a Mixed procedure. The autoregressive covariance structure was chosen with Week (1 to 53) as the repeated statement. The following model was used:

$$Y_{ijk} = \mu + Group_i + Week_j + (Group*Week)_{ij} + \varepsilon_{ijk}$$

Y: observed variable

μ: overall mean

$Group_i$: fixed effect of treatment group (Indoor or Pasture)

$Week_j$: fixed effect of the experimental week *j*

$(Group*Week)_{ij}$: interaction between the effects of group *i* and week *j*

ε_{ijk}: error term for the animal *k* of the group *i* on the week *j*

As animals differed in live weight along the experiment, they were grouped according to live weight classes for some analyses (see paragraph 3.2). Weight classes were <300 kg, 300-350 kg, 350-400 kg, 450-500 kg and 500-550 kg.

Slaughter characteristics

Fixed effect of Group was analysed with an analysis of covariance correcting for the effect of individual animal live weight at the start of the experiment. Data about carcass classification were analysed by paired sample t-tests and conclusions were confirmed with a Wilcoxon test.

Meat quality characteristics

Single measurements were analysed with an ANOVA and the fixed effect of Group was tested. Repeated measurements were analysed with a Mixed procedure. The mixed model included the fixed effect of Group, Ageing and their interaction. Ageing was used in the repeated statement. The covariance structure chosen was compound symmetry structure. For data about meat redness, yellowness and shear force of raw meat, the autoregressive covariance structure showed lower AICC and BIC. However, the difference between autoregressive and compound symmetry structure regarding AICC and BIC was small and compound symmetry was preferred because it was simple (Wang and Goonewardene, 2004). The following model was used:

$$Y_{ijk} = \mu + Group_i + Ageing_j + (Group*Ageing)_{ij} + \varepsilon_{ijk}$$

Y: observed variable

μ: overall mean

$Group_i$: fixed effect of treatment group (Indoor or Pasture)

$Ageing_j$: fixed effect of the ageing day (7, 14 or 21)

$(Group*Ageing)_{ij}$: interaction between the group *i* and the week *j*

ε_{ijk}: error term for the animal *k* of the group *i* on the week *j*

Oxidation effect on meat colour was assessed using the same model, adding the fixed effect of Oxidation and interactions with Ageing and Group. Oxidation was a dummy variable, “0” stood for no oxidation and “1” stood for one hour oxidation.

3 Results

3.1 Feedstuff analysis

As described in the material and methods chapter, animals received daily a diet composed of 30% hay and 70% grass silage (on a DM basis) and 2 kg concentrates. Composition and energy content of hay, grass silage and concentrates were evaluated monthly; results are presented in Table 2.

Table 2. Feed composition (means ± SD)

	Hay	Grass silage	Concentrates
Dry matter (%)	89 ± 1.9	34 ± 4.3	89 ± 0.8
Metabolisable energy (MJ kg^{-1} DM)	9.2 ± 0.3	10.0 ± 0.2	13.3 ± 0.1
Crude protein	116 ± 14	144 ± 8.7	145 ± 15
Crude fat	22 ± 4.9	34 ± 3.6	27 ± 1.9
Crude fiber	271 ± 14	268 ± 19.7	54 ± 8.9
NDF	522 ± 19	500 ± 15	174 ± 12
ADF	290 ± 38	312 ± 28	71 ± 5.7
Lignin	36 ± 4.8	36 ± 6.0	20 ± 4.2
Ash	81 ± 12	100 ± 17	29 ± 1.8
Minerals			
Ca	7.6 ± 0.42	8.5 ± 0.83	1.9 ± 0.18
Mg	3.5 ± 0.35	3.5 ± 0.27	1.6 ± 0.13
P	2.7 ± 0.30	3.2 ± 0.64	4.2 ± 0.36
K	15.6 ± 1.94	22.6 ± 3.66	8.7 ± 0.54
Na	0.21 ± 0.096	0.23 ± 0.06	0.18 ± 0.18
Mn (mg kg^{-1} DM)	106 ± 42.8	87 ± 10	32 ± 24
Zn (mg kg^{-1} DM)	32 ± 2.9	33 ± 2.9	31 ± 2.8
Cu (mg kg^{-1} DM)	10.1 ± 1.6	12.3 ± 1.8	5.5 ± 1.9

When not specified, data are in g kg^{-1} DM.
ADF: acid detergent fiber; DM: dry matter; MJ: mega Joules; NDF: neutral detergent fiber.

The grazing area was adapted so that the sward height surface remained between 3 and 6 cm as showed in Figure 3. Average stocking rate over the whole grazing period was 9 GVE ha^{-1} (livestock unit: 1 GVE = 500 kg live weight). Grazing area was at its minimum in May with 0.48 ha and at its maximum in October with 4.50 ha.

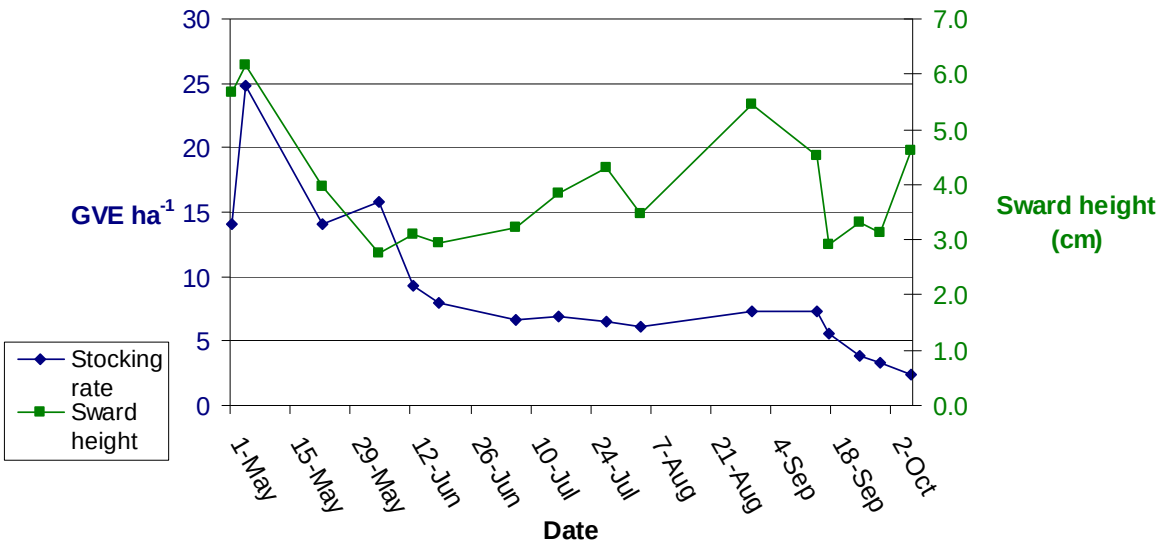

Figure 3. Stocking rate and sward height of the pasture grazed by the Pasture group (GVE: Grossvieheinheiten (livestock unit), 0.4 GVE= bovine up to 6 months, 0.6 GVE= bovine between 6 and 24 months old, 1GVE= 500 kg live weight (bovine above 24 months old) (ÖPUL, 2007))

3.2 Growth performances

When the Pasture group was turned on pasture on the 27th of April, mean live weight was 292 kg (SD=34 kg) while mean live weight in the Indoor group was 312 kg (SD=45kg). Two animals of the Pasture group were housed for the finishing period from the 21st of September onwards because they had reached a live weight of 472 and 481 kg, respectively. The remaining animals of the Pasture group were housed from the 13th of October onwards due to bad weather conditions. The mean live weight in the Pasture group at the beginning of the finishing period was 431 kg (SD=35 kg) while the mean live weight in the Indoor group at the same period was 464 kg (SD=48 kg). Over the whole experiment, ADG of the Pasture group and the Indoor group were 1026 and 993 g d^{-1}, respectively (SEM=119 g d^{-1}). Regarding the whole experiment, ADG were not significantly different between groups. Detailed growth performances and feed intake for each period are presented in Table 3. During the grazing period as during the finishing period, ADG were not significantly different between groups. Furthermore, average feed intake and feed conversion were similar between groups.

Table 3. Fattening results and feed consumption for each period

	Pasture group	Indoor group	SEM*
Grazing period [1]			
Growth			
ADG (g day^{-1})	767	936	95
Daily feed intake			
Total feed intake (kg DM)	-	6.9	0.22
Grass silage (kg DM)	-	3.7	0.14
Hay (kg DM)	-	1.5	0.07
Concentrates (kg DM)	-	1.76	<0.01
ME (MJ)	-	72.9	2.08
CP (g)	-	884	27.9
EE (g)	-	203	6.3
CF (g)	-	1408	58
NDF (g)	-	2644	105
ADF (g)	-	1612	68
Lignin (g)	-	191	8.7
Ash (g)	-	529	19.7
Ratio CP/ME	-	12.1	0.04
Feed conversion			
ME (MJ kg^{-1} gain)	-	82	6.1
DM (kg kg^{-1} gain)	-	7.8	0.6
Crude protein (g kg^{-1} gain)	-	992	75
Finishing period [1]			
Growth			
ADG (g day^{-1})	1190	1075	111
Daily feed intake			
Total feed intake (kg DM)	8.9	9.1	0.39
Grass silage (kg DM)	5.1	5.3	0.29
Hay (kg DM)	2.2	2.1	0.09
Concentrates (kg DM)	1.76	1.75	<0.01
ME (MJ)	92.7	94.1	3.75
CP (g)	1228	1252	54
EE (g)	229	236	19
CF (g)	1821	1881	98
NDF (g)	3754	3837	190
ADF (g)	2108	2191	115
Lignin (g)	289	300	14.7
Ash (g)	625	653	34
Ratio CP/ME	13.1	13.3	0.06
Feed conversion			
ME (MJ kg^{-1} gain)	95	97	10.5
DM (kg kg^{-1} gain)	9.2	9.4	0.96
Crude protein (g kg^{-1} gain)	1243	1288	124

ADF: acid detergent fiber; ADG: average daily gain; CF: crude fiber; CP: crude protein; DM: dry matter; EE: ether extract; ME: metabolisable energy; MJ: mega Joules; NDF: neutral detergent fiber; SEM: standard error of the mean.

*: data were unbalanced, the higher SEM was taken.

[1]: The Pasture group was on pasture during the grazing period and in barn during the so-called finishing period, the Indoor group remained in barn during both periods.

Animals from each group had different live weights from the beginning of the experiment onwards. Therefore, data are also presented per weight class in Figure 4 and Figure 5. More tables are available in appendix. No significant difference between groups was observed.

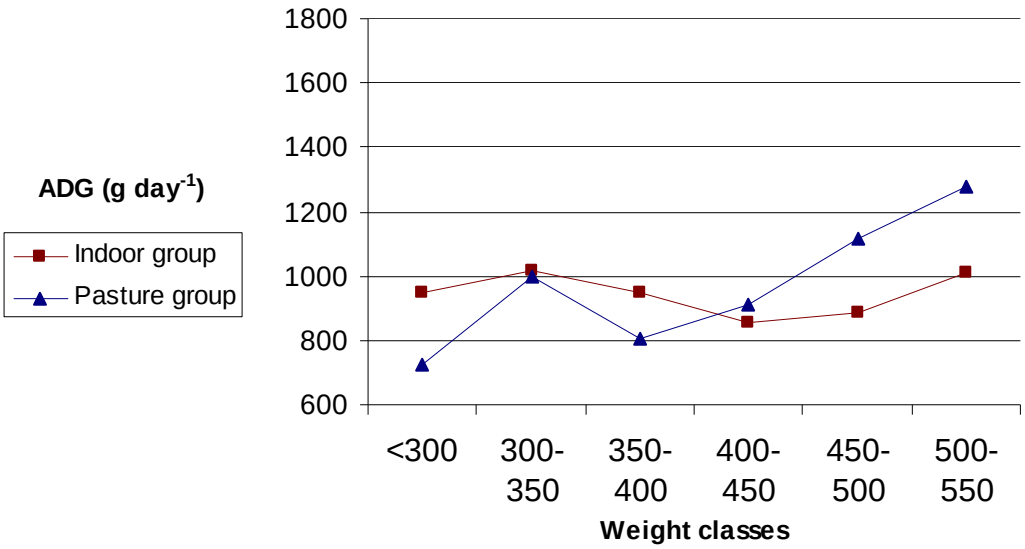

Figure 4. Average daily gain for each weight class in each group

ADG remained constant for the Indoor group at all weight classes while it was less stable for the Pasture group. However, no significant difference was found and a large variability was observed between animals of the same weight class. In Figure 4, the reduced ADG in the Pasture group for weight classes 350-400 kg and 400-450 kg corresponds to the weight at which animals were brought from pasture to barn for the finishing period.

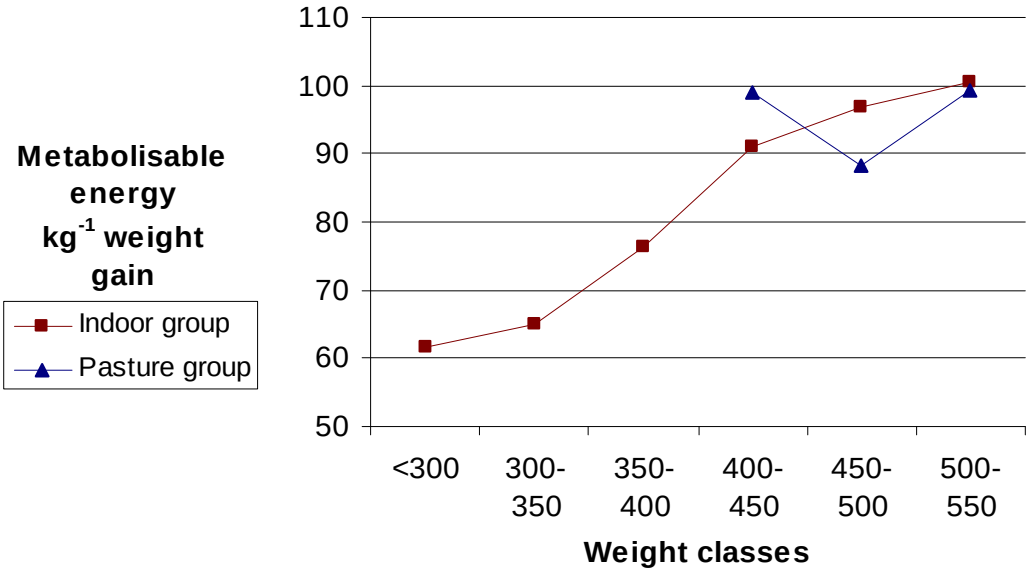

Figure 5. Metabolisable energy per kg weight gain for each weight class in each group

In Figure 5, feeding data of the Pasture group were available only from the weight class 400-450 kg onwards because feed intake on pasture was not recorded. Once again, no significant difference between groups was observed. Furthermore, the lower metabolisable energy conversion ratio of the Pasture group at the weight class 450-500 kg was of no significance.

3.3 Slaughter characteristics

3.3.1 Carcass yield and score

Animals were slaughtered at an average live weight of 549 kg and an average age of 511 days old. Mean live weight was 548 kg for the Indoor group and 550 kg for the Pasture group (SEM=3.4 kg). Therefore, mean live weight at slaughter was not different between groups. No difference in carcass weight was observed and mean carcass weight was 303 kg (SEM=3.1 kg). Hence, dressing percentage was similar in both groups and cold carcass weight represented 55% of the live weight. Frequency of muscularity and fatness scores are presented in Figure 6. There was no difference between groups for carcass length (mean lenght 167 cm) and muscularity score (mean score U). Mean fatness score was 2.8 (SD=0.42) for the Pasture group and 3.3 (SD=0.59) for the Indoor group. Animals from the Indoor group had fatter carcasses (*p*-value=0.04) but the group effect only explained 21% of the variability of carcass fatness score (R^2 value). For the *m. longissimus dorsi*, mean pH was 6.8 at 1 h *p.m.* and 5.7 at 48 h *p.m.*.

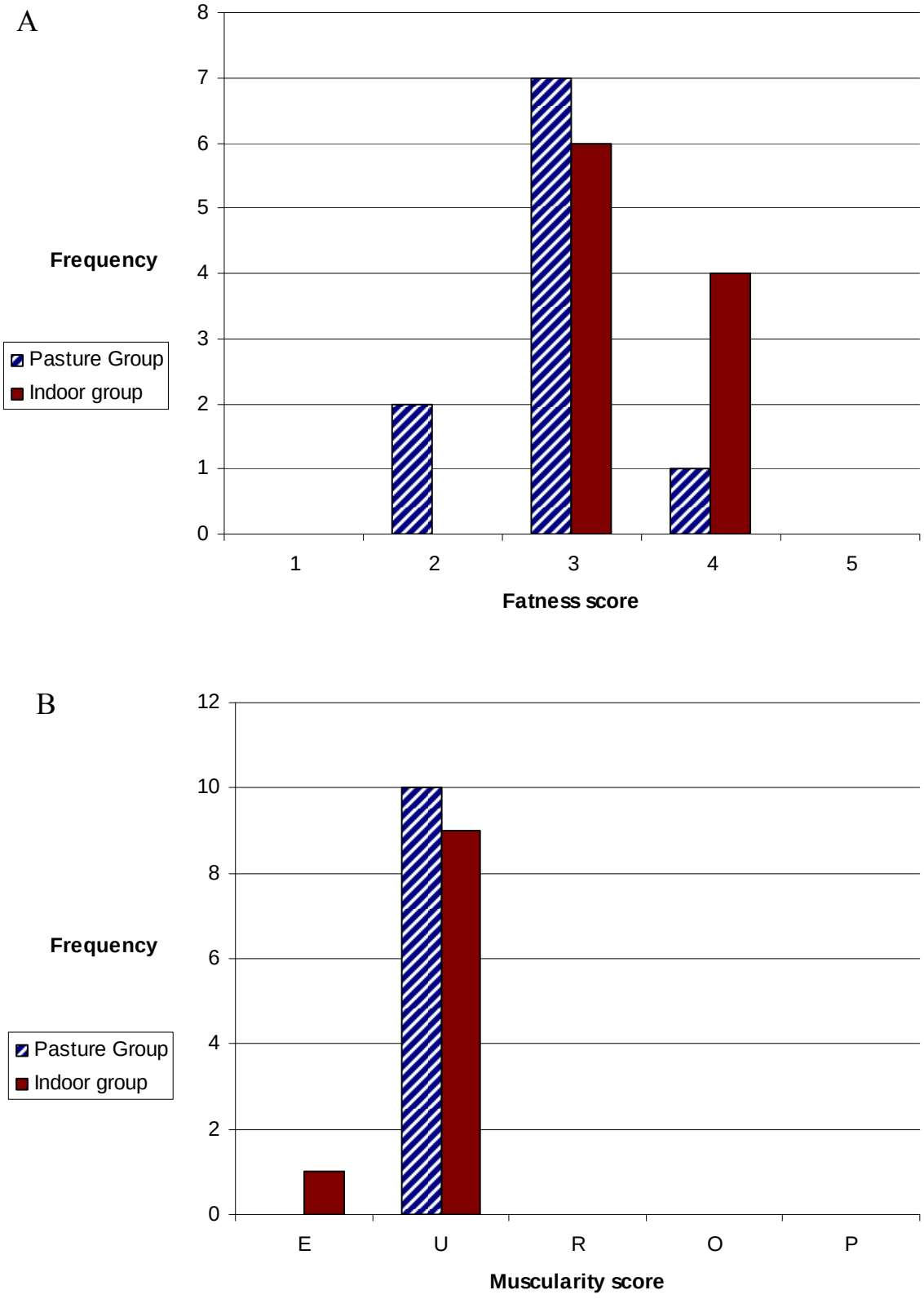

Figure 6. Carcass fatness (A) and muscularity (B) score frequency for each group

3.3.2 Organs and cuts

Weight of the main organs and weight of carcass cuts are presented in Table 4. Although there was no significant difference, the Indoor group tended to have more kidney fat and a higher kidney fat percentage than the Pasture group (*p*-value of 0.060 and 0.080 respectively). In contrast, organs of the circulatory and respiratory system were heavier in the Pasture group. Furthermore, the liver was also slightly but significantly heavier in the Pasture group. For most of the cuts, there was no difference between groups. The flank and sirloin were heavier on carcasses from the Indoor group.

Table 4. Weight of the main organs and of each cut of the right half carcass

	Pasture group	**Indoor group**	**SEM**	**Significance**[1]
Organs				
Liver	6.0	5.5	0.10	**
Spleen	1.0	1.2	0.07	ns
Heart, lungs and diaphragm	9.1	7.7	0.24	**
Kidneys	1.0	0.9	0.04	ns
Kidney fat	7.8	10.9	1.04	ns
Kidney fat (%)[2]	2.6	3.5	0.36	ns
Cuts				
Neck	10.5	10.2	0.23	ns
Breast and plate	14.3	14.6	0.30	ns
Chuck back rib	12.0	11.9	0.34	ns
Fore shank	4.6	4.4	0.09	ns
Shoulder	19.2	19.3	0.28	ns
Flank	17.5	18.7	0.35	*
Tenderloin	2.6	2.4	0.07	ns
Sirloin	14.0	14.9	0.26	*
Round	46	45	0.82	ns
Rear shank	7.1	7.0	0.14	ns

Values are least square means in kg.
SEM: standard error of the mean for ten animals per group.
[1] ns: not significant *p*-value > 0.05, * *p*-value < 0.05, ** *p*-value < 0.01, *** *p*-value < 0.001.
[2] in percentage of warm carcass weight.

3.4 Meat quality

3.4.1 Size and composition of the *m. longissimus dorsi*

As shown in Table 5, muscle fat content and marbling showed significantly lower values for the Pasture group than for the Indoor group. Pictures of the two extreme marbling percentages are presented in appendix. Crude protein and ash content were similar for both groups whilst fat and DM content were higher for the Indoor group. Although there was no significant difference, muscle size tended to be smaller for the Pasture group (*p*-value=0.085).

Table 5. Meat characteristics and composition in each group of the *m. longissimus dorsi*

	Pasture Group	Indoor Group	SEM	Significance[1]
Muscle characteristics				
Muscle size (cm²)	79.3	93.3	5.42	ns
Marbling (% of muscle area)	3.1	4.6	0.42	*
Meat composition (g kg^{-1} FM)				
DM	248	256	2.8	*
Crude protein	219	218	1.1	ns
Total fat	17.9	28.6	2.95	*
Ash	11.32	10.45	0.37	ns

Values are least square means.
DM: dry matter; FM: fresh matter; SEM: standard error of the mean for ten animals per group
[1] ns: not significant *p*-value > 0.05, * *p*-value < 0.05, ** *p*-value < 0.01, *** *p*-value < 0.001.

3.4.2 Fatty acid profile of the *m. longissimus dorsi*

Regarding the fatty acid profile, meat from the Indoor group contained more SFA, mainly due to higher values for myristic acid (C14:0) and palmitic acid (C16:0) as showed in Table 6. In contrast, meat from animals of the Pasture group was higher in PUFA, mainly due to higher values for linoleic acid (C18:2 *cis* 9, 12) and α-linolenic acid (C18:3 *cis* 9, 12, 15). The group effect explained 39% and 42% of variations in SFA and PUFA respectively (R^2 values). Some fatty acids (C11:0, C15:1, C18:4, C22:1, C22:2, C22:3) are not presented in Table 6 because they were not found in the analysis. CLA *trans* 10, *cis* 12 was only found for one animal of the Pasture group, at 0.06% of the total fatty acids.

Table 6. Fatty acid composition of the *m. longissimus dorsi* in each group (% of total fatty acids)

	Pasture Group	Indoor Group	SEM	Significance[1]
Fatty acid profile				
C8:0 (caprylic)	0.093	0.089	0.0109	ns
C10:0 (capric)	0.072	0.086	0.0048	ns
C12:0 (lauric)	0.082	0.097	0.0075	ns
C13:0	0.008	0.014	0.002	*
C14:0 (myristic)	2.64	3.45	0.190	**
C14:1	0.42	0.60	0.051	*
C15:0	0.52	0.61	0.033	ns
C16:0 (palmitic)	26.01	29.47	0.530	***
C16:1 *trans* 9	0.066	0.114	0.0099	**
C16:1 *cis* 9	2.81	3.23	0.210	ns
C17:0	1.48	1.57	0.067	ns
C17:1	0.66	0.70	0.016	ns
C18:0 (stearic)	16.01	15.37	0.550	ns
Σ C18:1 *trans*	4.76	4.67	0.444	ns
C18:1 *cis* 9 (oleic)	31.99	31.36	0.890	ns
C18:1 *cis* 11	2.83	2.47	0.171	ns
C18:2 *trans* 9,12	0.15	0.13	0.014	ns
C18:2 *cis* 9,12 (linoleic)	4.00	2.41	0.334	**
C20:0 (arachidic)	0.097	0.098	0.0049	ns
C18:3 *cis* 6,9,12	0.032	0.022	0.003	*
C18:3 *cis* 9,12,15 (α-linolenic)	1.35	0.97	0.078	**
C20:1	0.11	0.11	0.008	ns
CLA *cis* 9, t 11	0.65	0.53	0.026	**
CLA *cis* 9, *cis* 11	0.069	0.067	0.0075	ns
C20:2	0.068	0.053	0.005	*
C22:0	0.013	0.010	0.0023	ns
C20:3 *cis* 8,11,14	0.31	0.21	0.027	*
C20:3 *cis* 11,14,17	0.033	0.025	0.0027	*
C20:4 (arachidonic)	1.00	0.56	0.097	**
C23:0	0.038	0.021	0.0046	*
C20:5 (eicosapentaenoic, EPA)	0.39	0.18	0.039	**
C24:0	0.003	0.002	0.0018	ns
C24:1	0.030	0.030	0.0042	ns
C22:4	0.118	0.086	0.0120	ns
C22:5 *cis* 4,7,10,13,16	0.065	0.049	0.0053	*
C22:5 *cis* 7,10,13,16,19 (docosapentaenoic, DPA)	0.91	0.54	0.093	*
C22:6 (docosahexaenoic, DHA)	0.066	0.048	0.0060	*
Total fatty acids				
SFA	47.1	50.9	0.80	**
MUFA	43.7	43.2	0.84	ns
PUFA	9.21	5.88	0.658	**
CLA	0.73	0.60	0.028	**
n-3	2.76	1.75	0.212	**
n-6	5.73	3.53	0.467	**
n-6/n-3	2.08	2.00	0.096	ns

Values are least square means.
CLA: conjugated linoleic acids; MUFA: Monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; SEM: standard error of the mean for ten animals per group; SFA: saturated fatty acids.
[1] ns: not significant p-value > 0.05, * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001.

The average length of the finishing period in barn was 129 days (SD=41 days). For animals of the Pasture group, concentrations of some FA were significantly correlated to the length of the finishing period in barn as indicated in Table 7. Concentrations of C20:1 and MUFA increased with the stay in barn while other fatty acid concentrations decreased. Although there was no significant relationship, concentration of C18:3 *cis* 6,9,12 tended to decrease with days in barn (Pearson correlation coefficient= -0.602 and p-value=0.066) while concentration of MUFA tended to increase (Pearson correlation coefficient=0.622 and p-value=0.055).

Table 7. Meat fatty acids which concentrations were significantly correlated with the length of the finishing period in barn of the Pasture group animals

	Pearson correlation coefficient	**significance[1]**	**coefficient of determination (%)**
C12:0 (lauric)	-0.638	*	41
C15:0	-0.897	***	80
C16:1 *trans* 9	-0.706	*	50
C17:0	-0.706	*	50
C18:1 *cis* 9 (oleic)	0.936	***	88
C18:1 *cis* 11	-0.691	*	48
C18:2 *trans* 9,12	-0.769	**	59
C20:1	0.681	*	46
C20:5 (EPA)	-0.643	*	41

[1] * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001.

3.4.3 Water holding capacity

Water holding capacity of the *m. longissimus dorsi* was assessed by drip loss, cooking loss, cooking loss after drip loss and grill loss. No significant group effect, ageing effect or interaction was observed. Mean values were 3.2 % loss by dripping, 26 % loss by cooking in a water bath, 21 % loss by grilling and 29 % loss after cooling the grilled meat, expressed as the percentage of weight lost.

3.4.4 Meat and fat colour

Colour of the meat and the subcutaneous fat was assessed at different ageing points for each group. As presented in **Table 8**, fat redness and yellowness were more intense for the Pasture group. Ageing increased intensity of meat lightness, fat redness and fat yellowness. Group effect was not significant for meat colour, although meat tended to be more red in the Pasture group (p-value=0.099). For fat L*-brightness, a significant interaction of Group and Ageing effects was observed. Indeed, fat L*-brightness decreased in the Pasture group with ageing days while it remained constant in the Indoor group. Oxidation (at T=1 h) rendered the meat

more red (p-value<0.001), more yellow (p-value<0.001) and tended to make it brighter (p-value=0.060).

Table 8. Brightness (L*), redness (a*) and yellowness (b*) of meat and subcutaneous fat in each group, at different ageing points on a fresh cut and after one hour oxidation

	Group			Ageing				Effect[1]		
	Pasture	Indoor	SEM	7 days	14 days	21 days	SEM	Group	Ageing	Group*Ageing
Meat colour T=0										
L*	38.6	39.3	0.84	37.4 [b]	39.5 [a]	39.9 [a]	0.66	ns	**	ns
a*	11.3	10.3	0.39	10.7	10.9	10.9	0.33	ns	ns	ns
b*	7.5	6.8	0.37	7.1	7.3	7.2	0.33	ns	ns	ns
Meat colour T=1 h[2]										
L*	39.3	40.2	0.78	39.2	39.5	40.6	0.75	ns	ns	ns
a*	14.1	13.4	0.43	13.1 [b]	13.9 [a]	14.3 [a]	0.38	ns	*	ns
b*	10.4	10.2	0.3	9.7 [b]	10.4 [a]	10.8 [a]	0.29	ns	*	ns
F**at colour T=0**										
L*	69.3	70.6	1.06	70.3	70.4	69.2	0.91	ns	ns	*
a*	2.2	0.7	0.28	0.0[c]	1.6 [b]	2.6 [a]	0.24	***	***	ns
b*	8.8	7.2	0.44	6.8 [c]	8.2 [b]	8.9 [a]	0.33	*	***	ns

Values are least square means in the CIE L*a*b* colour space.
SEM: standard error of the mean for ten animals per group.
[1] ns: not significant p-value > 0.05, * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001.
[2]: after 1 h oxidation
[a, b]: different superscripts within a row indicate significant differences.

3.4.5 Shear force

Results of the Warner-Bratzler shear force test are presented in Table 9. There was neither a significant group effect nor an interaction of group and ageing effects, but significant ageing effects were found. Although shear force of the raw meat increased with ageing time, the grilled meat had lower shear force values from 14 days of ageing onwards.

Table 9. Shear force values of raw and grilled meat in each group and at different ageing points

	Group			Ageing				Effect [1]	
	Pasture	Indoor	SEM	7 days	14 days	21 days	SEM	Group	Ageing
Raw meat	2.46	2.61	0.163	2.25[b]	2.50 [b]	2.85 [a]	0.143	ns	***
Grilled meat	3.15	3.28	0.228	4.06 [a]	2.96 [b]	2.61 [b]	0.189	ns	***

Values are least square means, expressed in kilogram-force (1 kgf = 9.8 newtons)
SEM: standard error of the mean for ten animals per group.
[1] ns: not significant p-value > 0.05, * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001.
[a, b]: different superscripts within a row indicate significant differences (p-value < 0.05).

4 Discussion

4.1 Growth performance

According to the values given by Garcia *et al.* (2003), hay was of medium quality regarding crude protein and NDF but of prime quality regarding ADF content. The grass silage was of medium quality regarding the values given by Kirkland and Patterson (2005) for low and high quality grass silages. Grazing allowance was in accordance with the results presented by Friedrich (2010) for heifers fattening on continuous short grass pasture. Although sward height was lower than usually recommended for this pasture management, it was in accordance with the results of Friedrich (2010) who reported a sward height of at 4 to 5.5 cm. Furthermore, Häusler *et al*. (2008) precised a sward height of 3 to 4 cm was optimal for this pasture management. ADG of both Pasture and Indoor groups were about 1010 g day^{-1}, which is in accordance with the results of Noci *et al*. (2005), Häusler *et al.* (2008) and Friedrich (2010). Regarding ADG per period, there was no significant difference between the two groups. However, the Pasture group had a less stable growth rate than the Indoor group over the whole experiment and ADG of the Pasture group was numerically lower than in the Indoor group over the grazing period. Inversely, the ADG over the barn period was slightly higher for the Pasture group. In the study of Friedrich (2010), animals on pasture also showed a less stable growth rate than animals in barn. Animals on pasture are more active than indoor kept animals and are exposed to changing climatic conditions influencing grass supply and maintenance requirements (Young, 1983; NRC, 2001; Legrand *et al*., 2009) which could have punctually altered the growth rate of the Pasture group. Regarding the finishing period in barn, conversion of crude protein, metabolisable energy and feed dry matter into live weight was within the range observed by Friedrich (2010). Feed dry matter conversion ratio was slightly above the results of Dufey *et al*. (2002) with steers and Sami *et al*. (2004) with bulls, most likely because of different feed energy content and gender effects (see paragraph 1.2.2).

4.2 Carcass characteristics and organ weights

While carcass conformation score was similar in both groups, fatness score was lower for the Pasture group (*p*-value=0.04). This observation is in accordance with the results of Realini *et al.* (2003), Steen *et al*. (2003) and Keane and Moloney (2009). Furthermore, Friedrich (2010) found no significant difference (*p*-value=0.15) but obtained numerical differences between silage-fed and grazing animals. However, in the present study, the fixed group effect explained only 21% of the variability of the fatness score (R^2 value). A carcass fatness score of 2 has the same value as a fatness score of 3 according to the Austrian beef market, while penalties are applied for a fatness score of 4 (Österreichische Rinderbörse, 2010). In the

present study, five animals had a fatness score above 3, among which four animals were from the Indoor group and one from the Pasture group. Hence, the Pasture group would have received less penalties for carcass fatness than the Indoor group in a commercial slaughter house.

Although there was no significant difference between groups, kidney fat and kidney fat percentage in the warm carcass weight showed the same trends as carcass fatness scores (*p*-value=0.060 and 0.080, respectively). Dressing percentage was in accordance with the results of Steen *et al*. (2003) who also used crossbred Charolais heifers slaughtered between 529 and 560 kg live weight, and with the results of Friedrich (2010). Carcass cuts had mostly the same weight in both groups but striploin and flank were significantly heavier in the Indoor group. These results are in contrast with the results of Friedrich (2010) who found no difference in cuts weight. However, striploin and flank of the Indoor group were heavier by only 6%, which may be of low practical importance.

Liver, heart, lungs and diaphragm were significantly heavier in the Pasture group. Friedrich (2010) observed the same phenomenon. Heavier liver, increased blood flow and higher oxygen consumption are associated with a higher feed intake (Burrin et *al*., 1989). Myers *et al*. (1999) concluded that hypertrophy occurs, subsequently to increase in feed intake, in organs that have high-maintenance energy expenditures such as heart, liver and gut. In the study of French *et al*. (2000a), animals on pasture had a higher DM intake than animals fed a maize silage-based diet but both groups had the same ADG. Feed intake of the animals on pasture was not recorded but based on the feed intake measurements of French *et al*. (2000a), it can be hypothesised that in the present study dry matter intake of animals on pasture was higher than the intake of animals in barn, which matches with the heavier organs. Furthermore, Bowden and Clarke (1963) observed that pigs raised on pasture had heavier hearts than pigs raised in barn and explained this finding by the higher exercise of animals on pasture according to Bowden (1957).

4.3 Meat quality

4.3.1 Muscle size and composition

IMF was higher in the meat of the Indoor group whether it was measured as marbling percentage with the software PicedCora or by chemical analysis. As for Muir *et al*. (1998), this observation is in accordance with the higher carcass fatness score of the Indoor group. Steen *et al*. (2003) found similar results regarding marbling percentage. However, in other studies in which animals had similar ADG, carcass fatness score and intramuscular fat content

were also similar regardless of the diet (French *et al*., 2000b; Steen *et al*., 2003; Friedrich, 2010). As presented in Table 11, the average IMF in the pasture group is below the threshold recommended by Frickh *et al*. (2005). Furthermore, the size of the *m. longissimus dorsi* tended to be smaller in the Pasture group (*p*-value=0.085), which matches with the lower weight of the striploin. Ash and protein content of the meat did not differ between groups, which confirms the results of Friedrich (2010) and French *et al*. (2000b). As a consequence of higher meat lipid content in the Indoor group, ash and protein being in equal proportions, DM content of the meat was higher in the Indoor group. Steen et al. (2003) obtained a wider *m. longissimus dorsi* area in pasture-fed than in high concentrate-fed steers when adjusted to the same ADG (*p*-value=0.07), whereas heifers showed the opposite result but without significant difference between feeding groups (*p*-value=0.18).

4.3.2 Fatty acid profile of the meat

Heifers fattened on pasture had lower SFA but higher PUFA and CLA concentrations in FAME than heifers fed a grass silage-based diet in accordance with the results of French *et al*. (2000a) and Noci *et al*. (2005) and partly in contrast with the results of Steen *et al*. (2003) and Friedrich (2010) as shown in Table 10.

Table 10. Results of the present study compared to results of other authors regarding saturated (SFA), monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) concentrations in the grazing group compared to the silage- or concentrate-fed group

	Present study	**Friedrich (2010)**	**French *et al.* (2000a)**	**Noci *et al.* (2005)**	**Steen *et al.* (2003)**
SFA	-	ns	-	-	ns
MUFA	ns	-*	ns	ns	-
PUFA	+	ns	+	+	+

- : grazing group had a significantly lower concentration of these fatty acids; +: grazing group had a significantly higher concentration of these fatty acids; ns: no significant difference between the two groups for these fatty acids.
*: only a trend with *p*-value=0.06.

In the present study, heifers of the Indoor group had higher concentrations of C12:0 (lauric acid) and to a larger extent, higher concentrations of C14:0 (myristic acid) and C16:0 (palmitic acid). Similarly, French *et al*. (2000b) obtained more C16:0 and unchanged proportions of C18:0 in the silage-fed group than in the grazing group. However, French *et al*. (2000b) did not obtain higher proportions of C12:0 and C14:0 in meat of the grass silage-fed animals. Important PUFA such as C18:2 (linoleic acid), C18:3 (α-linolenic acid), C20:4 (arachidonic acid), C20:5 (EPA), C22:5 (DPA) and C22:6 (DHA) were all in significantly

higher concentrations in the meat of the Pasture group animals. French *et al*. (2000a) also obtained higher proportion of C18:2 and C18:3 but no change in C20:5 or C20:4. Regarding n-3 and n-6 fatty acids in the present study, higher concentrations were found in the Pasture group than in the Indoor group. Higher n-3 proportions in meat from grazing animals were already mentioned by Steen *et al*. (2003) and French *et al*. (2000a). Regarding n-6 fatty acids, higher proportions in grazing animals than barn- or feedlot-fed animals were also observed by Rule *et al*. (2002), Realini *et al*. (2004), Sami *et al*. (2004) and Holló *et al*. (2005). As grass is richer in n-3 fatty acids than preserved forage (Dewhurst *et al*., 2003), grazing animals are more susceptible to show high n-3 content than barn-fed animals. In the present study, pasture management maintained the grass in a vegetative stage; hence, grass had high sugar levels and low fiber content. This could have enhanced biohydrogenation in the rumen (Ferlay, 2006). A high C18:3 intake associated with a high biohydrogentaion process would then have enhanced C18:2 levels. Indeed, linoleic acid (C18:2 *cis* 9, 12) concentration was significantly higher in the Pasture group in the present study. Consequently to the increase in both n-3 and n-6, the ratio n-6:n-3 did not differ between groups in the present study as in Sami et al. (2004). In contrast, Friedrich (2010), Noci *et al*. (2005), Realini *et al*. (2004), Steen *et al*. (2003) and French *et al*. (2000a) obtained lower n-6:n-3 ratio in the grazing group than in the silage- or concentrate-fed group. Meat from animals of the Indoor group had higher concentrations of C12:0 (lauric acid), C14:0 (myristic acid) and C16:0 (palmitic acid) which are all three known to have a cholesterol rising effect (Daley *et al*., 2010).

While Duckett *et al.* (1993) found a quadratic decrease in PUFA and linear increase in SFA with days on a maize silage finishing diet after fattening on pasture, only MUFA tended to increase with days on a grass silage-based finishing diet in the present study. The Indoor group had higher concentrations of C12:0 and C16:1 *trans* 9 than the Pasture group and, surprisingly, concentrations of these fatty acids were negatively correlated with days in barn for the Pasture group. Concentration of these two non-essential fatty acids was equal to or lower than 0.1 %. Hence, their correlation with days in barn is of low importance. Concentration of C18:1 *cis* 9 (oleic acid), was strongly positively correlated with days on the finishing diet in barn (Pearson correlation coefficient = 0.936) which matches the trend to increased MUFA concentration with days in barn and is in agreement with the results of Smith *et al*. (2009). This may indicate a high IMF deposit in the Pasture group during the finishing period in barn (Smith *et al*., 2009). Although C20:5 (EPA) concentration decreased with days on the finishing diet in barn, the Pasture group still showed a concentration of this beneficial fatty acid twice higher than the Indoor group. Thus, finishing in barn did not impair

the beneficial fatty acid profile the meat acquired from pasture grazing. Correlations between days on the finishing diet after pasture fattening and meat fatty acid profile have been assessed from 10 animals on pasture. These observations need to be confirmed with a larger sample size.

4.3.3 Water holding capacity and pH

In the present study, the *m. longissimus dorsi* of both Pasture and Indoor group animals had a pH_u of 5.7, which is also the value obtained by Realini *et al*. (2004) and within the normal range according to Viljoen *et al*. (2002) and Immonen *et al*. (2000). Furthermore, this value is within the range of pH_u advised by Frickh *et al*. (2005) as shown in Table 11 and close to 5.5 which is the "normal meat" value according to Warriss (2010). Furthermore, WHC was within the range advised by Frickh *et al*. (2005), which could be expected regarding the pH_u value (see paragraph 1.2.4). There was no difference in WHC between groups, which confirms the results of Friedrich (2010) and Razminowicz *et al*. (2006).

4.3.4 Meat and fat colour

Meat colour was not different whether the meat was from the Pasture or the Indoor group, which is in agreement with the results of Friedrich (2010) and French *et al*. (2000b). Furthermore, values for meat L*-brightness and a*-redness were within the range advised by Frickh *et al*. (2005) as shown in Table 11. The present results contrast with the results of Gatellier *et al*. (2005) who observed pasture-finished animals had lower haeminic iron content than mixed diet-finished animals, which indicates pasture-finished animals had a more red meat. The latter experiment was carried out on farms and iron supplementation in the farm mixed diet could not be excluded according to the authors. In the present study as in the study of Friedrich (2010), values for meat a*-redness were lower than described by French *et al*. (2000b) and Vieira *et al*. (2007). However, the two latter studies were carried out with older animals and colour was measured after a longer oxidation time and at an earlier ageing time point than in the present study, which all influence a*-redness value as observed in the present study and in Friedrich (2010), Muir *et al*. (1998), Jayasooriya *et al*. (2006) and Irureta *et al*. (2008).

Effect of grazing on fat yellowness is well known (see paragraph 1.2.4) and the present study confirmed the observations of Muir *et al*. (1998), French *et al*. (2000b), Realini *et al*. (2003) and Friedrich (2010). However, a significantly more reddish colour of subcutaneous fat from grazing animals had already been observed only by Friedrich (2010) although results of Realini *et al*. (2003) showed numerical differences. Furthermore, ageing significantly

enhanced fat colour intensity for both groups, as already observed by Revilla and Vivar-Quintana (2006), while brightness remained unchanged in the Indoor group and slightly lowered in the Pasture group. Yellowness of the fat can impair the acceptance of the meat by some consumers but can be reduced by trimming the fat (Kerth *et al*., 2007).

4.3.5 Shear force

Warner-Bratzler shear force values were below the threshold advised by Frickh *et al*. (2005) from 14 days of ageing onwards, which is also the minimum ageing time advised by Frickh *et al*. (2005). As it has been already widely acknowledged (Irurueta *et al*., 2008; Revilla and Vivar-Quintana, 2006; Marino *et al*., 2006; Gruber *et al*., 2006), ageing lowered shear force values of the cooked meat. Although raw meat showed higher shear force values at 21 days *p.m*. than at 14 days *p.m*., all measurements were below the threshold recommended by Frickh *et al*. (2005) and therefore, difference in raw meat tenderness between 14 and 21 days of ageing was most likely of low practical importance. As presented in Table 11, IMF in the pasture group was below the thresholds recommended by Frickh *et al*. (2005) but remained above the 1.5% threshold for acceptable tenderness of Fortin et al. (2005) and Razminowicz et al. (2006).

Table 11. Comparison of reference thresholds for meat quality criteria (Frickh *et al*., 2005) with the results of the present study and the results of Friedrich (2010)

	Present study		**Friedrich (2010)**		**Frickh *et al*. (2005)**
	Pasture group*	Indoor group*	Pasture group*	Indoor group*	Recommended thresholds
pH_u	5.7		5.9		5.4-5.8
WHC (%)					
Drip loss	3.2		2.5		3.0-4.5
Cooking loss	26		26		< 30
Grill loss (warm)	21		17.8		< 22
IMF (% fresh meat weight)	1.8	2.9	3.2		2.5-4.5
Shear force (kgf)					
Raw meat	2.85		2.7		-
Grilled meat	2.61		2.6		< 4.0
Meat colour					
L*-brightness	40.6		39.9		34-40
a*-redness	14.3		11.6		> 10
b*-yellowness	10.8		7.7		-

WHC: water holding capacity, IMF: intramuscular fat; FM: fresh matter
For WHC, shear force and meat colour, values are given for measurements at 21 days of ageing.
*The mean value is given when differences between groups were not-significant (*p*-value>0.05)

Ender (1995, in Branscheid *et al*., 2007) recommended the same values as Frickh *et al*. (2005) for drip loss, shear force, IMF and L*-brightness and recommended a pH_u between 5.6 and 6.0.

5 Conclusions and implications

5.1 Conclusions

The aim of this study was to determine whether fattening heifers on pasture with a finishing period in barn allowed as good performances and meat quality as current rearing in barn on a grass silage-based diet with low amounts of concentrates. Results showed that fattening on pasture with a finishing period in barn allowed as good growth performance as raising solely in barn. Animals fattened on pasture and finished in barn had in average lower carcass fatness scores than animals solely kept in barn, although scores remain within the desirable interval. In contrast, animals solely kept in barn had more often a too high carcass fatness score than animals fattened on pasture and finished in barn. Meat from animals fattened on pasture or solely fed in barn was within the thresholds for acceptable meat palatability. Meat colour was not influenced by either feeding practice but fat colour was more red and more yellow in the grazing animals. Meat from grazing animals was leaner but this characteristic had no consequence on shear force. Furthermore, meat from animals fattened on pasture had enhanced proportions of n-3, PUFA and CLA and a reduced proportion of SFA, known to have a cholesterol rising effect. The finishing period did not significantly impair this beneficial fatty acid profile but results needs to be confirmed with a larger sample size.

5.2 Implications

According to the present study and the study of Friedrich (2010), fattening heifers on Alpine pastures is a suitable practice. Continuous grazing on short grass provides as good growth performances for heifers as the current feeding practices in barn. However, the growth rate of the animals on pasture is less stable than in barn and the transition from pasture to barn can be delicate. Meat palatability and processing quality is not impaired if animals are grazing. Allowing the cattle to graze improves the fatty acid profile of the meat regarding human health needs. Colour of the fat may be inconvenient regarding consumer preferences but may also help differenciating meat from grazing animals. In contrast, the leaner meat of the animals on pasture could be more attractive for consumers concerned by fat in their diets. A finishing period in barn from 450 kg to 550 kg is sufficient to obtain desirable carcass fatness and conformation and did not impair the advantageous n-3, PUFA and CLA concentrations.

Appendix

A.Botanical composition of the pasture

Table 1. Inventory of the botanical composition of a pasture on continuous grazing on short grass in Ennstal (% of total area when not indicated) (LFZ Raumberg-Gumpenstein, 2010)

	08/2007		08/2006	
	Old pasture	**New pasture**	**Old pasture**	**New pasture**
Grass (% DM weight)	40	50	53	65
Legumes (% DM weight)	48	35	25	20
Herbs (% DM weight)	12	15	22	15
Bare ground	4	5	4	3
Agrostis capillaris	15	1	15	
Alopecurus partensis	10	8	12	8
Dactylis glomerata	6	25	12	45
Elymus repens		0,3		
Festuca pratensis	8	6	18	10
Festuca rubra			0.3	
Lolium x boucheanum	0,3			
Lolium perenne		5		4
Phleum pratense	3	5	1	
Poa pratensis	10	12	8	5
Poa trivialis	2	4	3	8
Trisetum flavescens	1	1		
Total grass	**55**	**67**	**69**	**80**
Trifolium pratense				1
Trifolium repens	50	38	28	22
Total legumes	**50**	**38**	**28**	**23**
Achillea millefolium	2		6	1
Cerastium holosteoides	0,3	0,7	1	0.3
Galinsoga ciliata		0,3		0.3
Glechoma hederacea			0.3	1
Leontodon autumnialis				1
Plantago lanceolata				1
Plantago major				1
Ranunculus acris	1	2	0.7	0.3
Ranunculus repens	3	2	4	1
Rumex acetosa	0,3		1	
Rumex obtusifolius	3	1	2	
Taraxacum officinale agg.	6	12	8	18
Veronica serpyllifolia	0,3	0,7	0.3	
Heracleum sphondylium		0,3		
Total herbs	**16**	**19**	**23**	**24**

B. Meat quality measurements

Figure 1. Preparation of a 2 cm-thick fresh cut of meat from the carcass rib

Figure 2. Meat and fat colour measurements with a spectrophotometer

Figure 3. Meat sample cooking in the water bath

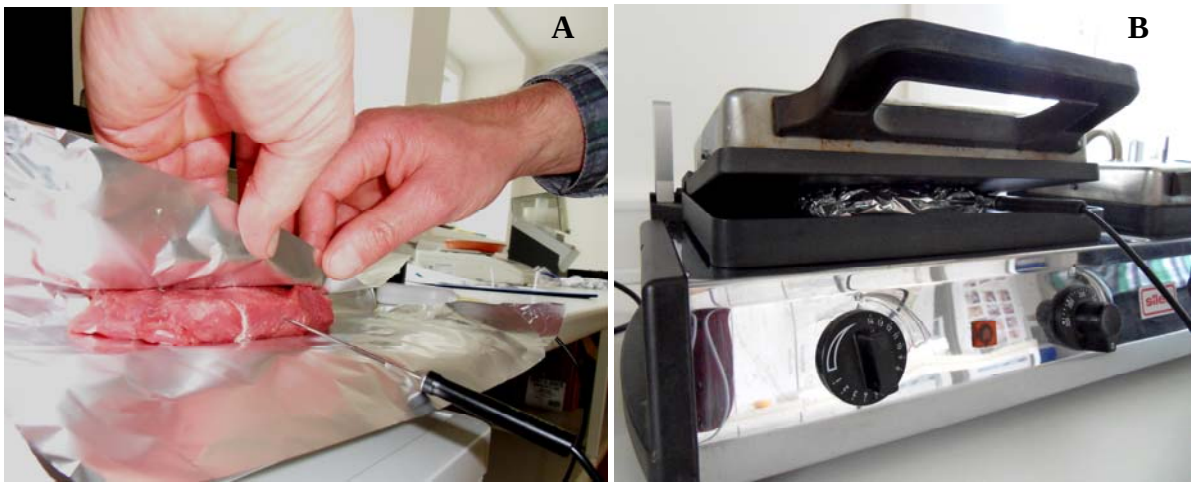

Figure 4. Meat sample to be grilled and the thermometer to control internal temperature (A) and the meat grilling in a Silex double plate (B).

Figure 5. Sampling in grilled meat for shear force measurements

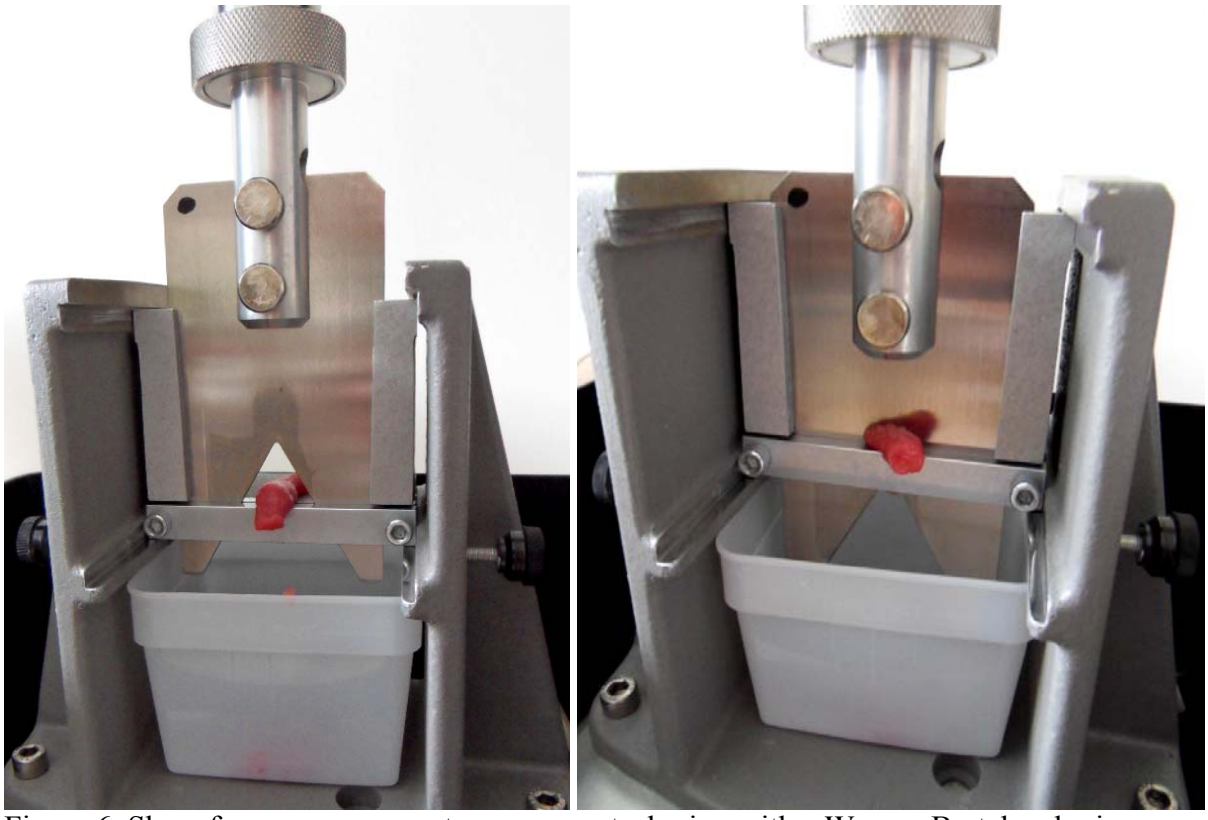

Figure 6. Shear force measurement on raw meat, sharing with a Warner-Bratzler sharing device

Figure 7. 2 cm-cut at the 8th rib showing the highest marbling percentage of this study (A) and the lowest marbling percentage of this study (B)

C. Results per weight class and per group

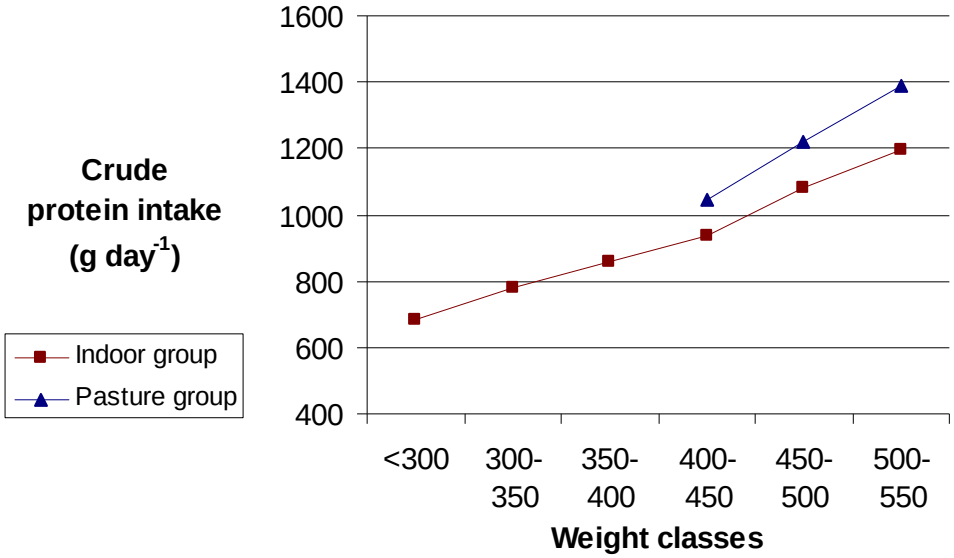

Figure 8. Crude protein intake for each weight class in each group.

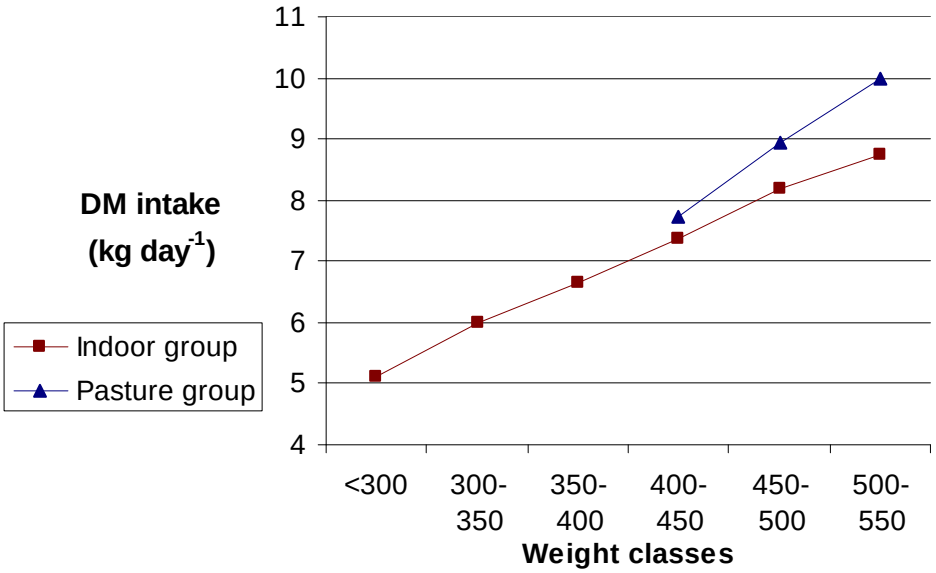

Figure 9. Dry matter intake for each weight class in each group.

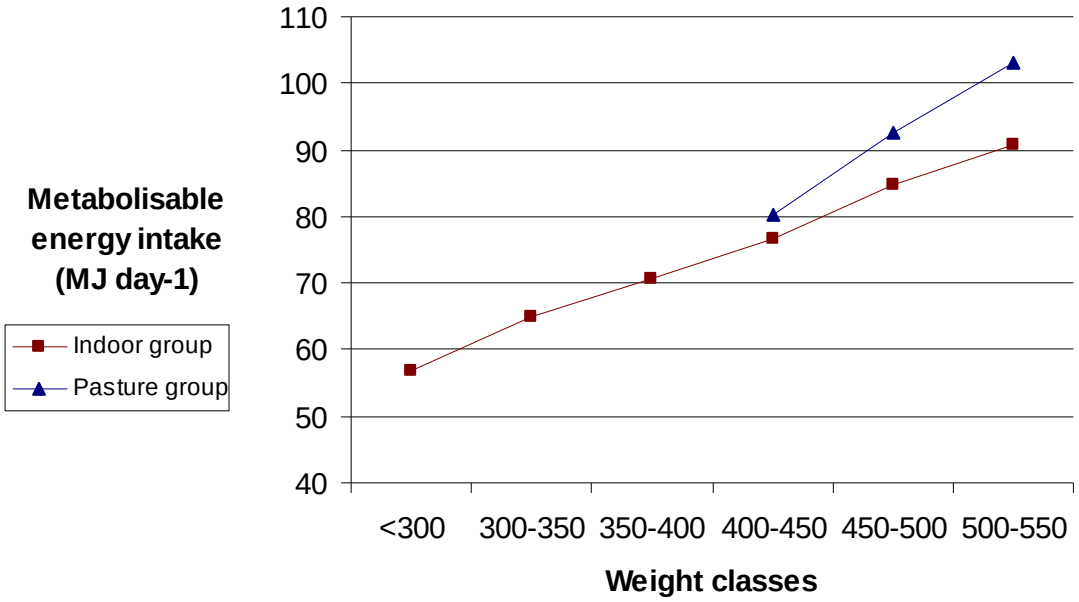

Figure 10. Metabolisable energy intake for each weight class in each group.

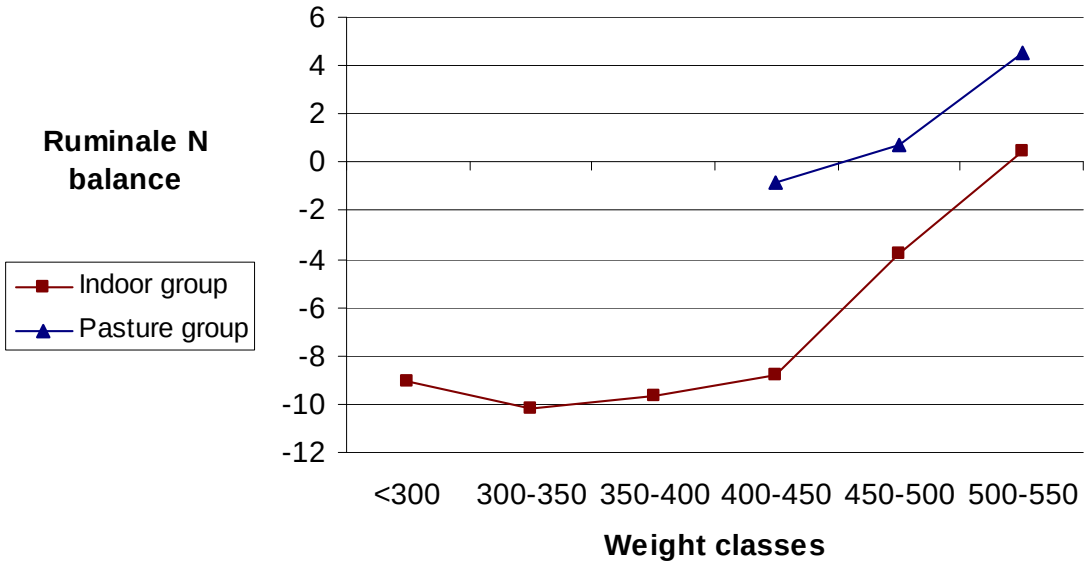

Figure 11. Ruminal N balance for each weight class in each group.

References

Albertí P., Panea B., Sañudo C., Olleta J.L., Ripoll G., Ertbjerg P., Christensen M., Gigli S., Failla S., Concetti S., Hocquette J.F., Jailler R., Rudel S., Renand G., Nute G.R., Richardson R.I. and Williams J.L., 2008. Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. *Livestock Science*, 114: 19-30.

ALVA (Arbeitsgemeinschaft für Lebensmittel-, Veterinär- und Agrarwesen), 1983. Österreichisches Methodenbuch für die Untersuchung von Futtermitteln, Futterzusatzstoffen und Schadstoffen. *Alva, Austria*.

Arthaud V.H., Mandigo R.W., Koch R.M. and Kotula A.W, 1977. Carcass composition, quality and palatability attributes of bulls and steers fed different energy levels and killed at four ages. *Journal of Animal Science*, 44: 53-64.

Bavarian State Research Center for Agriculture (Bayerische Landesanstalt für Landwirtschaft –LfL), 2010. Kurzrasenweide, Kennzeichen und Empfehlungen zur erfolgreichen Umsetzung. Ed. *Bayerische Landesanstalt für Landwirtschaft*.

Berges, E., 1999. Importance of vitamin E in the oxidative stability of meat: organoleptic qualities and consequences. In Brufau J. and Tacon A.,1999. Feed manufacturing in the Mediterranean region: recent advances in research and technology. *CIHEAM-IAMZ*, 360-363.

Bowden D.M. and Clarke M.F., 1963. Grass-legume forage fed fresh and as silage for market hogs. *Journal of Animal Science*, 22: 934-939.

Branscheid W., Honikel K.O., von Lengerken G., Troeger K., 2007. Qualität von Rindfleisch und Fleischwaren. Band 1. 2., überarbeitete und erweiterte Auflage. *Deutscher Fachverlag*.

Buchgraber and Gindl, 2004. Zeitgemässe Grünlandbewirtschaftung. 2. Völlig neu bearbeitete Auflage. *Ed. Leopold Stocker Verlag, Graz, Austria*.

Burrin D.G., Ferrell C.L., Eisemann J.H:, Briton R.A: and Nienaber J.A., 1989. Effect of level of nutrition on splanchnic blood flow and oxygen consumption in sheep. *British Journal of Nutrition*, 62: 23-34.

Cabel C.A. and Ellis N.R., 1942. The vitamin E content of certain varieties of wheat, corn, grasses and legumes as determined by rat assay. *The Journal of Nutrition*, 23: 633-644.

Crook D.S. and Jones A.M., 1999. Traditional irrigation and its importance to the tourist landscape of Valais, Switzerland. *Landscape Research*, 24 (1): 49-65.

Crouse J.D., Cross H.R. and Seideman S.C., 1984. Effects of a grass or grain diet on the quality of three beef muscles. *Journal of Animal Science*, 58 (3): 619-625.

Daley C.A., Abbott A., Doyle P.S., Nader G.A. and Larson S., 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutrition Journal*, 9(10): 1-12.

Destefanis G., Brugiapaglia A., Barge M.T. and Molin Dal E., 2008. Relationship between beef consumer tenderness perception and Warner-Bratzler shear force. *Meat Science*, 78: 153-156.

Dewhurst R.J., Scollan N.D., Lee M.R.F., Ougham H.J. and Humphreys M.O., 2003. Forage breeding and management to increase the beneficial fatty acid content of ruminant products. *Proceedings of the Nutrition Society*, 62 (2): 329-336.

DGF- Deutsche Gesellschaft für Fettwissenschaften (Hrsg): Methode C-VI 11 (98) – Fettsäurenmethylesther (TMSH-Methode). In DGF: DGF-Einheitsmethoden – Deutsche Einheitmethoden zur Untersuchung von Fetten, Fettprodukten, Tensiden und verwandten Stoffen. Wiss. *Verlagsgesellschaft mbH, Stuttgart*, 2. Auflage einschlieβlich 11.Akt.-Lfg., 2006.

Duckett S.K., Wagner D.G., Yates L.D., Dolezal H.G. and May S.G., 1993. Effects of time on feed on beef nutrient composition. *Journal of Animal Science*, 71: 2079-2088.

Dudouet C., 2004. La production des bovins allaitants, deuxième édition. *France Agricole*.

Dufey P.-A., Chambaz A., Morel I. and Chassot A., 2002. Performances d´engraissement de boeufs de six races à viande. *Revue Suisse Agricole*, 34 (3): 117-124.

Durgiai B., 1996. Mit Kurzrasenweide die Milchproduktionskosten senken. *Agrarforschung*, 3 (10): 509-512.

Durgiai B. and Müller R., 2004. Projet Opti-Lait: résultats économiques. *Revue Suisse Agricole*, 36 (4) : 173-178.

Folch J., Lees M. and Sloane Stanley G.H., 1957. A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry*, 226 (1): 497-509.

Food and Agriculture Organisation of the United Nations, 2002. Human vitamin and minerals requirements. Report of a joint FAO/WHO expert consultation, September 1998, Bangkok, Thailand. Edition *FAO and WHO*.

Food and Agriculture Organisation of the United Nations, 2008. Interim summary of conclusions and dietary recommendations on total fat. Joint FAO/WHO expert consultation on fats and fatty acids in Human nutrition, November 10-14, 2008, World Health Organisation head quarters, Geneva. Edition *FAO and WHO*.

Ferlay A., Martin B., Pradel Ph., Coulon J.B. and Chilliard Y., 2006. Influence of grass-based diets on milk fatty acid composition and milk lipolytic system in Tarentaise and Montbéliarde cow breeds. *Journal of Dairy Science*, 89: 4026-4041.

Field R.A., 1971. Effect of castration on meat quality and quantity. *Journal of Animal Science*, 32: 849-858.

French P., Stanton C., Lawless F., O´Riordan E.G., Monahan F.J., Caffrey P.J. and Moloney A.P., 2000a. Fatty acid composition, including conjugated linoleic acid, of intramuscular fat from steers offered grazed grass, grass silage, or concentrate-based diets. *Journal of Animal Science*, 78: 2849-2855.

French P., O´Riordan E.G., Monahan F.J., Caffrey P.J., Vidal M., Mooney M.T., Troy D.J. and Moloney A.P., 2000b. Meat quality of steers finished on autumn grass, grass silage or concentrate-based diets. *Meat Science*, 56: 173-180.

Fortin A., Robertson W.M. and Tong A.K.W., 2005. The eating quality of Canadian pork and its relationship with intramuscular fat. *Meat Science*, 69: 297-305.

Frickh J.K., Elixhauser K and G. Ibi, 2005. Forschungsbericht, Untersuchung des Pinzgauer Rindes auf Fleischqualität im Rahmen einer stationären Fleischleistungsprüfung. *Landwirtschaftliche Bundesversuchswirtschaften GmbH*.

Friedrich E.M., 2010. Kalbinnenmast im Grünland: Einfluss von Kurzrasenweide mit Stallendmast auf Merkmale der Mastleitung, der Schlachtleistung und der Fleischqualität. *MSc thesis, Universität für Bodenkultur, Wien.*

Garcia A., Thiex N., Kalscheur K. and Tjardes K., 2003. Interpreting hay and haylage analysis. *Dairy Science*, Extension Extra 4002.

Geay Y. and Robelin J., 1979. Variation of meat production capacity in cattle due to genotype and level of feeding: genotype-nutrition interaction. *Livestock Production Science*, 6: 263-276.

Gruber S.L., Tatum J.D., Scanga J.A., Chapman P.L., Smith G.C. and Belk K.E., 2006. Effects of post-mortem ageing and USDA quality grade on Warner-Bratzler shear force values of seventeen individual beef muscles. *Journal of Animal Science*, 84: 3387-3396.

Hakkarainen J. and Pehrson B., 1987. Vitamin E and polyunsaturated fatty acids in Swedish feedstuffs for cattle. *Acta Agriculturae Scandinavica*, 37: 341-346.

Handbuch der Lebensmittelchemie – Tierische Lebensmittel Eier, Fleisch, Fisch, Buttermilch 1968. (L. Acker, K.G. Bergner, W. Diemair, W. Heimann, F. Kiermeier, J. Schormüller, S.W. Sourci). *Springer Verlag Berlin, Heidelberg, New York*. Band III, 2. Teil.

Häusler J., Velik M., Eingang D. and Wildling J., 2008. Ergebnisse zur Weideaufzucht von Kalbinnen. *Vierte Österreichische Fachtagung für biologische Landwirtschaft*, *LFZ Raumberg-Gumpenstein*.

Hedrick H.B., Thompson G.B. and Krause G.F., 1969. Comparison of feedlot performances and carcass characteristics of half-sib bulls, steers and heifers. *Journal of Animal Science*, 29: 687-694.

Herring H.K., Cassens R.G. and Rriskey E.J., 1965. Further studies on bovine muscle tenderness as influenced by carcass position, sarcomere length and fiber diameter. *Journal of Food Science*, 30 (6): 1049-1054.

Holló G., Nuernberg K., Repa I., Holló I., Seregi J., Pohn G. and Ender K., 2005. Der Einfluss der Fütterung auf die Zusammensetzung des intramuskulären Fettes des *Musculus longissimus* und verschiedener Fettdepots von Jungbullen der Rassen Ungarisches Grauvieh und Holstein Friesian. *Archiv Tierzucht Dummerstorf*, 48 (6): 537-546.

Immonen K., Ruusunen M. and Puolanne E., 2000. Some effects of residual glycogen concentration on the physical and sensory quality of normal pH beef. *Meat Science*, 55: 33-38.

Irureta M., Cadoppi A., Langman L., Grigioni G., Carduza F., 2008. Effect of ageing on the characteristics of meat from water buffalo grown in the Delta del Paraná region of Argentina. *Meat Science*, 79: 529-533.

Issanchou S., 1996. Consumer expectations and perceptions of meat and meat product quality. *Meat Science*, 43 (Supplement 1): 5-19.

Jayasooriya S.D., Torley P.J., D´Arcy B.R. and Bhandari B.R., 2007. Effect of high power ultrasound and ageing on the physical properties of bovine *semitendinosus* and *longissimus* muscles. *Meat Science*, 75: 628-639.

Keane M.G. and Moloney A.P., 2009. A comparison of finishing systems and duration for spring-born Aberdeen Angus x Holstein-Friesian steers. *Livestock Science*, 124: 223-232.

Kenward M.G. and Roger J.H., 1997. Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics*, 53(3): 983-997.

Kerth C.R., Braden K.W., Cox R., Kerth L.K. and Rankins D.L. Jr., 2007. Carcass, sensory, fat color, and consumer acceptance characteristics of Angus-cross steers finished on ryegrass (*Lolium multiflorum*) forage or on a high-concentrate diet. *Meat Science*, 72(2): 324-331.

Kirkland R.M. and Patterson D.C., 2005. The effect of quality of grass and maize silage on the intake and performance of beef cattle. *Livestock Science*, 100 (2-3): 179-188.

Landesstatistik Steiermark, 2010. Aigen im Ennstal, Klimadaten Jänner 2003 bis Februar 2010. From: Zentralanstalt für Meteorologie und Geodynamik, Graz. Available at www.verwaltung.steiermark.at (consulted on 02/09/2010).

Legrand A.L., von Keyserlingk M.A.G. and Weary D.M., 2009. Preference and usage of pasture versus free-stall housing by lactating dairy cattle. *Journal of Dairy Science*, 92: 3651-3658.

LFZ Raumberg-Gumpenstein, 2010. Data from the plant science department. Contact person Elisabeth Schwab.

Marino R., Albenzio M., Braghieri A., Muscio A. and Sevi A., 2006. Organic farming: effects of forage to concentrate ratio and ageing time on meat quality of Podolian young bulls. *Livestock Science*, 102: 42-50.

Maurer K., Weyand A., Fischer M. and Stöcklin J., 2006. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. *Biological Conservation*, 130: 438-446.

Muir P.D., Deaker J.M. and Bown M.D., 1998. Effects of forage- and grain-based feeding systems on beef quality: a review. *New Zealand Journal of Agricultural Research*, 41: 623-635.

Myers S.E., Faulkner D.B., Nash T.G., Berger L.L., Parrett D.F. and McKeith F.K., 1999. Performance and carcass traits of early-weaned steers receiving either a pasture growing period or a finishing diet at weaning. *Journal of Animal Science*, 77: 311-322.

Nierdrist G., Tasser E., Lüth C., Dalla Via J and Tappeiner U., 2008. Plant diversity declines with recent land use changes in European Alps. *Plant Ecology*, 202 (2): 195-210.

Noci F., Monahan F.J., French P. and Moloney A.P., 2005. The fatty acid composition of muscle fat and subcutaneous adipose tissue of pasture-fed beef heifers: influence of the duration of grazing. *Journal of Animal Science*, 83: 1167-1178.

Nozière P., Graulet B., Lucas A., Martin B., Grolier P. and Doreau M., 2006. Carotenoids for ruminants : from forages to dairy products. *Animal Feed Science and Technology*, 131: 418-450.

NRC (National Research Council of the United States), 2001. Nutrient requirements of dairy cattle. Seventh revised edition. *National Academy Press*.

Nuernberg K., Dannenberger D., Nuernberg G., Ender K., Voigt J., Scollan N.D., Wood J.D., Nute G.R. and Richardson R.I., 2005. Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of *longissimus* muscle in different cattle breeds. *Livestock Production Science*, 94: 137-147.

O´Sullivan A., O´Sullivan K., Galvin K., Moloney A.P., Troy D.J. and Kerry J.P., 2002. Grass silage versus maize silage effects on retail packaged beef quality. *Journal of Animal Science*, 80: 1556-1563.

ÖPUL-Österreichisches Programm zur Förderung einer umweltgerechten, extensiven und den natürlichen Lebensraum schützenden Landwirtschaft, 2007. Agrarumweltprogramm und Tierschutz: Anhänge. *Lebensministerium Österreich.*

Österreichisches Rinderbörse GmbH, 2010. Marketbericht-Rindermarkt. Available at http://www.rinderboerse.at/ (consulted on 19/07/2010).

Oury M.P., Dumont R., Agabriel C., Blanquet J., Dransfield E., Istasse L., Micol D., Picard B. and Roux M., 2006. Différenciation de la qualité sensorielle des viands par le mode de conduite chez la génisse Charolaise. *Rencontres Recherche Ruminants 2006, INRA.*

Perry D. and Thompson J.M., 2005. The effect of growth rate during backgrounding and finishing on meat quality traits in beef cattle. *Meat Science*, 69: 691-702.

Platter W.J., Tatum J.D., Belk K.E., Chapman P.L., Scanga J.A. and Smith G.C., 2003. Relationship of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science*, 81: 2741-2750.

Prost E., Pelczynska E. and Kotula A.W., 1975. Quality characteristics of bovine meat. II. Beef tenderness in relation to individual muscles, age and sex of animals and carcass quality grade. *Journal of Animal Science*, 41: 541-547.

Razminowicz R.H., Kreuzer M. and Scheeder M.R.L., 2006. Quality of retail beef from grass-based production systems in comparison with conventional beef. *Meat Science*, 73: 351-361.

Realini C.E., Duckett S.K., Brito G.W., Dalla Rizza M. and De Mattos D., 2003. Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. *Meat Science*, 66: 567-577.

Revilla I. and Vivar-Quintana A.M., 2006. Effect of breed and ageing time on meat quality and sensory attributes of veal calves of the "Ternera de Aliste" quality label. *Meat Science*, 73: 189-195.

Rule D.C., Broughton K.S., Shellito S.M. and Maiorano G., 2002. Comparison of muscle fatty acid profiles and cholesterol concentrations of bison, beef cattle, elk, and chicken. *Journal of Animal Science*, 80: 1202-1211.

Sami A.S., Augustini C. and Schwarz F.J., 2004. Effects of feeding intensity and time on feed on performance, carcass characteristics and meat quality of Simmental bulls. *Meat Science*, 67: 195-201.

Smith S.B., Gill C.A., Lunt D.K. and Brooks M.A., 2009. Regulation of fat and fatty acid composition in beef cattle. *Asian-Australian Journal of Animal Science*, 22 (9):1225-1233.

Steen R.W.J., 1995. The effect of plane of nutrition and slaughter weight on growth and food efficiency in bulls, steers and heifers of three breed crosses. *Livestock Production Science*, 42: 1-11.

Steen R.W.J., Lavery N.P., Kilpatrick D.J. and Porter M.G., 2003. Effects of pasture and high-concentrate diets on the performance of beef cattle, carcass composition at equal growth rates, and the fatty acid composition of beef. *New Zealand Journal of Agricultural Research*, 46: 69-81.

Steinwidder A., Starz W., Podstatzky L., Kirner L., Pötsch E.M., Pfister R. and Gallenböck M., 2010. Low-input Vollweidehaltung von Milchkühen im Berggebiet Österreichs, Ergebnisse von Pilotbetrieben bei der Betriebsumstellung. *Züchtungskunde*, 82 (3): 241-252.

Tarant P.V., 1998. Some recent advances and future priorities in research for the meat industry. *Meat Science*, 49(S1):S1-S16.

Thompson J., 2002. Managing meat tenderness. *Meat Science*, 62: 295-308.

Vassilopoulos A., Klonaris S., Drichoutis A.C., Lazaridis P., 2009. Quality demand for meat and fish products : a microeconometric analysis. *International Conference on Applied Business Research 2009*.

VDLUFA (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten), 1976. Methodenbuch Band III. Die chemische Untersuchung von Futtermitteln. *VDLUFA*, Germany.

Vieira C., Cerdeño A., Serrano E., Lavín P. and Mantecón A.R., 2007. Breed and ageing extent on carcass and meat quality of beef from adult steers (oxen). *Livestock Science*, 107: 62-69.

Viljoen H.F., de Kock H.L. and Webb E.C., 2002. Consumer acceptability of dark, firm and dry (DFD) and normal pH beef steaks. Meat Science, 61: 181-185.

Velik, M. Personal communication. May 2010.

Vestergaard M., Oksbjerg N. and Henckel P., 2000. Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendinosus*, *longissimus dorsi* and *supraspinatus* muscles of young bulls. *Meat Science*, 54: 177-185.

Wang Z. and Goonewardene L.A., 2004. The use of MIXED models in the analysis of animal experiments with repeated measures data. *Canadian Journal of Animal Science*, 84: 1-11.

Warriss P.D., 2010. Meat science: an introductory text, second edition. *CAB International*, 9-22.

Young B.A., 1983. Ruminant cold stress: effect on production. *Journal of Animal Science*, 57: 1601-1607.