Assessment of the variation of marbling and intramuscular fat content of beef, and validation of possible factors to increase sensory beef quality

Dissertation for the acquisition of the academic degree

Doktorin der Agrarwissenschaften (Dr. agr.)

Submitted to the Faculty of Organic Agricultural Sciences

of the University of Kassel

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Witzenhausen, Juni 2022

This work has been accepted by the Faculty of Organic Agricultrual Sciences of the University of Kassel as a thesis for aquiring the academic degree of Doctor of Agricultural Sciences (Dr. agr.)

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Defense Date: 06. May 2022

Abstract

This thesis focuses on the intramuscular fat content (IMF) or the marbling of beef as main parameters of sensory beef quality. The aim is to identify the high variability of these traits and to verify possible influences such as genetics, age, gender and feeding strategies to increase marbling.

The first part of this research focuses on the variation of quality traits within a genetically homogeneous line of an endangered German beef cattle breed "Rotes Höhenvieh" (RHV). The intramuscular fat content of beef samples (n = 539) of this breed was objectively assessed, and high variations (0.2 % - 22.9 %) in this trait were found within the whole RHV population.

The second part of the thesis involves the validation of Video Image Analysis (VIA) as an objective measurement and evaluation method for German beef carcasses without any destruction of the carcass within the slaughter line. The marbling level of industrial German carcasses from young bulls (n = 300) was assessed at a standardized industrial cutting position with reference to the USDA classification system, which focuses mainly on the estimation of marbling. High correlations (r = 0.82 and R = 0.64) were found, emphasizing the feasibility of an adaption of the USDA beef classification system to focus on sensory quality attributes as a determining parameter of classification of German beef carcasses.

In a third step, a special feeding regime as a main influencing factor and possible strategy to increase the intramuscular fat percentage of German beef heifers was investigated and verified. Two feeding trials were conducted with Uckermärker heifers to examine the influence of high energy and starch density. Different amounts of undegradable protein (UDP) were fed to a group of 122 heifers during the finishing fattening period and the other group of 190 heifers were fed during the marbling window with two different high energy and low energy diets and then received 3 different UDP diets in the late fattening period. Carcasses of all these animals were graded according to VIA marbling scores and subcutaneous back fat thickness after slaughtering. Results showed that the purposive feeding strategy combining a high energy and starch diet during the early fattening period with a high UDP Diet in the finishing fattening period might lead to increased marbling scores.

Overall, variation of marbling and intramuscular fat content emerged in all studies. Results illustrate the need for an objective assessment of marbling or intramuscular fat content in German beef carcasses to compare the actual quality level of beef, and in another step, to verify the success or failure of different management or feeding strategies that might influence marbling and intramuscular fat content and therefore increase beef quality in the long run.

Zusammenfassung

Diese Arbeit fokussiert auf die Merkmale Marmorierung und intramuskulärer Fettgehalt (IMF) als maßgebliche Parameter der sensorischen Rindfleischqualität. Ziel war es, die Variabilität dieser Merkmale in verschiedenen Stichproben von Rinderschlachtkörpern zu erfassen, und die Effekte möglicher Einflussfaktoren auf die Erhöhung dieser Merkmale zu verifizieren.

Das erste Teilprojekt dieser Arbeit beleuchtet die Heterogenität des Fleischqualitätsmerkmals Intramuskulärer Fettgehalt in einer vom Aussterben bedrohten Rinderpopulation Rotes Höhenvieh (RHV). Im Rahmen dieser Studie wurde der IMF von 539 Rindfleischproben an einer standardisietren Messposition analysiert. Der mittlere IMF – Gehalt der Fleischproben betrug 2,5 % (SD: 2,8). Generell wiesen die Fleischproben der Gesamtpopulation aufgrund der Vielzahl an potenziellen Einflussfaktoren jedoch eine maßgebliche Streuung in diesem Merkmal zwischen 0,2 % und 22,9 % auf.

Im zweiten Teilprojekt wurde ein internationales System der Videobildanalyse (VIA), das in internationalen Klassifizierungssystemen bereits standardisiert zur Erfassung von Marmorierung genutzt wird, an einer deutschen industriellen Schnittposition des *M. longissimus dorsi* von Rinderschlachtkörpern mit Referenz zur amerikanischen Schnittposition validiert. Hierzu wurde das Marmorierungsniveau von 300 Schlachtkörpern von Jungbullen, die zur Schlachtung für den deutschen Rindfleischmarkt bestimmt waren, erfasst. Es wurden hohe Korrelationen (r = 0.82) zwischen den Marmorierungsgraden an der 10. Rippe des *M. longissimus dorsi* und an der in den USA standardisierten Messposition an der 12. Rippe des *M. longissimus dorsi* gemessen. Die Ergebnisse zeigen, dass die Anwendung des VIA - Systems zur Erfassung der Marmorierung deutscher Rinderschlachtkörper mit hoher Präzision und Referenz zur US - Schnittposition möglich ist.

Im dritten Teilprojekt dieser Arbeit wurde durch zwei Fütterungsversuche mit Färsen der Rasse Uckermärker die Möglichkeit der Einflussnahme auf den intramuskulären Fettgehalt geprüft. In zwei Fütterungsversuchen wurden 122 bzw. 192 Uckermärker Färsen einerseits mit verschiedenen Anteilen des pansenbeständigen Proteins (UDP) in der Endmast gefüttert, um mögliche Einflüsse auf eine erhöhte Marmorierung festzustellen. Im zweiten Fütterungsversuch wurde zusätzlich ermittelt, ob eine hohe Energie- und Stärkezufuhr in der frühen Mastphase zu einer erhöhten Marmorierung führt. Die Marmorierungsgrade der Schlachtkörper wurden mit VIA im Schlachthof erfasst. Die Ergebnisse zeigten, dass Fleisch von Tieren, die mit hohem UDP – Anteil in der Endmast gefüttert wurden, signifikant höhere Marmorierungsgrade

aufwies. In allen Teilprojekten trat eine hohe Variabilität der Merkmale IMF bzw. Marmorierung zutage. Dies unterstreicht die Notwendigkeit einer objektiven Qualitätserfassung von Rindfleisch, um einerseits Aussagen über das Fleischqualitätsniveau zu erhalten, andererseits aber auch Maßnahmen zur Optimierung dieser Merkmale hinsichtlich der Wirksamkeit im jeweiligen Kontext zu validieren und damit langfristig zu einer höheren Fleischqualität beizutragen.

To Lars Reese, who moved mountains...

Preface

This thesis is submitted to the Faculty of Organic Agricultural Sciences of the University of Kassel as a partial fulfilment of the requirements for the degree of Doctor of Agricultural Sciences (Dr. agr.). One part of the research of this work was carried out within the *Q – Fleisch RHV* project.

This project was supported by funding from the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support programme. (Förderkennzeichen 2816BM011). It was carried out in cooperation with the Justus Liebig Universität Gießen (Förderkennzeichen: 2816BM010).

The second part of this research came under the "Pro – Qualität" project, which was funded by the Stiftung Block and the Block Foods AG. Further, this work received support from the e+v technology company, Oranienburg as well as the Danish Crown Beef company Teterow.

Many people took part and contributed to the successful completion of this final work. First of all, I would like to thank my first supervisor, Prof. Dr. Albert Sundrum, for giving me the possibility to explore and to work in this field of research. During the master's thesis and the following research work, I always had the opportunity to work independently to develop my own thoughts, and at the same time, was brought into line when things deviated too much. You taught me to stay persistent and to question myself again and again and thus reach meaningful results.

To all colleagues of the Department of Animal Nutrition and Animal Health of the University of Kassel I express gratitude. First of all, your valuable advice and support in crisis times were essential to lead this work to completion. In particular, Leonie Blume supported and developed my ideas of feeding strategies and supported the huge organization of LuPerne ingredients. Angela Pitz worked very closely on my subject of research and always respected my individual ideas and peculiarities. Petra Zahnwetzer and Susanne Hartmann are gratefully acknowledged for their great work in the laboratory barbecuing all the beef and analyzing the feeding ingredients at every step. Eva Schwabenbauer joined the Lupine toasting and endured all form, statistical and methodical questions. Theresa Rumphorst, thank you for your valuable time to talk about my research ideas and your overall support. Jonas Habel, who helped me in the Uckermärker stables, Silvia Minke, Margret Krieger and Susanne Hoischen - Taubner, who supported this work with organization and technical support are gratefully acknowledged.

Josef Spahn inspired my interest and my work about the Rotes Höhenvieh and encouraged me to believe in this special breed. Dr. Kathrin Halli and Prof. Dr. Sven König were part of the RHV project. I appreciated this cooperation to analyse the RHV potential.

I am sincerely grateful to all the farmers and butchers who supported me during the work. In particular, I would like to thank the people working in Wichmannsdorf, especially Martin Saenger and Dietrich and Karsten Twietmeyer, who gave me the opportunity and the trust to feed their heifers in my way.

When I started the work in the field of industrial beef market, I had no experience and was thrown in at the deep end. I appreciated the cooperation and the work with Karl-Heinz Krämer, Thomas Naber, Anja Mußmann, Olaf Renn, Dirk van der Reith, Jenny Galda, Stefan Krewin and Ralf Heisterkamp. You helped me to find my way, to develop my ideas, organized everything I needed, answered every single question and working together was a real pleasure. I know that some of the challenges were more than exhausting.

Ralf Rothe, Horst Eger and Mouhammad Abomoharam are gratefully acknowledged for their great technical support and their patience answering every single question again and again.

Special thanks belong to Lars Reese, who supported me during the whole project. You believed in me when I did not, you enabled the impossible when I lost control. Thank you for your honest and meaningful words. Working with you is a real pleasure - so much informative and so efficient. You did not intend, and you might not know, but having the support of someone like you is exceptional and influences my attitude in a special way.

My friends and family, especially my parents, helped me during this work to stay focused by enriching my life with quality times and enduring my crisis times. I sincerely acknowledge the time with Helena Knaus and Matthias Mock, who took part during my whole research journey and were always friends. Every discussion and question about my research topic enriched my perspective and my practical work. Thank you for every day you asked me when this project will be finally finished.

Mostly, I want to thank Alexander Schlung, who enriches my life, respected all conditions of this project and encouraged me all the time to go on, to believe in myself and who supports me in all situations. Thank you for being there and even joining the project with your valuable work in the Uckermärker stables, on the road to the Höhenvieh and around everything else.

List of Publications

This thesis is based on the work contained in the following publications referred to by Roman numerals in the text:

I. Schulz, L.; Halli, K.; König, S.; Sundrum, A. (2021): Potenziale der Erzeugung von Qualitätsfleisch in der Population Rotes Höhenvieh. *Züchtungskunde,* 93, 362–378.

II. Schulz, L.; Sundrum, A. (2021): Determining Relationships between Marbling Scores and Carcass Yield Traits of German Beef Bull Carcasses Using Video-Image Analysis at the 12th and 10th Rib Position of Longissimus Thoracis and EUROP Classification. *Applied Science*, 11, 269.

III. Schulz, L.; Blume, L.; Pitz, A.; Schwabenbauer, E.; Sundrum, A. (2021): Marbling Scores of Beef Can Be Increased by Purposive Feeding Regimes. *Animals Special Issue Dietary Impact on Animal Products' Quality*. ID - 1411827 (submitted).

All three publications are based on studies carried out in Germany and address the intramuscular fat content or marbling as a certain parameter of sensory beef quality. In particular, the publication concerning the Rotes Höhenvieh population has a specific reference to German beef production with endangered cattle breeds and was funded by a German institution. The aim of this article was to obtain information about an endangered livestock population in Germany and to apply these results to other comparable populations in Germany, if possible. Due to the specific regional factors to which this population is exposed and in order to make the results as accessible as possible to the relevant farmers and stakeholders, this article was published in German and supplemented by an executive summary for English-speaking readers.

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List of Abbreviations

-	Down
+	Up
<	Less than
>	More than
AA	Amino Acid(s)
bzw.	Beziehungsweise
d	Days
DM	Dry matter
et al.	Et alii / et aliae
g	Gramm
GAA	Glucoplastic Amino Acids
IMF	Intramuscular fat content
Kg	Kilogramm
KPH fat	Kidney pelvic heart fat
M. longissimus dorsi	Musculus longissimus dorsi
Max	Maximum
Min	Minimum
MJME	Megajoules of metabolisable energy
mm	Millimeter
MSA	Meat Standards Australia
n	Number in sample
N	Nitrogenium
No	Number
r	Pearson correlation coefficient
RHV	Rotes Höhenvieh
SD	Standard deviation
UDP	undegradable protein
US	United States
USDA	United States Department of Agriculture
VBG2000	VideoBeefGrading2000, e+v Software
VIA	Video Image Analysis
XF	Crude fiber
XP	Crude protein
YG	Yield Grade

1 General Introduction

In 2019, 1.3 million tons of beef were produced in Germany (Bundesanstalt für Landwirtschaft und Ernährung (BLE), 2019). This makes Germany the second largest European beef producer after France. About 46 percent of German beef derives from fattening bulls. Most bulls are slaughtered between one and two years of age. 34 % of German beef consists of beef from (old) cows from dairy production or suckler cow herds and only 15 % of German beef derives from young heifers. The remaining 5 % of beef is from young cattle aged under 8 months (Thünen-Institut, 2020). German beef production is mainly associated with dairy production and the meat is mostly from carcasses of animals that are not or no longer suitable for dairy production.

German bull fattening differs between intensive, economic and grazing fattening. Intensive and economic fattening methods focus mainly on daily gain and high slaughter weights of animals. Therefore, intensive feeding diets are used so that high live-weights of the animals are reached early. Grazing or extensive fattening of cattle, which focuses on the use of grassland as feeding diet, is of only minor importance in German beef production (Thünen-Institut, 2020).

In contrast, international beef production systems, as implemented for example in the United States, Australia, Canada and Japan, beef production focuses mainly on the fattening of heifers and steers. In the United States, 33.6 million cattle were slaughtered in 2019. In total, 49.3 % of the beef production derived from steers, 29.7 % of beef was from carcasses of heifers, 9.7 % included animals from dairy livestock. The remaining 1.6 % of slaughtered beef cattle were bulls (USDA, 2019). US beef production as well as production in countries such as Australia and South Africa mainly focus on feedlot production (Thünen-Institut, 2020). Feedlots are used during the finishing fattening periods of beef cattle and represent a defined area for feeding a concentrated diet to a high number of steers and heifers to produce high value carcasses of beef. US beef carcasses are graded according to different carcass traits and quality attributes that lead to higher producer prices for higher carcass quality.

German producer prices of beef have consistently been falling for several years. According to the BMEL, the slaughter price for young bulls in 2019 averaged 3.57 € / kg (-0.26 € / kg compared to the previous year), and for cows 2.99 € / kg (-0.18 € / kg) (BLE, 2020). Currently, beef prices are based on quantitative attributes such as slaughter weight and fat covering instead of sensory quality attributes (Brinkmann et al., 2008; Polkinghorne and Thompson, 2010; Bonny et al., 2016; Liu et al., 2020). Thus, German beef production is subjected to different challenges. Facing falling prices, higher production costs and rising imports of beef, producers

and stakeholders within the process line need to develop strategies to define their beef on the market.

To become economical, and in order to distinguish beef products on the market and to generate higher prices, beef has to become a proven high-quality product. Therefore, the whole slaughter line has to increase value creation of beef in German beef production. Monteils et al. (2017) described the differing perspectives on beef carcasses of breeder, slaughterer and retailor within the value chain. Additionally, Verbeke et al. (2010) described the lack of quality differentiation in European beef production and the increasing interest of consumers in high quality beef products. This requires beef quality guarantee systems that would enhance quality beef production and improve the competitiveness of European beef production.

1.1 Beef quality and beef classification

To date, the definition of the term "beef quality" varies widely among different perspectives. The term is used in different ways and there are various adaptations and classifications of beef quality. Hocquette et al. (2014) described the differences between intrinsic factors that concern the product itself and extrinsic factors such as pricing, animal health and environmental impacts on meat quality.

From a scientific point of view, beef quality is defined as the sum of sensory, nutritive, hygienic-toxicological and processing-technological properties (Hoffmann, 1973) of beef. Detailed parameters of these attributes are given in Figure 1.

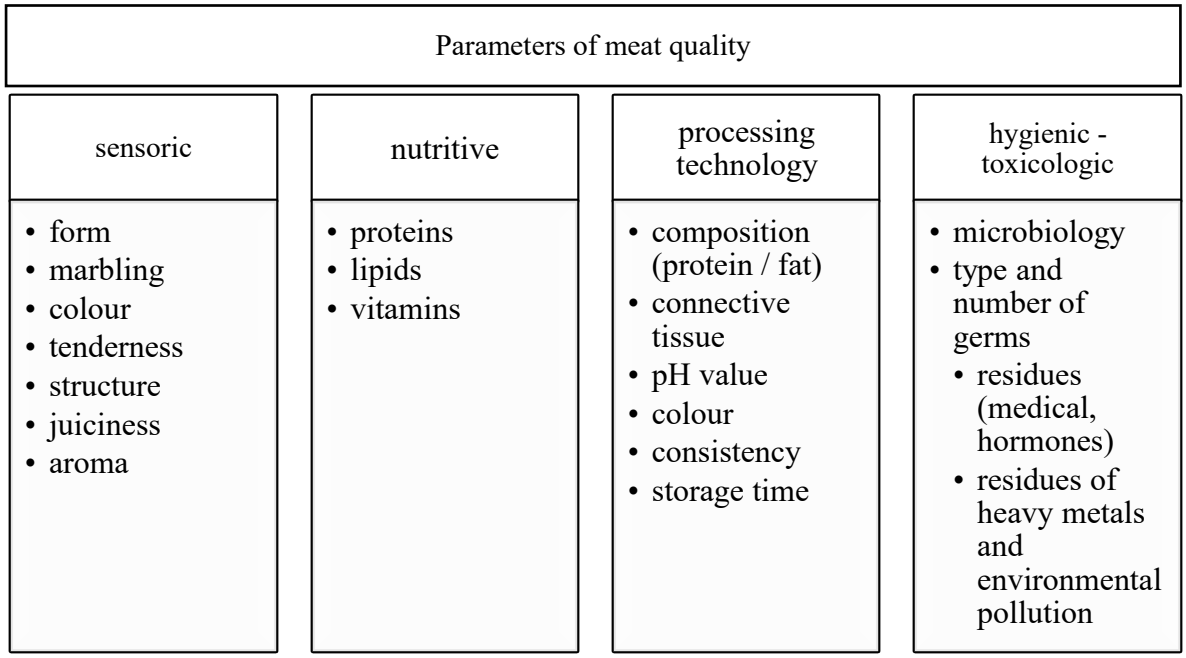

Figure 1: Parameters of meat quality (Augustini, 1987; Hoffmann, 1973)

Brinkmann (2008) described the definition of carcass or slaughter value and the differences between meat quality and yield quality formulated by Augustini (1987) and Augustini et al. (1987). The term slaughter value, which also includes the carcass conformation, the hot carcass weight and the amount of different saleable cuts, differs from meat quality (Velik, 2008), which refers to the different traits of the product itself and includes the definition given by Augustini et al. (1987).

1.1.1 Different grading and classification schemes of beef carcasses

In order to create a recognized basis for the comparability of carcasses and the slaughter values of carcasses between different countries and between breeders, producers and processors, different classification and grading systems were established which focus on different carcass traits of beef (Hocquette et al., 2014). European carcasses are graded using the commonly used EUROP class scheme (Verordnung (EWG) Nr. 1208/81) to determine the slaughter value of beef carcasses. EUROP includes the subjective assessment of trained graders focusing on 5 main carcass conformation classes (E to P, finer gradations up (+) or down (-) are possible) and 4 subcutaneous fat classes of the carcasses in different commercial classes, specified by gender (Polkinghorne and Thompson, 2010).

Weaknesses and disadvantages of the EUROP classification have been discussed for a long time. Among other reasons it is disputed for not recognizing the demands of the market (Augustini, 1999; Brinkmann, 2008) and for not being able to differentiate between various quality attributes (Bonny et al., 2016; Liu et al., 2020). Of even greater importance is that the classification system is not related to the characteristics of sensory beef quality (Bonny et al., 2016; Monteils et al., 2017; Liu et al., 2020). The focus on higher payment for carcasses with a high amount of lean meat particularly promotes those animals with a high muscularity and slaughter weight yield (Monteils et al., 2017). However, these animals are generally assumed to show disadvantages in sensory beef quality attributes such as the amount of intramuscular fat (Hocquette et al., 2009).

In contrast to the current EUROP grading scheme, international grading or classification systems focus mainly on the estimation of marbling as a determining parameter of beef carcass quality. Grading schemes among different countries were reviewed by Polkinghorne and Thompson (2010) and Farmer and Farrel (2018). They described that the United States, Australia, Canada, Japan, and South Korea make use of grading systems of beef that focus on, or at least include, marbling as one of the main parameters of beef carcass value. In contrast,

beef classification systems in Europe, New Zealand and South Africa do not consider marbling in beef valuing.

Hocquette et al. (2014) described a general tendency towards objective assessment methods instead of visual and mostly subjective assessing methods of different carcass traits. The determining criteria for different assessing methods are accuracy, speed, on–line application on the slaughter line and repeatability (Cheng et al., 2015). In most international classification systems, carcasses are classified using validated Video Image Analysis (VIA) systems which has two stages: Yield Grade, which takes into account the weight and size of the valuable cuts, and Quality Grade, which includes the level of marbling at a standardized rib eye position (Polkinghorne and Thompson, 2010; Craigie et al., 2012)

Numerous authors have rated the VIA as a useful and valuable tool (Branscheid et. al., 1998; Allen, 2003; Sönnichsen et al. 2005; Craigie et al., 2012) in beef classification systems. In contrast to chemical analysis of intramuscular fat content, it is not necessary to destroy the beef carcass. Therefore, this tool is usable in the industrial slaughter line.
In addition, compared to subjective visual assessment by trained graders, VIA provides advantages in its objective and repeatable assessment of quality traits (Cheng et al., 2015). Its high precision and reliability are also substantiated by the long use of the VIA in international beef grading schemes and the associated intensive test and validation phase (USDA, 2006a; 2006b; 2006c). In the USA, Canada and other countries, the VIA is currently the gold standard for the industrial, non-destructive and objective assessment of the quality of beef carcasses (USDA, 2006a; 2006b; 2006c; Polkinghorne and Thompson, 2010).

In Germany, however, besides a general hesitation towards grading schemes focusing on marbling as one key parameter, different cutting positions of carcasses hamper the use of VIA in the industrial slaughter line. While in international countries the cross section is determined at the 12^{th} / 13^{th} rib of the *M. longissimus dorsi* muscle, a uniform incision has not been necessary in European evaluation systems up to now. However, comparability of the carcasses between different countries or slaughter houses is not given as statements about the quality level of various beef carcasses can only be made through objective uniform measurement.

As marbling and intramuscular fat content are part of many international grading schemes and are both generally accepted as main parameters of sensory beef quality, in this thesis, the term *quality* refers mainly to these two parameters. Cheng et al. (2015) described the importance of marbling as one of the most important quality traits of beef that highly influences other sensory quality traits. Hocquette et al. (2014) described consumers' choices based mainly on high-

quality eating attributes when buying meat. However, to increase marbling or intramuscular fat content in beef, it is necessary to have more knowledge about the development of these quality traits to identify possible influencing factors that might be useful for increasing sensory beef quality.

1.2 Intramuscular fat content and marbling

Technically, marbling and intramuscular fat content address different traits (Cheng et al., 2015) The term "intramuscular fat content" describes the adipose tissue within muscles and is defined as the amount of fat, or from a chemical definition, the sum of phospholipids, triglycerides and cholesterol within muscles (Hocquette et al., 2009).

The term marbling is used to describe the amount of visible appearance and the distribution of white flecks of adipose tissue that are found between the bundles of muscle fibres in muscles (Harper and Pethick, 2004; Cheng et al., 2015). Invisible fat deposits do not show as marbling but can be determined by chemical analysis of intramuscular fat content. Thus, the main parameter is IMF because it is based on the objective chemical analysis of meat, whereas the degree of visible marbling serves as a tool of assessment via visualization of this trait. The distribution of visible fat deposits is not synonymous with the distribution of fat in the tissue. However, the relationship between marbling and the intramuscular fat is generally accepted as linear (Savell et al., 1986; Hocquette et al., 2009; Dow et al., 2011; Cheng et al., 2015). Furthermore, IMF is highly correlated to sensory quality traits of meat (Hocquette et al., 2009; Bonny et al., 2016). It influences the tenderness of meat (Reverter et al., 2003), and retains the juiciness of meat. The fat carries a lot of aromatic substances that develop during cooking / frying.

1.2.1 Influences in intramuscular fat content and marbling

Intramuscular fat content and marbling are mainly affected by four influencing factors: age, gender, genetics and feeding of the animals. (Harper and Pethick, 2004; Hocquette et al., 2009; Park et al., 2018). Harper and Pethick (2004) summarized that fat tends to redistribute with increased age into non – adipose tissues (Kirkland et al., 2002), and that factors that affect adipogenesis might lessen with increased animal age. Hocquette et al. (2003) found that in Angus cattle, marbling was mainly developed in animals that were aged under 28 months. In accordance with this, Harper and Pethick (2004) described age as one of the main factors influencing adiposity in mammals. Hocquette et al (2009) and Harper and Pethick (2004) described that adipose tissue is the last tissue that is accumulated in muscles although the origin

of adipocytes is in the early life of animals. Park et al. (2018) summarized that intramuscular fat content increases with animal age and cited different studies that showed increased IMF in animals up to 35 months.

With comparable slaughter weights, it is generally accepted that the portion of intramuscular fat is higher in steers and heifers (Harper and Pethick. 2004; Hocquette et al., 2009; Park et al., 2018). Due to a suggested but not defined influence of sex hormones, young bulls should be castrated as early as possible because the intramuscular fat accumulates earlier as a result (Meaker et al., 1986; Worrel et al., 1987; Harper and Pethick, 2004; Park et al., 2018).

Furthermore, Hocquette et al. (2009) illustrated that genomic principles might explain the accumulation of intramuscular fat content and marbling but highlighted that the final expression of animals' marbling in meat is not uniquely influenced by genes. Park et al. (2018) refered to various studies concerning different breeds and marbling levels. Beef cattle are differentiated into large, medium and small-framed beef breeds differing in growth and maturity. It is generally accepted that small-framed breeds tend to have higher fattening while larger breeds tend to show higher muscularity than intramuscular fat content. (Warzecha and Reichardt, 1997; Reichardt et al., 2006; Waßmuth and Pabst, 2013; Schmutz, 2014). The highest intramuscular fat content values are generally shown in Wagyu beef, with a mean value of 36 % (Albrecht et al., 2011; Irie et al., 2011; Park et al., 2018). Angus cattle tend to have higher intramuscular fat content (Dinh et al., 2010; Park et al., 2018) than Hereford (mean: 2.8 %). Alberti et al. (2008) described different European beef breeds and showed that those beef breeds that tended to show high muscularity, such as Piemontese, Limousin and Charolais, had low to medium levels of fat. Although the genetics and the age of animals may influence the amount of the IMF in cattle, the different breeds are also subjected to a high number of further influences that determine the development of marbling and IMF. Additionally, it is suggested that different influences on intramuscular fat content and marbling interact. Production-related factors such as final fattening weight, slaughter age, fattening intensity also have a major effect on carcass characteristics. In addition, the perimortal treatment of the meat (transport, cooling, maturation) is important (Augustini, 1987; Velik et al., 2008).

As the factors of age, gender and genetics are also expected to lead to high variations in industrial beef production, a homogeneous structure of management strategies related to age and gender, but mainly purposive and needs-based feeding strategies, are essential ways of influencing the increase of the intramuscular fat percentage. However, Hocquette et al. (2009) highlight that the nutritional manipulation of IMF might be more challenging than genetic

strategies. Therefore, evidence on the development of intramuscular fat is necessary to optimize animal feeding regimes conducive to developing high intramuscular fat content.

1.2.2 Development of marbling and intramuscular fat content

Intramuscular adipocytes have their origin in stem cells or progenitor cells that have the capacity to differentiate into various cells with different functions as well as into fibroblastic and myogenic cells (Du et al., 2013). Animals that develop high muscularity with high glycolytic activity show a reduced development of IMF (Hocquette et al., 2009). The mechanisms that relate to the derivation of the transformation of stem cells into adipocytes, muscle or fibroblast cells are rudimentary. Hocquette et al. (2009) suggested possible interactions that might influence the proliferation and differentiation of adipocytes and myoblasts in the very early stages of growth.

The amount of intramuscular fat content does not only depend on the number of adipocytes. It is rather a balance of the development of adipocytic and myofibers cells that might be regulated by nutritional, environmental and genetic factors (Joe et al., 2010; Du et al., 2012). But as the development of progenitor cells decreases with increased age of animals, the manipulation of progenitor cells is required at an early age. During the following growing and aging processes of the animals, present adipocytes continue to grow in volume (Hood and Allen, 1973; Hocquette et al., 2010) as they are fed with substrates that are transformed into fat (Leibel et al., 1989). To produce beef with a high amount of intramuscular fat content, Harper et al. (2004) suggested feeding strategies that increase both the differentiation of adipocytes that are later filled with fat to increase the volume of these cells. Hocquette et al. (2009) and Pethick et al. (2006; 2007) described the IMF level during the early growth period as one of the main parameters influencing the amount of IMF after the finishing period.

Studies show that particularly at an early age or in the so-called “marbling window” between weaning and day 250, there is the possibility of specifically influencing the increased formation (hyperplasia) of fat cells (Du, 2012). In the further fattening period of feeding, these cells are then filled with substrate (hypertrophy), depending on the feed which they can convert into fat and store.

Sami et al. (2009) described the importance of protein sources which affect carcass characteristics and performance of beef cattle in the fattening period. Duarte et al. (2011) emphasized that crude protein might not be the unique parameter influencing protein requirements of ruminants. Numerous studies have explored influences of UDP-based diets in

dairy cows but influences of ruminally undegradable protein in beef quality traits are widely unknown.

Furthermore, Hocquette et al. (2009) described the challenging character of beef feeding strategies to influence marbling due to the high risk of increased subcutaneous back fat thickness when increasing intramuscular fat content.

In the case of monogastric animals, Sundrum et al. (2000) revealed that a diet of lupine and faba beans lead to increased intramuscular fat content without increased subcutaneous fat. The authors hypothesized that the amount of intramuscular fat content might be affected by the quantitative relationship of non-essential to essential amino acids. In a further feeding trial, the authors suggested that the specific amount of non-essential amino acids of lupine added to a needs-based feeding strategy might lead to an increased amount of intramuscular fat content. This hypothesis could be clarified in a following trial with a combination of faba beans and lupines (Sundrum et al., 2004; Sundrum et al., 2011).

These results are so far not adapted to beef production. The strategy could be to increase the availability of non-essential glucoplastic amino acids in the amino acid pool to increase the intramuscular fat content. It is expected that the glucoplastic amino acids, which are not used in muscle cells for protein synthesis, are used as substrates for intramuscular fat formation (Sundrum et al., 2011).

In view of the different influencing factors on intramuscular fat and marbling, a wide range of variation is expected for the quality characteristics of beef carcasses. Additionally, interactions between these factors are expected (Velik, 2008). Therefore, the need for reliable assessment of marbling or intramuscular fat content in beef is evident, on the one hand, to investigate the existing level of sensory beef quality but, on the other hand, to investigate the appropriateness of strategies to increase marbling or IMF.

2 Aims of the Thesis

The overall aim of the research work was to explore the variation of these traits and to validate options that are suited to increase intramuscular fat content or marbling as determining parameters of beef quality. Furthermore, a reliable assessment method of marbling in German industrial slaughter lines should be validated.

The specific aims were:

i. to assess the high variation and current state of specified sensory quality parameters of beef within the German breed of “Rotes Höhenvieh”.

ii. to validate a current and international assessment method on German beef carcasses ribbed at an industrial German cutting position to create a possibility for objective and non-destructive assessment of marbling within the slaughter line

iii. to verify a purposive feeding strategy of fattening young heifers as a possibility to influence one of the main factors in increasing marbling as sensory quality attribute of German beef carcasses.

3 Potentials of quality beef production in association with the German endangered cattle breed population Rotes Höhenvieh (RHV)

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Executive Summary

The main objective of this study was to explore the potential of an endangered beef breed RHV in beef quality production, that might serve as a unique selling point and could lead at long term to the conservation of this breed.

As animals of the breed 'Rotes Höhenvieh' show only reduced performance traits such as daily gain, hot carcass weight and lower muscularity, the population of this breed was highly reduced during the last twenty years. The carcasses from animals of this breed that is small to medium sized, often show disadvantages in the current EUROP classification, that favours especially low fat covering and high conformation scores of beef carcasses. Thus, RHV has main disadvantages in the German beef market and risks to be decimated. Therefore, owners and farmers of RHV receive public funding in 6 federal States per animal and year. This funding shall compensate economic disadvantages that might result of lower carcass weights and daily gains.

Although so far, there exists no evidence, livestock of endangered breeds is often associated with advantages in production traits. Marketing initiatives and labels promise high quality beef of endangered livestock populations. But currently, no studies were carried out to validate those opinions.

Advantages in traits of sensory beef quality or performance of RHV could enhance Unique selling points of this population and thus, lead at long term to preservation of this breed due to economic independence. Therefore, evidence about the current quality level of this breed is necessary.

In this study, 539 beef samples from animals of the RHV population were collected at the 12th rib position of *M. longissimus dorsi* and chemical and NIRS-IMF content was analysed to investigate the current quality level within the RHV population.

Average IMF values reached 2.55 % within the total RHV – population, including beef from heifers, steers and bulls. The beef samples showed high variation between 0.2 % IMF to 22.9 % IMF.

It was investigated, that beef samples from steers showed higher IMF content (5.9 %) than samples from heifers (4.7 %) and bulls (1.6 %).

The large variability of this traits within a homogeneous breed illustrates that high beef quality might not uniquely be expected by choice of genetics although in individual cases, high IMF were investigated.

The high variation in IMF fat content of the analysed samples illustrates the high variability among the RHV population. In this study, 26 RHV farms with 16 to 616 RHV animals (Figure 1) were visited in 6 different federal states and their production orientation in connection with the RHV breed was asked. In total, all farms differed widely in feeding strategies, management, reasons for the choice of RHV cattle and production orientation.

It was investigated, that in 7 of the farmers and owners from RHV, the predominant source of income included extensive cattle grazing based landscape conservation that is mostly publicly funded (Figure 2). 9 of the farmers named beef production as main incoming source, but combinations of these production systems are possible.

In addition, high numbers RHV animals do not mean at the same time high slaughter numbers or the orientation towards purposive meat production as the conservation of the breed is often favoured than beef production in most of the cases.

Additionally, in most of RHV farms, the strategies and programs of landscape conservation implicate very extensive feeding strategies that offer no possibilities of purposive feeding strategies in the finishing fattening periods of animals. Although beef samples in the current study showed similar IMF contents than other European beef breeds that were fed extensively, it has to be emphasized, that higher IMF contents (> 10 %) are required in international beef production systems.

In total, it could be investigated, that the potential of the breed for quality beef production is currently not sufficiently exploited and in parts, the extensive feeding diets and guidelines of landscape conservation contradict the production of beef quality with this breed. Improved profitability in the use of the breed can only be achieved through competitive advantages in the context of use. Considering the current motives of the farmers in the decision for the breed ‘Rotes Höhenvieh’ it was emphasized that animals of this breed are mainly used in the

financially supported landscape maintenance with meat only as by product. The maintenance of the landscape and the efforts of the cattle farmers in environment conservation differ widely, however, depending on the regional conditions with regard to could not be assessed in a standardized way.

To improve at long term the conservation of RHV in combination with landscape conservation or extensive feeding, proven advantages in beef quality have to be focused to support values of carcasses of RHV and to support the economic independence of this breed. The combination of RHV and the maintenance of the landscape or nature conservation could be taken into account and emphasized as a further factor of the process quality of the end product meat under the premises of the targeted grassland-based feeding and a targeted high beef quality.

The results of this study emphasize the wide variability of beef quality traits within a breed and on farms. For the successful marketing of beef of RHV and also other beef breeds it is therefore necessary to assess quality traits in order to validate optimal further processing and distribution. There are many reasons to suggest that the preservation of the breed can only be secured in the long term through increased added value through higher quality products.

Potenziale der Erzeugung von Qualitätsfleisch in der Population Rotes Höhenvieh

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Zusammenfassung

Das Rote Höhenvieh ist eine vom Aussterben bedrohte Rasse. Aufgrund geringerer Tageszunahmen und Schlachtgewichte sind die Masttiere gegenüber herkömmlichen Fleischrassen nicht wettbewerbsfähig. Was ihnen an Muskelfülle fehlt, können sie möglicherweise durch eine erhöhte Fleischqualität wettmachen, sofern diese vorhanden ist und über spezielle Vermarktungswege eine verbesserte Wertschöpfung realisiert werden kann. Ziel der vorliegenden Studie war es, die Potenziale der bedrohten Nutztierpopulation Rotes Höhenvieh im Hinblick auf Qualitätsfleisch auszuloten, um darüber zum Erhalt der Rasse beitragen zu können.

Im Rahmen der Studie wurden 539 Fleischproben von geschlachteten Tieren der Rasse Rotes Höhenvieh gesammelt und hinsichtlich des intramuskulären Fettgehaltes als maßgeblichen Parameter der sensorischen Fleischqualität analysiert. Der mittlere IMF – Gehalt betrug 2,5 % (SD: 2,8). Allerdings wiesen die Werte in der Gesamtpopulation eine erhebliche Streuung in diesem Merkmal (0,2 % – 22,9 %) auf. Die höchsten Mittelwerte wurden für Ochsen (5,9 %) ermittelt; auch die mittleren IMF – Gehalte der Färsen lagen mit 4,7 % über denen der Gesamtpopulation. Die Relevanz möglicher Einflussfaktoren sowie deren heterogene Ausprägungen werden im Hinblick auf die Entwicklung des IMF-Gehaltes reflektiert.

Die qualitativen Unterschiede innerhalb der Population Rotes Höhenvieh unterstreichen die Notwendigkeit einer kontinuierlichen Erfassung von sensorischen Qualitätsmerkmalen, um das Potenzial der Rasse zur Qualitätsfleischerzeugung nutzen und gezielt verbessern zu können. Die Ergebnisse legen den Schluss nahe, dass sich die vom Aussterben bedrohte Rinderrasse langfristig nur bei einer evidenzbasierten Vorzüglichkeit von anderen genetischen Herkünften abheben und auf diese Weise erhalten werden kann.

Schlüsselwörter: Rindfleischqualität, Qualitätsnachweis, intramuskulärer Fettgehalt, Wettbewerbsfähigkeit

Summary

The aim of this study was to analyse the meat quality of the endangered cattle breed Rotes Höhenvieh (RHV) by focussing on the intramuscular fat (IMF) content. As a small- to medium sized breed and with regards to the EUROP classification system that focuses mainly on highly muscled beef carcasses, animals of this population are highly decimated due to the low meatiness of their carcasses and the competitive disadvantages deriving therefrom on the German beef market. In public opinion, endangered livestock populations are often associated with advantages in sensory quality attributes. To our knowledge, however, no investigations have been conducted to prove this assumption.

On the other hand, potential advantages in sensory quality traits such as intramuscular fat content might serve as a unique selling point of this breed and differentiate the RHV beef as proven quality beef. A generally higher level in meat quality might serve as a starting point to convert a competitive disadvantage into an advantage.

To assess the meat quality, IMF content of 539 RHV beef samples of *M. longissimus dorsi* were analysed. Mean values for IMF reached 2,55 %, however, showing a large variation (0.2 % to 22.9 %) between the carcasses. Samples from steers reached higher mean values of intramuscular fat content (5.9 %) than samples from heifers (4.7 %). In total, variation in IMF emerged among the RHV population, emphasizing the need of an objective assessment of the quality level of each carcass as well as the implementation of purposeful strategies to increase the sensory quality level of German regional beef production.

Keywords: endangered livestock breeds, beef quality, intramuscular fat content

3.1 Einleitung

Die deutsche Rinderrasse Rotes Höhenvieh (RHV) wird seit über 20 Jahren auf den Listen der bedrohten Nutztierpopulationen als Erhaltungs- oder Beobachtungspopulation geführt. Über das nationale Programm zur Förderung und Erhaltung der Biodiversität werden in sieben Bundesländern finanzielle Fördermittel für Halter dieser Rasse zur Verfügung gestellt (BLE, 2019). Diese Förderung erweist sich allein als nicht hinreichend, um das Ziel des Erhalts der Rasse zu gewährleisten. Da die quantitativen Schlachtkörpermerkmale dieser Tiere auf dem Rindfleischmarkt nicht hinreichend wettbewerbsfähig sind, läuft das Rote Höhenvieh als kleinrahmige Fleischrinderrasse Gefahr, endgültig vom Markt verdrängt zu werden. Neben einer kulturellen Erhaltungswürdigkeit könnten nachgewiesene Qualitätsunterschiede der Rasse Rotes Höhenvieh in Merkmalen der sensorischen Fleischqualität zu einem

wirtschaftlichen Wettbewerbsvorteil und über eine Mehrpreisgenerierung zum Erhalt beitragen. Im Rahmen regionaler Vermarktungsstrategien bzw. in Marketinginitiativen des Lebensmitteleinzelhandels werden die bedrohten Rassen häufig mit Vorteilen im Hinblick auf qualitative Produktionsmerkmalen assoziiert (Menger et al., 2020). Allerdings wurde dieser Zusammenhang bisher nicht umfänglich wissenschaftlich beleuchtet.

Die Population Rotes Höhenvieh zählt aktuell ca. 2006 weibliche und 157 männliche Tiere, die im Herdbuch eingetragen sind (BLE, 2019). Damit bietet sie rein zahlenmäßig die Minimalvoraussetzungen, um eine hinreichend große Stichprobe hinsichtlich der Fleischqualitätsmerkmale der Nachkommen zu beproben, die die Variation der Genetik annähernd beschreibt. Auch aus züchterischer Perspektive macht es Sinn, die Struktur bzw. den aktuellen Stand der Dinge der Variation der Produktionsmerkmale zu beleuchten, um Strategien zu formulieren, die zu einer zielgerichteten Optimierung der Rasse führen können. Hierzu fehlt allerdings aktuell das Wissen über die tatsächliche Nutzungsausrichtung der Rasse, die tatsächlichen Potenziale dieser Genetik, um qualitativ hochwertiges Fleisch zu erzeugen.

Zurzeit werden die Tiere dieser Rasse vor allem in der Landschaftspflege eingesetzt. Ziel der vorliegenden Studie war es, eine Übersicht über den Stand der Nutzungsrichtung des Roten Höhenviehs zu erstellen. Darüber hinaus sollten ausgewählte Fleischqualitätsmerkmale von Fleisch von Tieren der Rasse Rotes Höhenvieh berücksichtigt werden, um eine Aussage über das Fleischqualitätsniveau anhand zumindest eines Merkmals der sensorischen Fleischqualität treffen zu können. Aufgrund der spezifischen Bedingungen, die sich in der Population bedrohter Nutztierrassen ergeben (begrenzte Verfügbarkeit, kleinstrukturierte Betriebe, heterogene Betriebsstrukturen) wurde ein explorativer Ansatz gewählt. Gleichzeitig sollte mit den Untersuchungen des Genoms eruiert werden, ob mit gezielten züchterischen Maßnahmen die Fleischqualität ggf. erhöht werden kann.

Als ausgewählter Parameter der sensorischen Fleischqualität standen der intramuskuläre Fettgehalt (IMF) und die Scherkraft im Fokus. Weitere Parameter konnten aufgrund der sehr stark heterogenen Struktur innerhalb der Population nicht wie ursprünglich geplant einheitlich betrachtet werden. In internationalen Studien wird der IMF-Gehalt aufgrund seiner zahlreichen positiven Einflüsse auf weitere sensorische Merkmale (Safthaltvermögen, Zartheit, Marmorierung etc.) als wertgebendes Merkmal der sensorischen Fleischqualität anerkannt (Hocquette et al., 2010; Cheng et al., 2015). Ein weiterer Vorteil besteht darin, dass der Parameter auch bei unterschiedlichen Reifemethoden, die zwischen unterschiedlichen

Verarbeitungsmethoden bestehen, unverändert bleibt und eine weitgehend von der Probennahme unbeeinflusste Bestimmung gewährleistet.

3.2 Material und Methoden

Die ursprünglich geplante standardisierte Herangehensweise zur Analyse der Struktur des Roten Höhenviehs war aufgrund der angetroffenen Heterogenität der Produktionsbedingungen bei der Haltung dieser Rinderrasse nicht möglich. In Kooperation mit der Zuchtorganisation des Roten Höhenviehs, der Bundesarbeitsgemeinschaft Rotes Höhenvieh, wurden die Züchter und Halter der Rasse Rotes Höhenvieh ausfindig gemacht, welche über die größten Tierzahlen verfügten. Betriebe mit mehr als zehn Tieren wurden kontaktiert und telefonisch über ihre Schlachttierzahlen befragt. Sofern Betriebe Interesse bekundeten und eine entsprechende Ausrichtung in der Fleischproduktion angaben, wurden die Betriebe aufgesucht und Daten bzgl. der betrieblichen Produktionsmerkmale im Zusammenhang mit dem Roten Höhenvieh erhoben. Im Zeitraum von Mai 2018 bis Februar 2021 wurden insgesamt 27 RHV – haltende Betriebe mit jeweils mindestens 10 RHV-Tieren besucht. Mittels eines Fragebogens wurden Informationen über den Betrieb und die Nutzungsausrichtung in Verbindung mit dem Roten Höhenvieh eingeholt. Einige der Betriebe verfügen über feststehende Programme mit dem Lebensmitteleinzelhandel und konnten deshalb keine oder nur einen kleinen Anteil an Fleischproben zur Verfügung stellen.

3.2.1 Auswahl der Fleischproben

Im Rahmen der durch die Landwirte organisierten Schlachtungen wurden die untersuchten Fleischstücke durch die zuständigen Fleischer entnommen und nach der Entnahme unmittelbar eingefroren. Im Vorfeld wurden die jeweiligen Fleischer und Zerleger bezüglich der Probennahme eingewiesen und eine einheitliche Position der Entnahme an der 12. Rippe des *M. longissimus dorsi* vereinbart. Zur Abbildung einer repräsentativen Stichprobe wurden Proben von Tieren aller besuchten RHV–Betriebe einbezogen. Die Heterogenität der Betriebe wirkte sich allerdings auf die Verteilung der Stichproben der Fleischproben zwischen den Betrieben aus. So sind Betriebe mit hoher Schlachtfrequenz in höherer Zahl in der Stichprobe vertreten. Dieses Ungleichgewicht konnte aufgrund der sehr begrenzten Populationszahl nicht vermieden werden. Auch die Verteilung in den jeweiligen Kategorien (Färse, Bulle, Ochse, Kuh) wurde durch die Population selbst vorgegeben. Insgesamt wurden 539 Proben der Rasse Rotes Höhenvieh analysiert, darunter 343 Fleischproben von Bullen, 31 Fleischproben von Ochsen, 144 Proben von Kühen und 14 Proben von Färsen bis 28 Monate. Sechs der Proben

konnten nachträglich nicht mehr eindeutig einem Tier bzw. Geschlecht zugeordnet werden, gehen aber dennoch in die Werte der Gesamtpopulation ein. Die Tiere waren zum Zeitpunkt der Schlachtung zwischen 18 und 218 Monate alt. Das mittlere Schlachtalter der Tiere betrug 39 Monate.

3.2.2 Lokalisierung, Entnahme und Behandlung der Fleischproben

Im Vorfeld wurden die jeweils individuelle Abreifedauer, sowie Besonderheiten während der Schlachtung und Reifung (Temperatur, Dry Aged etc.) erfasst. Aus logistischen Gründen und der betriebsindividuellen Vermarktungsstrukturen konnte eine einheitliche perimortale Behandlung der Proben nicht gewährleistet werden, sodass die Proben nach Entnahme durch die Landwirte und Fleischer eingefroren wurden. Die Probeentnahme erfolgte an jedem Schlachtkörper einheitlich am Querschnitt der 12./13. Rippe des *M. longissmus dorsi*. Diese Position gilt in zahlreichen internationalen Klassifizierungssystemen wie den USA und in Kanada als standardisierte einheitliche Messposition (Polkinghorne und Thompson, 2010) und wurde deshalb auch im Rahmen dieser Studie gewählt, um Bezüge und Vergleiche zu anderen Studien herstellen zu können. Da nahezu alle RHV-Halter und Betriebe, die an dieser Erhebung teilnahmen ihr Fleisch direkt vermarkten und zu großen Teilen auch in kleinen Betriebsstätten schlachten lassen, konnten entgegen der ursprünglichen Planung keine Schlachtgewichte und EUROP Klassifizierungen erfasst werden.

3.2.3 Nasschemische und NIRS-Analyse des intramuskulären Fettgehaltes

Alle durch die Landwirte zur Verfügung gestellten Proben wurden im Labor des Fachgebietes Tierernährung und Tiergesundheit der Universität Kassel durchgeführt. Die Analyse des intramuskulären Fettgehaltes der Proben erfolgte in zwei Phasen zunächst nass-chemisch und nach dem Aufbau einer entsprechend präzisen Kalibrierung anhand der NIRS-Analyse. Proben mit IMF–Gehalten über 5 % wurden während des gesamten Projektzeitraums sowohl nasschemisch als auch mittels NIRS-Analytik bestimmt. Von allen Proben wurde Fleisch von ca. 5 g Muskelfleisch homogenisiert und nasschemisch nach der Soxhlet- und Weibull–Stoldt-Methode (Arneth, 1998) analysiert. Hierbei erfolgt die Rohfettbestimmung durch Extraktion mit vorangehender Hydrolyse. Nach der Säurehydrolyse wird die Probe in eine Hydrolysefritte überführt und mit einem Lösungsmittel mittels Soxhlet Apparatur analysiert (Arneth, 1998). Anhand der Ergebnisse der nasschemischen Bestimmung von 120 Proben wurde eine NIRS-Kalibrierung erstellt und validiert.

Zusätzlich wurde die Bestimmung der Scherkraft an den Proben durchgeführt, die die hierfür benötigte Dicke von 2,5 cm aufwiesen. Die Bestimmung mit der Warner-Bratzler Schere erfolgte nach dem Schema von Seenger et al (2005). Gefrorene Proben wurden mindestens 24 Stunden langsam und gleichmäßig aufgetaut. In einem nächsten Schritt wurde die Feuchtigkeit bzw. das Wasser von der Probe getupft und die Probe wurde, falls erforderlich, auf 2,5 cm geschnitten. Anschließend wurde dieses Gewicht der Probe eingewogen. Im nächsten Schritt wurden die einzelnen Fleischscheiben bei einer Kerntemperatur von 70 °C auf einem Kontaktgrill gegrillt. Die Verwendung eines Thermometers garantierte die konstante Temperatur während des Grillvorgangs. Nach dem Grillvorgang wurde die Probe auf Filterpapier 5 Minuten zum Auskühlen bereitgelegt um nach erneutem Wiegen den Kochverlust zu errechnen. Für die Scherkraftmessung wurden mittels Stechzylinder fünf Stanzproben von 1,27 cm verteilt über die gesamte Fleischfläche nach einem festen Schema ausgeschnitten. Diese Einzelproben wurden jeweils durch die Warner-Bratzler-Schere (V-förmig, 1 mm dicke Klinge) mit einer Schergeschwindigkeit von 4,5 mm/s geschnitten. Aus den jeweiligen Einzelproben wurde ein Mittelwert errechnet.

3.2.4 Statistische Analyse

Die statistische Auswertung der Daten erfolgte mit Excel und SPSS. Für die IMF – Werte wurde ein generalisiertes gemischtes lineares Model verwendet, das die vorhandenen Schlachtgewichte, das Geschlecht und das Schlachtalter der Tiere in Monaten als fixe Effekte berücksichtigte. Der Betrieb wurde als zufälliger Effekt definiert.

$$y_{ijklmn} = \mu + s_i + a_j + p_k + f_l + + e_{ijklm}$$

wobei

y = Beobachtungen für NIRS IMF

μ = Gesamtmittelwert

s_i = fixer Effekt für Geschlecht (Bulle, Ochse, Färse, Kuh)

a_j = fixer Effekt für Schlachtalter in Monaten (18 bis 218)

p_k = fixer Effekt für Produktionsrichtung (1 = Fleischproduktion, 2 = Landschaftspflege, 3 = Zucht, 4 = Schlachtierverkauf, 5 = Milchproduktion)

f_l = zufälliger Effekt für Betrieb (1 bis 24)

e = Restfehler

3.3 Ergebnisse

Charakterisierung der Betriebe

Abbildung 3.1 verdeutlicht die Bestandszahlen der teilnehmenden RHV-Betriebe, gruppiert nach Bundesland. Die meisten RHV-Betriebe und -halter wurden in den Mittelgebirgsregionen NRWs und Hessens angetroffen. Insgesamt nahmen 26 Betriebe teil, davon 9 aus Hessen, 3 aus Thüringen, 1 aus Bayern, 2 aus Niedersachsen, 2 aus Sachsen - Anhalt und 7 aus NRW. Vier der zahlenmäßig großen Betriebe liegen in der Ursprungsregion des Roten Höhenviehs, im Harz. Die besuchten Betriebe hielten zwischen 15 und 616 RHV-Tiere und fünf Betriebe mehr als 100 Tiere. Abbildung 3.2 visualisiert die RHV–Betriebe der vorliegenden Studie, gruppiert nach ihrer Nutzungsausrichtung und Anzahl der gehaltenen Tiere der Rasse Rotes Höhenvieh.

Insgesamt wurden 15 Haupterwerbsbetriebe und 9 Nebenerwerbs- bzw. Hobbybetriebe besucht. Es zeigt sich, dass für einen Großteil der Betriebe die von der öffentlichen Hand geförderte Landschaftspflege die maßgebliche Einnahmequelle ist. Vier Betriebe, die als Haupteinnahmequelle die Fleischerzeugung angaben, erhalten ebenfalls Förderungen im Zusammenhang mit der Landschaftspflege und Naturschutzmaßnahmen. Zusätzlich gaben diese Betriebe als hauptsächliche Einnahmequelle den Fleischverkauf mit Direktvermarktung an. Gleichzeitig vermarkten mindestens drei der Betriebe die als Haupteinnahmequelle die Landschaftspflege angaben, das Fleisch ihrer Tiere in regelmäßigen Abständen.

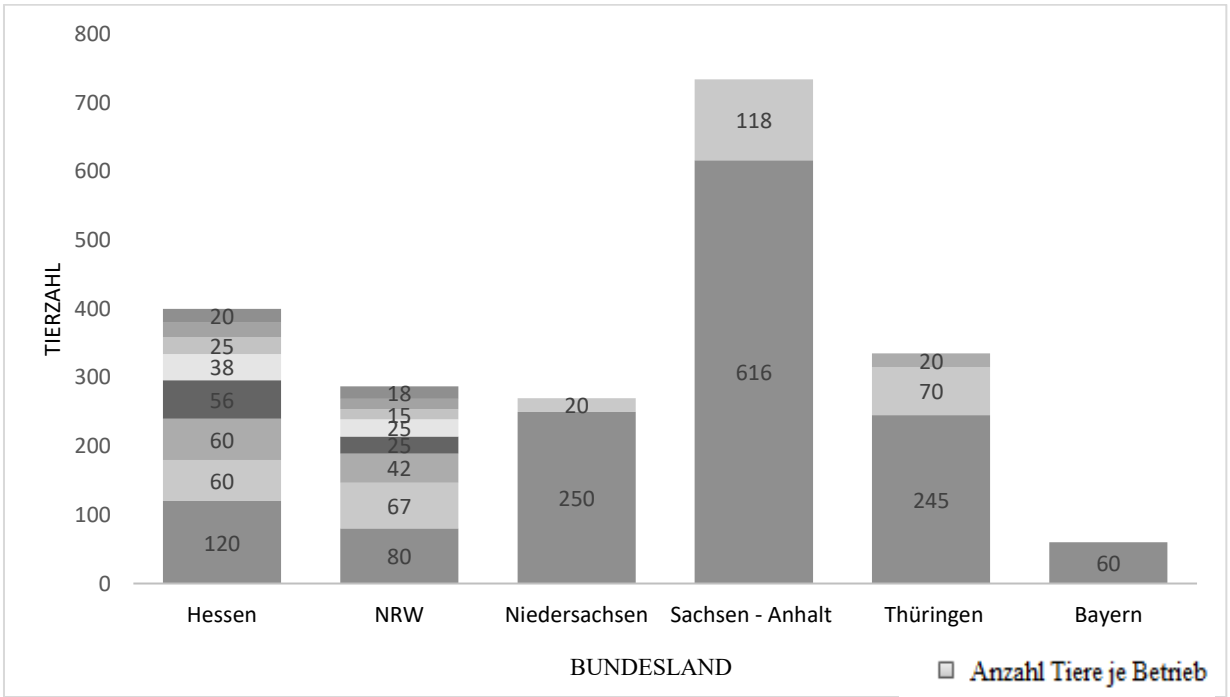

Figure 3.1: Regional Differentiation of RHV – farms and number of animals per farm

Abbildung 3.1: Regionale Verteilung der RHV – Betriebe und Anzahl der Tiere pro Betrieb

Darüber hinaus zeigte sich, dass hohe Bestandszahlen der einzelnen Betriebe nicht zwangsläufig mit der Höhe der Schlachtzahlen korrelieren. Zahlreiche Betriebe und Tierhalter schlachten nicht in regelmäßigen Schlachtrhythmen, sondern in Abhängigkeit von der Nachfrage. Mit Ausnahme eines Mästers, gaben alle Betriebe an, ihre Tiere während der Vegetationsperiode ab März auf der Weide zu halten. Darüber hinaus praktizierten vier der Betriebe eine ganzjährige Weidehaltung mit entsprechendem Witterungsschutz. Die weiteren 19 Betriebe gaben an, ihre Tiere zum Ende der Weideperiode zwischen Oktober und Dezember in verschiedenen Stallsystemen zu halten. Die Fütterung der Tiere erfolgt mit Ausnahme zweier Betriebe vorwiegend extensiv durch Grünlandfutter.

Eine Zufütterung während der Sommerperiode erfolgt auf lediglich drei Betrieben. Vier der Betriebe gaben an, die zur Schlachtung bestimmten Tiere vor der Schlachtung aufzustallen. Eine gezielte Endmast mit Kraftfuttereinsatz fand lediglich auf zwei Betrieben statt.

Neben der Haltung zum Zweck des Naturschutzes und der Landschaftspflege hatte auf vielen Betrieben der Erhalt der Rasse über die direkte Erhöhung der Bestandszahlen Priorität vor der Fleischproduktion. Dies zeigt sich insbesondere an der Auswahl der Schlachttiere: Insgesamt gaben 12 der Betriebe an, ihre Tiere je nach Zuchteignung (Inzucht, Erfüllung des Zuchtziels etc.) zur Schlachtung auszuwählen. In diesen Fällen wird ein Zuchttierverkauf oder -austausch priorisiert. Fünf der Betriebe schlachteten ihre Tiere nach vorheriger Erfassung des Lebendgewichts. Zwei Betriebe gaben vorrangig die älteren Tiere zur Schlachtung. Weitere vier Betriebe wählten ihre Schlachttiere nach dem Verhalten der Tiere aus. Das Kriterium der reduzierten Fruchtbarkeit wurde lediglich einmal genannt.

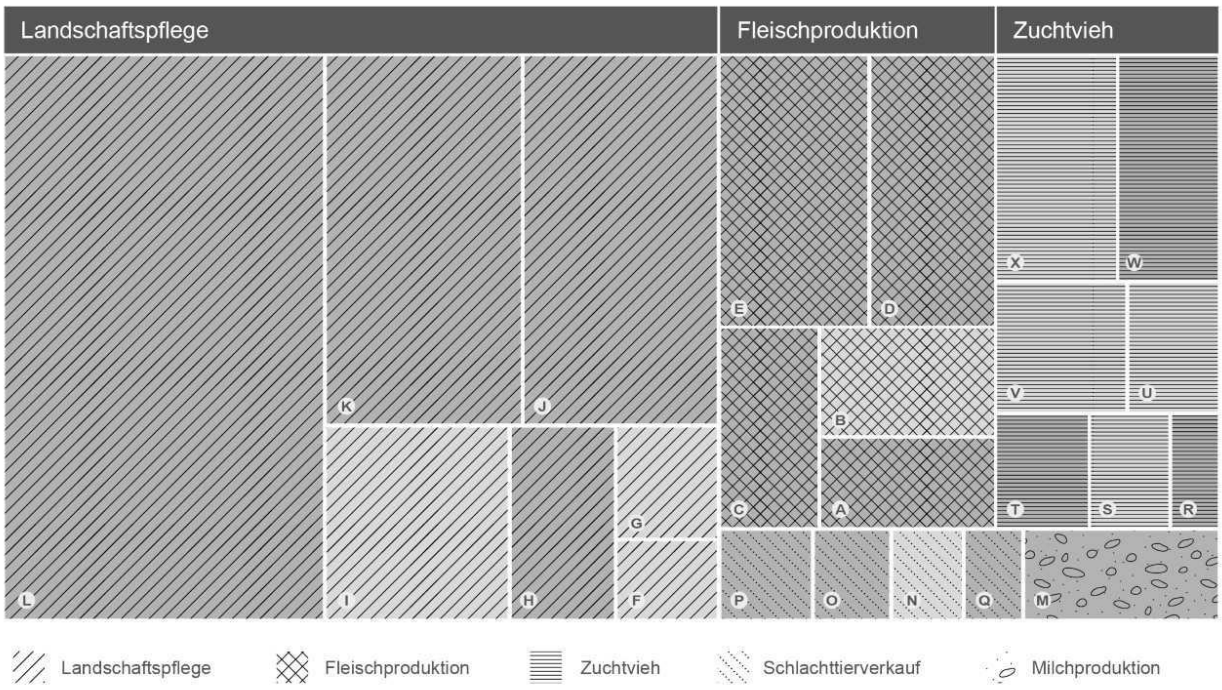

Figure 3.2: Visualisation of RHV – farmers by animal number (size of rectangle) and focus of production (hatching) *) transparently marked holdings (I, G, F, B, N, X, V, U and S) are secondary job farms and hobby – breeders
Abbildung 3.2: Visualisierung der RHV – Betriebe nach Tierzahl und Produktionsrichtung. Transparent markierte Felder (I, G, F, B, N, X, V, U und S) markieren Nebenerwerbsbetriebe und Hobbytierhalter

Die Schlachtung erfolgte auf einem Großteil der Betriebe in externen Schlachtstätten, vier der Betriebe verfügten über eine eigene Möglichkeit zur Schlachtung. Insgesamt gaben vier Betriebe an, ausschließlich für den Eigenbedarf zu schlachten. 12 der Betriebe vermarkteten das Fleisch der Tiere hauptsächlich auf Bestellung in Form gemischter Pakete. Drei der Betriebe vermarkteten das Fleisch der Tiere über einen Metzger. Vier der Betriebe verkauften das Fleisch ausschließlich über den eigenen Hofladen. Einer der Betriebe gab an, den Großteil des Fleisches über den Lebensmitteleinzelhandel zu vermarkten. Vier der Betriebe kombinierten unterschiedliche Vermarktungsstrategien in Form von gemischten Fleischpaketen bzw. im eigenen Hofladen, Abgaben an den Lebensmitteleinzelhandel sowie die Abgabe an eigene oder Fremdgastronomie.

3.3.1 Bestimmung der Fleischqualität anhand des IMF-Gehaltes

Insgesamt variierten die Werte des intramuskulären Fettgehaltes der RHV-Population zwischen 0,02 % – 22,9 %. Dabei wurden sowohl Werte für das Fleisch von Jungbullen, als auch von Färsen, Ochsen und Altkühen mit einbezogen. Der mittlere intramuskuläre Fettanteil liegt bei 2,5 % bei einer Standardabweichung von 2,8 %. Eine differenzierte Aufteilung nach Geschlecht zeigt Abbildung 3.3.

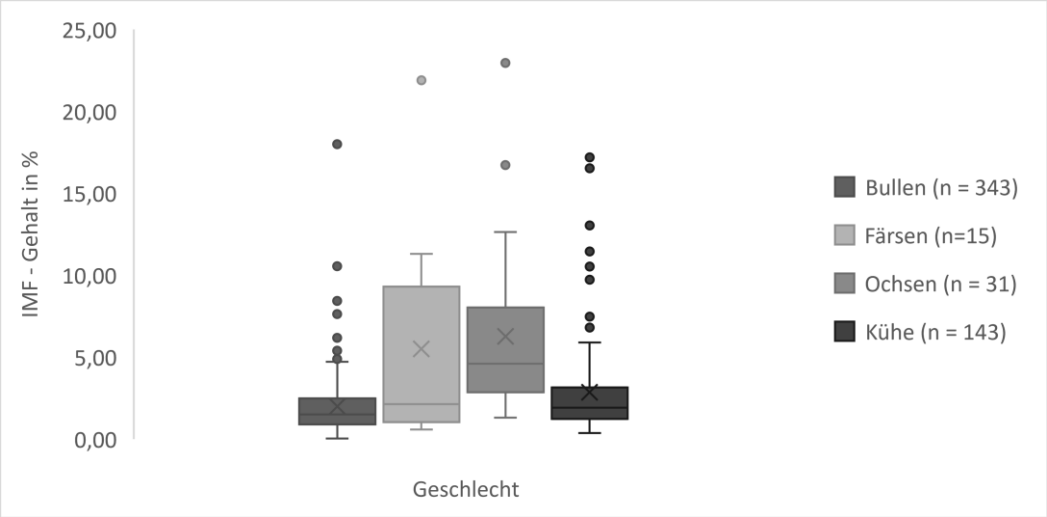

Figure 3.3: Variation of intramuscular fat content (in %) of RHV differentiated by gender (bulls, steers, heifers, cows)
Abbildung 3.3: Variation des IMF in % differenziert nach Geschlecht (Bullen, Ochsen, Färsen und Kühe)

Das Fleisch der Proben von RHV – Bullen wies mittlere IMF-Gehalte von 1,94 % (SD: 1,7 %) auf. Für das Fleisch von Färsen bis 28 Monate wurden mittlere IMF–Gehalte von 4,7 % (SD: 5,8 %) ermittelt. Für die Fleischproben weiblicher Tiere ab 28 Monate resultierten mittlere Gehalte von 2,9 % (SD: 2,9%). Die höchste mittlere IMF-Konzentration von 5,9 % (SD: 4,7%) wurde für Ochsen ermittelt. Die IMF-Gehalte schwankten zwischen 1,31 % und 23 %. Insgesamt lagen 17 Proben von RHV-Tieren über 10 % IMF, dieses Fleisch stammte von 7 Färsen, 5 Ochsen, 3 Kühen und 2 Bullen.

In Tabelle 3.1 wird die Variation der IMF–Werte differenziert nach Betrieb veranschaulicht. Hierbei wurden alle Betriebe berücksichtigt, die mehr als 5 Proben lieferten. Die Variationskoeffizienten zwischen den Betrieben lagen zwischen 0,5 und 1,1.

Table 3.1: Variation coefficients of IMF values differentiated by farm and breeder
Tabelle 3.1: Variationskoeffizienten des IMF differenziert nach Betrieb

	Betrieb												
	RHV 1	RHV 2	RHV 3	RHV 4	RHV 5	RHV 6	RHV 7	RHV 8	RHV 9	RHV 10	RHV 11	RHV 12	RHV 13
Min	1,2	0,6	0,01	2,9	0,4	1,0	1,8	0,4	1,0	0,9	2,9	0,7	0,4
Max	9,3	10,5	7,6	11,7	3,1	12,2	13,0	5,7	8,1	1,4	22,9	6,5	17,2
Mittelwert	2,7	3,8	1,7	7,1	1,8	6,0	6,6	2,3	2,5	1,0	11,1	2,6	3,8
SD	2,7	3,6	1,2	3,3	0,8	3,7	3,8	1,6	2,5	0,2	7,3	1,3	4,2
Variations-koeffizient	1,0	0,9	0,7	0,5	0,5	0,6	0,6	0,7	1,0	0,2	0,7	0,5	1,1

Da die Betriebe aufgrund individueller Schlachtstrukturen nur bedingt auf ihr Fleisch zurückgreifen konnten bzw. als Direktvermarkter bestimmte Schnittführungen vorgegeben waren,sah sich nur ein kleiner Teil der Betriebsleiter in der Lage, Fleisch in der für die Scherkraftmessung erforderlichen Dicke zu liefern. Deshalb konnten nur für insgesamt 60 Proben Scherkraftwerte analysiert werden. Die Ergebnisse sind differenziert nach Geschlecht in Tabelle 3.2 dargestellt. Zwischen dem intramuskulären Fettgehalt und der Scherkraft bestand keine signifikante Korrelation. Der Pearson Korrelationskoeffizient zwischen den IMF – Werte und der Warner-Bratzler Scherkraft betrug r = 0,04.

Table 3.2: Assessed Warner - Bratzler - Shear force values in kp differentiated by gender
Tabelle 3.2.: Gemessene Warner – Bratzer – Scherkraftwerte in kp differenziert nach Geschlecht (Bulle, Ochsen, Färsen)

	Gesamt	Bullen (n=343)	Ochsen (n = 31)	Färsen (n = 14)
Min.	4,3	4,4	5,4	5,4
Max.	15,1	15,1	10,7	8,4
Mittelwert	7,6	7,6	7,3	7,3

In einem generalisierten linearen Modell wurden signifikante Einflüsse von Geschlecht ($P < 0,01$) und Produktionsausrichtung ($P < 0,05$) auf den IMF ermittelt. Das Schlachtalter hatte nur einen tendeziellen Einfluss ($P < 0,06$) auf den IMF–Gehalt. Von den Betrieben als zufälligen Effekt ging kein Einfluss aus ($P > 1,0$). Die Ergebnisse unterstützen die Annahme, dass der intramuskuläre Fettgehalt vor allem durch das Geschlecht beeinflusst wird. Auch die Produktionsrichtung des Betriebes zeigte in der vorliegenden Studie einen signifikanten Einfluss auf den intramuskulären Fettgehalt. Das Modell kann die tatsächlichen Einflussfaktoren allerdings nur in begrenztem Maße erklären, da die Parameter der Fütterung, sowie des betrieblichen Managements etc. nicht umfassend erhoben werden konnten und dementsprechend keine Berücksichtigung fanden.

3.4 Diskussion

3.4.1 Heterogenität der Betriebe

Ziel dieser Studie war es, eine möglichst umfassende und damit repräsentative Stichprobe von Fleischproben von Tieren der Rasse Rotes Höhenvieh zu gewinnen und zu analysieren. Anhand dieser Ergebnisse sollte das Potenzial der Rasse zur Qualitätsfleischerzeugung eruiert werden. Dies erfordert die Berücksichtigung möglichst vieler Betriebe. Dieses Ziel konnte nur teilweise erreicht werden. Zwar konnte ein erheblicher Anteil der RHV-Betriebe ausfindig gemacht und kontaktiert werden. Allerdings verfügten viele RHV-Halter nur über geringe Bestandszahlen ohne Schlachtungen, sodass darauf verzichtet werden musste, diese aufzusuchen.

Die sehr stark heterogene Ausrichtung der Betriebe und RHV-Halter lässt keine allgemeingültige Aussage über das Fleischqualitätsniveau der Rasse zu, sondern lediglich über die Variation des IMF-Gehaltes innerhalb der Population. Eine umfassende Betrachtung des Fleischqualitätsniveaus impliziert weitere Parameter der Fleischqualität wie Safthaltevermögen, pH-Wert, umfasssende Scherkraftanalysen etc. Diese Parameter konnten aufgrund der starken einzelbetrieblichen Variation und den daraus resultierenden logistischen Hindernissen bzw. der unterschiedlichen perimortalen Fleischbehandlung nicht erfasst werden. Eine standardisierte Herangehensweise konnte daher in dieser spezifischen Nutztierpopulation nicht realisiert werden. Dies ergibt sich nicht zuletzt auch dadurch, dass in der praktischen RHV-Haltung keine standardisierten Parameter zur Erfassung von Schlachtkörper- oder sensorischer Fleischqualität angewendet werden. Die unterschiedliche Behandlung der Fleischproben, die der individuellen Vermarktung der Betriebe geschuldet war, verhinderte eine umfassende Bewertung der Fleischproben hinsichtlich der Scherkraft.

Es können lediglich Aussagen über das Potenzial einer zielgerichteten Nutzung getroffen werden, die es ermöglichen würden, ausgewählte Parameter wie den intramuskulären Fettgehalt zu erhöhen, um ein Produkt mit hoher sensorischer Qualität zu erzeugen. Neben der Nutzungsausrichtung unterscheiden sich die Betriebe beträchtlich bezüglich des Managements, der Fütterung, der Zuchtziele sowie der Motivation, die Rasse zu halten.

Hohe Bestandszahlen der Rasse Rotes Höhenvieh waren nicht gleichbedeutend mit hohen Schlachtzahlen. Auch ließen sich aus den Bestandszahlen keine Hinweise auf eine gezielte Ausrichtung des Produktionsverfahrens auf die Fleischerzeugung ableiten. Sowohl die züchterischen Strukturen, die den Zuchttieraustausch und die Schlachttierauswahl bedingten, als auch die Vermarktungsstrukturen führten zu verschiedenen Ausprägungen der Fleischerzeugung und Priorisierungen in Relation zu anderen Einnahmequellen. Die Tierhalter richteten die Verfahrensabläufe nach den Vermarktungswegen in der Direktvermarktung, für den Eigengebrauch oder in wenigen Fällen den Lebensmitteleinzelhandel aus. Auch die Produktionsausrichtung der Betriebe zeigt z.T. Kategorienüberschneidungen, da Betriebe die als Hauptproduktionszweig „Fleischerzeugung“ oder „Zuchtarbeit“ angaben, ebenfalls erhebliche finanzielle Förderung durch die Landschafspflege erhalten.

Die ermittelten IMF-Werte In der Stichprobe konnten die Tierkategorien nicht zu gleichen Anteilen berücksichtigt werden, da von den Landwirten und Tierhaltern vermehrt Fleischproben von Bullen (n= 343) geliefert wurden.

3.4.2 Methodik der Fleischqualitätsbestimmung

In dieser Studie wird vor allem der intramuskuläre Fettgehalt als maßgebliches Merkmal der sensorischen Fleischqualität herangezogen. Das ursprüngliche Ziel, weitere Qualitätsparameter zu erheben, konnte aufgrund der vor Ort angetroffenen Gegebenheiten nicht erreicht werden. Auch die sonst üblichen Parameter der Schlachtkörperqualität wie Schlachtgewichte oder EUROP-Grade finden bei auf den Schlachtbetrieben des Roten Höhenviehs keinerlei Berücksichtigung und konnten deshalb im Rahmen dieser Studie nicht erfasst werden. Dies gilt auch für andere Qualitätsmerkmale wie pH-Wert, Scherkraft etc., da logistische Strukturen der Population dies verunmöglichten. Um zukünftig eine allgemeingültige Aussage über diese Merkmale treffen zu können, müsste eine einheitliche Erfassung dieser Parameter erfolgen.

Generell gilt die nass-chemische Analyse des intramuskulären Fettgehaltes als Goldstandard zur wissenschaftlichen Erfassung dieses Merkmals (Cheng et al., 2015). Darüber hinaus konnte eine Kalibrierung der IMF-Bestimmung über die NIRS-Analyse als schnellere Methode zur Bestimmung dieses Merkmals etabliert werden. Mit einer entsprechenden Kalibrierung gilt auch diese Methode der IMF-Bestimmung als zuverlässig (Prieteo et al., 2006; Prieto et al., 2009; Cheng et al., 2015). Die Ergebnisse der NIRS-Analyse wiesen in dieser Studie hohe Korrelationen zu den Ergebnissen der nass-chemischen Analyse auf, zusätzlich präzisiert die Doppelbestimmung hoher Werte die vorliegenden Ergebnisse.

Der intramuskuläre Fettgehalt korreliert mit dem Marmorierungsgrad von Fleisch. Das Merkmal ist in der Wissenschaft als wertgebendes Kriterium der sensorischen Fleischqualität von Rindfleisch anerkannt (Cheng et al., 2015). Er weist einen engen Zusammenhang mit den Merkmalen der sensorischen Fleischqualität wie Safthaltvermögen, Zartheit und Geschmack auf (Hocquette et al., 2010). Die alleinige Betrachtung des IMFs reduziert die Komplexität der Summe der Fleischqualitätsmerkmale. Die stark unterschiedliche perimortale Behandlung der Proben auf den Betrieben und in den Schlachtstätten selbst verhinderte jedoch die Bestimmung weiterer Fleischqualitätsmerkmale wie pH-Werte, Fleisch- und Fettfarbe, die in erheblichem Maße von der Temperatur und Dauer des Einfrierens bestimmt werden. Die in einer Stichprobe ermittelten Werte für die Scherkraft können deshalb nicht in gleicher Weise verlässliche Aussagen liefern. Zwar wurden auch Scherkraftwerte für diejenigen Proben erfasst, die die erforderliche Dicke von 2,5 cm aufwiesen- Für eine Gesamtaussage ist die Zahl der Proben (n = 60) allerdings nicht hinreichend. Darüber hinaus müssen die Einflüsse der Tiefkühlung bzw. des Auftauens auf die Zartheit bedacht werden. Neben der perimortalen Behandlung hat vor

allem die Reifedauer einen erheblichen Einfluss auf die Zartheit des Fleisches (Frickh et al.; 2004; Velik et al., 2013).

Alle Proben wurden nach Probeneingang einheitlich, d.h. langsam und schonend aufgetaut. Sie wurden in dem Zustand beprobt, in dem sie bei der Mehrheit der Betriebe auch an den Verbraucher verkauft werden. Dennoch kann nicht ausgeschlossen werden, dass die Ergebnisse durch die heterogene perimortale Behandlung der Proben verzerrt wurden. Deshalb sind die Ergebnisse zur Scherkraft-Bestimmung von begrenztem Aussagegehalt.

In Untersuchungen von Dannenberger et al. (2006) wies das Fleisch extensiv- bzw. weidegefütterter Rinder höhere Scherkraftwerte auf. Realini et al. (2004) ermittelten keine Unterschiede in der Zartheit von für Fleisch von Rindern auf Weidehaltung gegenüber Fleisch von Tieren aus kraftfutterbasierter Endmast. Allerdings zeigte sich in dieser Studie insbesondere bei den Fleischproben der Tiere aus Weidehaltung eine maßgebliche Verbesserung der Zartheit nach verlängerter Reifezeit von 14 Tagen.

3.4.3 Intramuskulärer Fettgehalt

Die vorliegenden Ergebnisse der IMF-Gehalte verdeutlichen die erhebliche Variation der Fleischqualitätsmerkmale innerhalb der Population Rotes Höhenvieh sowohl zwischen als auch innerhalb der Betriebe. Die große Variation macht deutlich, dass nicht per se von einer guten Fleischqualität bzw. hohen IMF - Gehalte innerhalb der Rasse ausgegangen werden kann. Hohe IMF-Gehalte zeigen jedoch, dass unter bestimmten Voraussetzungen auch mit dem Roten Höhenvieh Fleisch mit hoher sensorischer Fleischqualität erzeugt werden könnte ieses Potenzial wird derzeit jedoch nicht ausgeschöpft. Der mittlere IMF-Gehalt der RHV-Bullen liegt vergleichsweise niedrig. Dies könnte möglicherweise der sehr extensiven Weidefütterung der Tiere geschuldet sein. Augustini und Tröger (2001) ermittelten für ähnlich extensiv gehaltene Jungbullen der Rassen Shorthorn, Aubrac und Galloway mittlere IMF-Gehalte zwischen 1,3 % und 2,2 %. Im Vergleich ermittelten Hornyak et al (2008) bei 196 Bullen der Rasse Pinzgauer Rind unter intensiven Mastbedingungen mittlere IMF-Gehalte von 2,9 %. Geuder et al. (2012) analysierten für 440 bis 460 Tage alte Bullen der Rasse Fleckvieh (n = 147), Braunvieh (n= 111), Schwarzbunte (n = 131) und Gelbvieh (n = 141) unter ebenfalls intensiven Bedingungen mittlere IMF–Gehalte von 2,57 %, 2,85 % 3,49 % bzw. 2,47 %. Auch wenn die ermittelten durchschnittlichen IMF-Gehalte mitteleuropäischen Verhältnissen entsprechen, liegen sie fern ab von internationalen Qualitätsanforderungen. In den USA werden beispielsweise IMF–Gehalte von deutlich über 10 % angestrebt und auch erreicht (Geuder et al., 2012). In der vorliegenden Studie erreichten diesen Wert lediglich 3,2 % der RHV-

Fleischproben. Die sehr starke Streuung dieses Merkmals zeigt, dass in Einzelfällen hohe IMF-Gehalte möglich sind. Die hohen Werte geben einen Hinweis darauf, dass es ein Potenzial der Rasse zur Qualitätsfleischerzeugung gibt. Um dieses Potential erschließen zu können, bedürfte es entsprechender Voraussetzungen, unter anderem eine gezielte Steuerung und Gestaltung der Einflussfaktoren auf den intramuskulären Fettgehalt Fütterung, Genetik und Geschlecht.

3.4.4 Maßnahmen zur Erhöhung des intramuskulären Fettgehalts

Bereits durch die Wahl der Genetik kann Einfluss auf die Ausprägung des IMF genommen werden. Allerdings treten innerhalb der verschiedenen Rinderrassen erhebliche tierindividuelle Schwankungen in den Fleischqualitätsmerkmalen auf. Dies unterstreichen auch die Ergebnisse der vorliegenden Studie. Eine Möglichkeit zur Einflussnahme auf die Erhöhung des intramuskulären Fettanteils bietet die Kastration oder die gezielte Färsenmast (Frickh et al., 2003; Weissmann et al., 2007). Harper und Pethick (2004) sowie Hocquette et al. (2010) beschreiben die Auswirkungen einer frühzeitigen Kastration auf den intramuskulären Fettanteil. Männliche Tiere sollten bereits früh kastriert werden, damit sich das intramuskuläre Fett früh anreichern kann (Morgan et al., 1993; Branscheid et al., 2007). Diese Annahmen können anhand der vorliegenden Ergebnisse für die Ochsen bestätigt werden. Die höchsten IMF-Gehalte erreichte das RHV-Fleisch von Ochsen, auch die mittleren IMF-Gehalte lagen deutlich über denen der Gesamtpopulation. Dies gilt auch für das Fleisch der Färsen.

Eine weitere bedeutende Option zur Erhöhung des intramuskulären Fettgehaltes ist die zielorientierte Nährstoffversorgung. Die Fleischproben der Tiere in dieser Studie stammen nahezu vollständig von extensiv gehaltenen und gefütterten Tieren, die im Rahmen der Landschaftspflege genutzt und nicht oder kaum zugefüttert wurden. Auf einem Großteil der Betriebe ist das Ertragsniveau bzw. der Nährstoffgehalt des Grünlandes nicht bekannt. Schmutz et al. (2013) bestimmten für 69 Weideochsen der Rassen Simmental und Holstein in verschiedenen Weidesystemen mittlere IMF-Gehalte von 3,89 % bzw. 2.47 %. Reichardt et al. (2006) konnten zeigen, dass durch eine gezielte Kombination der Weide mit Grünfutter oder Anwelksilage in einer geringen Stichprobe von Bullen, Färsen und Ochsen (n = 34) durchaus mittlere IMF-Gehalte von 4,86 % erreicht wurden. In dieser Studie erreichten jedoch auch Färsen (4,85 %) höhere IMF-Gehalte als Ochsen (4,19 %). Velik et al. (2013) ermittelten für gemästete Färsen der Rasse Fleckvieh x Charolais auf Kurzrasenweide und im Stall bei gleichen Tageszunahmen IMF-Gehalte von 2,9 % bzw. 3,5 %. Die Autoren betonen, dass eine gezielte Fütterung für hohe intramuskuläre Fettgehalte nur im Rahmen einer Endmast im Stall umsetzbar ist. Eine solche Lösung könnte auch für das Rote Höhenvieh von Bedeutung sein.

Kiefer et al. (2020) beschreiben die Diskrepanz zwischen den Ansprüchen des Verbrauchers an eine hohe Fleischqualität und den Voraussetzungen, die für eine Qualitätsfleischerzeugung nötig wären. Die Autoren schlagen für eine möglichst effiziente Nutzung der Grünlandressourcen eine dezentrale Lösung mit entsprechenden Sammelstellen für die Endmast vor. Eine solche Lösung könnte möglicherweise auch auf das Rote Höhenvieh übertragbar sein und sollte entsprechend geprüft werden.

Eine gezielte Fütterung zwecks Steigerung der Schlachtleistung und der Schlachtkörperzusammensetzung findet beim Roten Höhenvieh selten statt. Darüber hinaus variieren die Grünlandbedingungen der verschiedenen RHV-Betriebe in erheblichem Maße und sind unter anderem abhängig vom Standort, der Betriebsausrichtung und dem Weidemanagement. Zu einem Großteil wurde Fleisch von RHV-Tieren der bundesweiten Halter der Landschaftspflege bzw. der Naturschutzbeweidung auf stark heterogenen Grünlandflächen analysiert. Diese Flächen unterscheiden sich stark in ihren Einflussfaktoren (Klima, Boden, etc.), aber auch bzgl. der Nutzungsintensität und -form der RHV-Betriebe. Darüber hinaus stehen die RHV-Tiere oft in verschiedenen kleinen Herden verteilt auf verschiedenen Weiden. Im Rahmen dieser Studie konnten diese Flächen nicht aggregiert erfasst werden und deshalb keine Aussagen über die Ertragspotenziale dieser Flächen als Fütterungsgrundlage der RHV-Tiere getroffen werden.

3.4.5 Besonderheiten bedrohter Nutztierpopulationen

Besonderheiten bei der Förderung bedrohter Nutztierrassen ergeben sich immer auch durch die begrenzten Tierzahlen pro Betrieb und in der Gesamtpopulation. Der Fachbeirat Tiergenetische Ressourcen (2012) verweist ausdrücklich darauf, dass der Erhalt genetischer Diversität in Erhaltungspopulationen Vorrang vor einer intensiven Selektion haben sollte. Gleichzeitig sollten die ursprünglichen Nutzungsmöglichkeiten und Produktionsmerkmale der jeweiligen bedrohten Rasse wo möglich, züchterisch verbessert werden. Das Ziel einer erhöhten Fleischqualität könnte jedoch nicht nur durch die Wahl der Genetik, sondern vor allem durch eine entsprechende Fütterungsstrategie bzw. zielgerichtete Managementmaßnahmen wie Kastration etc. auf den Betrieben optimiert werden. Nicht zuletzt durch eine finanzielle Förderung von bis zu 200 Euro je Tier und Jahr in verschiedenen Bundesländern konnten die reinen Bestandszahlen der Rasse RHV in den letzten Jahren erhöht werden. Diese Förderung bezieht sich aber bisher insbesondere auf den reinen Fortbestand der Rasse als Beitrag zur Kulturlandschaft. Bestrebungen zur Etablierung einer wirtschaftlich eigenständigen Qualitätserzeugung sind bisher nicht erkennbar.

Der Wissenschaftliche Beirat für Biodiversität und Genetische Ressourcen des Bundesministeriums für Ernährung und Landwirtschaft (2014) betont, dass im Rahmen eines Erhaltungszuchtprogrammes auch die Steigerung der Wirtschaftlichkeit Berücksichtigung finden sollte. Eine entsprechende finanzielle Förderung sollte wirtschaftliche Nachteile im Vergleich zu leistungsfähigeren Rassen kompensieren. Dabei wird auf die Notwendigkeit neuer Nutzungsstrategien verwiesen, die zu einer Verbesserung der Wirtschaftlichkeit oder aber auch zur Eigenständigkeit einer bedrohten Rasse führen können.

Eine verbesserte Wirtschaftlichkeit bei der Nutzung der Rasse kann nur durch wettbewerbsrelevante Vorteile im Kontext der Nutzung erzielt werden. Bezieht man die aktuellen Motive der Landwirte bei der Entscheidung für die Rasse Rotes Höhenvieh mit ein, wird vor allem deutlich, dass Tiere dieser Rasse vor allem in der finanziell geförderten Landschaftspflege mit Nebenerzeugnis Fleisch eingesetzt werden. Die Landschaftspflege bzw. die Naturschutzbemühungen der Rinderhalter unterscheiden sich jedoch stark in Abhängigkeit der regionalen Gegebenheiten bzgl. Maßnahmen, Vorgaben und Förderung.

Die Kombination extensive Beweidung im Rahmen der Landschaftspflege und Fleischerzeugung lässt häufig keine gezielte Fütterungsstrategie zu, die eine erhöhte sensorische Fleischqualität begünstigen könnte. Dadurch unterliegt die Bedeutung der sensorischen Fleischqualität auf einem Großteil der Betriebe der Entscheidung nach Fördermöglichkeiten für Naturschutznutzung. Das Potenzial der Rasse zur gezielten Erzeugung von qualitativ hochwertigem Fleisch kann unter diesen Rahmenbedingungen nicht erschlossen werden. Zwar sind auch Aspekte der Landschaftspflege mit Hinblick auf die Prozessqualität von hohem Wert, da die Tiere in seminatürlicher Haltungsumwelt gehalten werden und einen Beitrag zu Landschafts- und Naturschutzzwecken leisten. Dieser Aspekt der Prozessqualität gewinnt zunehmend an Bedeutung (Hocquette et al., 2014; Sahlin et al., 2020) und kann für kleinrahmige oder extensive Rinderrassen Vorteile darstellen. Allerdings kann hier nur ein Wettbewerbsvorteil entstehen, wenn das Endprodukt bzw. das Fleischerzeugnis einen nachweislich höheren Genusswert aufweist. Bisher werden keine fortlaufenden Erhebungen zu den Produktionsleistungen und von Parametern der sensorischen Fleischqualität durchgeführt. Damit fehlen wesentliche Voraussetzungen für die Durchführung zielgerichteter Fütterungsstrategien.

Bisher stehen Landschaftspflege- und Naturschutzbestimmungen in ihrer aktuell betriebenen Form häufig im Widerspruch zu einer gezielten qualitätsorientierten Rinderfütterung. Wenngleich aufgrund der Bestandszahlen des Roten Höhenviehs begrenzte Möglichkeiten

bestehen und der Erhalt der Rasse in Zuchtprogrammen immer zu berücksichtigen ist, bietet die Population durchaus die erforderlichen Tierzahlen, um die Weichen für eine gezielte Zuchtarbeit bzw. Ausrichtung auf qualitativ hochwertige Fleischproduktion zu liefern. Eine Neuausrichtung der bisherigen stark extensiven Produktion unter Berücksichtigung der Fleischqualität in Abstimmung mit Landschaftspflegebestimmungen wäre dafür unerlässlich. Auch eine organisierte dezentrale zielgerichtete Endmast könnte die Landschaftspflege bzw. die Weidefütterung sinnvoll ergänzen, um die Ressource Grünland im Rahmen einer Qualitätsfleischerzeugung effizient zu nutzen (Kiefer et al., 2020). Erst wenn die nachgewiesene Fleischqualität in den Fokus der Bemühungen rückt, kann ein Mehrwehrt der Rasse in Kombination mit Naturschutz- und Landschaftspflege zurecht ausgewiesen werden und zeitgleich eine Eigenständigkeit der Rasse befördern. Darüber hinaus rücken Herkunft und Nachhaltigkeit als extrinsische Faktoren der Prozessqualität mehr und mehr in den Verbraucherfokus (Hocquette et al., 2014; Sahlin et al., 2020). Die Kombination des Roten Höhenviehs und der Landschaftspflege bzw. des Naturschutzes könnte unter den Prämissen der zielgerichteten grünlandbasieren Fütterung durchaus als weiterer Faktor der Prozessqualität des Endproduktes Fleisch Berücksichtigung finden und hervorgehoben werden.

Kiefer et al. (2020) kalkulierten für verschiedene deutsche Mittelgebirgsregionen wie dem Harz unter verschiedenen ökonomischen Voraussetzungen angemessenes Potenzial einer Weiderindfleischvermarktung. Sie beschreiben aber zeitgleich auch das Spanungsfeld der reduzieren Tageszunahmen, mangelnder Futterqualität und hohen Aufwand der Weidefütterung. Voraussetzung einer erfolgreichen Kombination der Weide bzw. der Landschaftspflege und der Fleischerzeugung ist allerdings der Nachweis über tatsächliche Erfolge und Optimierungen durch die Landschaftspflege und Naturschutz, sowie der Nachweis erbrachter Produktqualitäten.

3.5 Schlussfolgerungen

Eine abschließende Aussage über die Potenziale der Rasse zur Qualitätsfleischerzeugung ist im Rahmen dieser Studie nicht möglich. Die aktuelle Situation des Roten Höhenviehs ist geprägt von einer großen Heterogenität. Dies betrifft einerseits die betrieblichen Strukturen der Betriebe mit RHV-Genetik, andererseits aber auch die Fütterungsstrategien, die Ausrichtung der Nutzung und die Maßnahmen des Managements im Rahmen der Fleischerzeugung. Diese Heterogenität spiegelt sich ebenfalls in den Ergebnissen der analysierten intramuskulären Fettgehalte des Fleisches wider. Der Genetik Rotes Höhenvieh kann aufgrund der großen Variation der IMF-Gehalte keine Vorzüglichkeit hinsichtlich der Fleischqualität per se zu- oder

abgesprochen werden. Das vollständige Potenzial der Rasse wird derzeit nicht erschlossen. Ohne eine zielgerichtete Steuerung betrieblicher Maßnahmen zur Verbesserung der Fleischqualität ist die Gewährleistung, dass die Käufer von RHV-Fleisch ein hochwertiges Fleisch zu Premiumpreisen einkaufen, nicht gewährleistet.

Für eine erfolgreiche Vermarktung von Fleisch der Rasse Rotes Höhenvieh und auch anderer Rassen, besteht deshalb die Notwendigkeit, die Merkmale der Fleischqualität jedes Schlachtkörpers individuell zu erheben, um eine optimale Weiterverarbeitung und Distribution zu gewährleisten. Einige relevante Aspekte sprechen dafür, dass der Erhalt der Rasse langfristig nur über eine gesteigerte Wertschöpfung durch qualitativ höherwertige Produkte gesichert werden kann.

Förderung

Die Förderung des Projektes erfolgte aus Mitteln des Bundesministeriums für Ernährung und Landwirtschaft (BMEL) aufgrund eines Beschlusses des deutschen Bundestages. Die Projektträgerschaft erfolgte über die Bundesanstalt für Landwirtschaft und Ernährung (BLE) im Rahmen des Programms zur Förderung von Modell- und Demonstrationsvorhaben im Bereich der Erhaltung und innovativen, nachhaltigen Nutzung der biologischen Vielfalt unter den Förderkennzeichen der Justus-Liebig-Universität Gießen (Förderkennzeichen: 2816BM010) und der Universität Kassel (Förderkennzeichen: 2816BM011).

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4 Determining Relationships between Marbling Scores and Carcass Yield Traits of German Beef Bull Carcasses Using Video-Image Analysis at the 12th and 10th Rib Position of Longissimus Thoracis and EUROP Classification

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Abstract

In contrast to other international beef classification systems, the European EUROP system disregards marbling in meat quality assessment. Instead, it focuses primarily on the assessment of conformation and fat score. Due to the lack of more specific assessment, beef quality in Germany is less known than beef produced in other countries and is largely incomparable to international standards. The aim of this study was to explore the potential of Video-Image Analysis (VIA) for the assessment of bull carcasses for the commercial beef market in Germany. Marbling scores and carcass traits of 170 carcasses were assessed at the 10th/11th and 12th/13th rib-eye sections of *M. longissimus dorsi*. Results showed that VIA is able to precisely assess marbling scores at a German cutting position with a close relation (r = 0.83) to the US position. Furthermore, carcass traits integral to the US Yield Grade, such as rib fat (mean 112 mm) and a modified trait of fat/meat ratio, were assessed at the 10th/11th rib-eye position in a process reliably corresponding to the US position (mean 98 mm). EUROP traits showed only weak relationships with marbling scores, VIA measured rib fat thickness, and carcass weights. Although complete validation of video image analysis requires further research with a higher number of test animals, VIA is a viable tool for classifying the variation of German beef carcasses more reliably during the slaughter line and it could valuably supplement EUROP classification traits.

Keywords: Video-Image Analysis; marbling scores; carcass classification

4.1 Introduction

In Germany, the classification of beef carcasses focuses almost exclusively on the European EUROP system, which includes the semi-quantitative estimation of conformation and fat score according to weight, age and sex of animal (Monteils et al., 2017). This system was developed in different European countries as a basis for common trade of carcasses and to have comparability in the amount of saleable meat from each carcass (Verordnung [EWG] Nr. 1208/81). Although limitations and disadvantages of the EUROP concept have been criticized at length for the subjectivity of the assessment and having no link to meat quality traits (Bonny et al., 2016; Przysucha, 2016; Monteils et al., 2017). German industrial beef classification still disregards quality attributes such as marbling scores and the instrumental assessment of carcass traits in the slaughter line. Furthermore, European beef breeders primarily produce highly muscled beef carcasses with moderate fat, which is well known for contradicting sensory quality attributes (Bonny et al., 2016; Monteils et al., 2017).

As the subjective assessment of carcass conformation no longer fulfills the increasing demand for quality attributes on the European market, Bonny et al. (2016) and Monteils et al. (2017) emphasized the need for additional traits and the implementation of objective systems to better classify, and in the long term, increase the value of high-quality beef carcasses within the industrial slaughter line. It is not by accident that marbling has become the determinant trait in international beef grading systems as it is highly correlated to thesensory traits of juiciness, tenderness and flavor of meat (Savell et al., 1987; Wheeler et al., 1994; Cheng et al., 2015). In Australia, Japan, the United States (US), Canada and South Korea, grading systems based on yield and quality grades, including video-image analysis (VIA)-based solutions, have been implemented since the 1980s to assess carcass traits at different rib positions of *M. longissimus dorsi* within the slaughter line without any destruction to the carcass (Allen, 2003; Woerner and Belk, 2008; Jackman et al., 2009; Polkinghorne and Thompson, 2010). As the demand for highly marbled beef increases in Germany, and at least a few European countries are already trying to explore improved grading schemes based on Meat Standards Australia (MSA) (Liu et al., 2020) for the assessment of carcass traits, the need for a viable solution for the assessment of marbling score as well as yield grade is evident.

Besides a general hesitation to include meat quality traits in the EUROP classification system, the use of video-image analysis in the German process line is also hampered by varying cutting positions. While US beef carcasses are ribbed and graded at the $12^{th}/13^{th}$ rib position of *M. longissimus dorsi*, the German beef market does not demand any standard rib-eye cutting

position. Carcass cuts differ due to regional and marketing reasons as well as different processing steps (Craigie et al., 2012). Therefore, comparability of quality and yield traits between European carcasses is not given.

To adapt the VIA system to different cutting systems, information about the comparability of assessed marbling scores at different positions is necessary, but has been insufficiently studied (Harris et al., 1995; Zembayashi and Lunt, 1995; Konarska et al., 2017; Schulz and Sundrum, 2019). Instead, most recent research is concerned with the comparison of intramuscular fat content and visual appraisal of marbling. In a previous study, the correlation of VIA marbling scores at the $10^{th}/11^{th}$ rib-eye position and the $12^{th}/13^{th}$ rib-eye position was assessed on carcasses of young heifers (Schulz and Sundrum, 2019). But as this study included only carcasses of heifers, information about marbling scores of bulls' carcasses representing the German industrial beef market is needed. As the German beef market is mainly dominated by carcasses of young bulls and heifers only represent a small number of carcasses slaughtered in Germany, additional information about marbling scores and yield grade traits from carcasses of bulls which differ in conformation score to optimize the validation of the VIA system is inevitable. The aim of the current study was to explore the use of a VIA system to estimate marbling score and yield grade of young bull carcasses at the cutting positions at the $10^{th}/11^{th}$ rib of *M. longissimus dorsi* in relation to the US cutting position. This position was chosen because older studies indicated that marbling scores at this position had the highest correlations to visual appraisal and intramuscular fat content at the 10^{th}–13^{th} rib position of *M. longissimus dorsi* (Fischer, 1994). Additionally, this position is already established as one of the industrial standardized positions in northern Germany. Furthermore, the relationship between marbling scores and EUROP fat classes and trade grades were analyzed to investigate the usability of EUROP traits for the prediction of beef quality attributes.

4.2 Materials and Methods

4.2.1 Selection of Carcasses

The investigation was carried out at six different dates in a slaughterhouse in the north-east of Germany. The carcasses were those of 300 young bulls of various breeds such as Holstein Friesian, Angus, Simmental, Uckermarker as well as different crossbreds from north-east Germany. They are representative of the different types of young bull carcasses that are slaughtered for the German beef trade. Information about the feeding regime and the housing conditions was not available. Carcass halves were stored between 2 to 7 days at 0-2 °C. Hot

carcass weights ranged from 357 up to 430 kg (mean: 318.4 kg). Animals were between 18 and 28 months old (mean: 22 months). EUROP trade grades and fat classes were estimated by graders at the slaughterhouse. Carcasses were classified with fat classes from 1 to 3+, while trade classes ranged from P to U.

4.2.2 Assessing Marbling Scores and Yield Grades

The left and right halves of the 300 carcasses were ribbed. Marbling scores and yield grades were directly estimated using the VIA-based camera system VBG 2000 (e+v, Oranienburg) at the rib-eye cut between the $10^{th}/11^{th}$ rib interfaces of *M. longissimus dorsi*. All halves were further ribbed to assess marbling scores and yield grades (including meat surface, rib fat thickness and carcass weight) at the US grading position between the $12^{th}/13^{th}$ rib section. The official numerical USDA (United States Department of Agriculture) marbling scores, Practically Devoid (100-199) Traces (200-299) Slight (300-399), Small (400-499), Modest (500–599), Moderate (600-699) and Slightly Abundant (700-799), were used. Assessment of the yield grades at the $12^{th}/13^{th}$ rib-eye section included the parameters of hot carcass weight, measured subcutaneous fat thickness and rib-eye area using the established yield formula of VBG 2000.

VBG 2000 was initially created to classify US beef carcasses. It is a camera-based system with special lighting to photograph the rib-eye. It is positioned at the spinal channel, the ribs and the meat All measurements were taken on the same flat surface. Images of each rib-eye were linked to processing software. The images erroneously included the outside area of the rib-eye musculus spinalis because of its different size at the $10^{th}/11^{th}$ rib-eye section. Software predictors and colour values of VBG 2000 were generated for the larger $12^{th}/13^{th}$ rib-eye position. Therefore, it was later necessary to modify the digital estimation thresholds and colour values with the developer of VBG 2000 (e+v, Oranienburg, Germany).

The process line and the butchers were not familiar with the new cutting position and the changed size of the rib-eye, resulting in improper cuts of the meat surface. Thus, 126 of the 300 selected carcasses could not be assessed in the slaughterhouse. A correct camera assessment requires a very accurate cut but as this was not always provided, it was not possible to capture all carcasses in pictures. Consequently, with some carcasses, not all parameters could be reliably assessed. In total, complete data could be assessed for 174 carcasses.

VBG 2000 usually includes kidney pelvic heart (KPH) fat as a yield parameter but this was not possible to assess at the 10^{th} rib position in the current study because there was no occasion to

scan the whole carcass. Furthermore, the rib-eye size at the 10th/11th rib-eye position could not be determined precisely in this investigation due to the inaccurate rib-eye cut. Instead, the images were segmented into pixels of beef and fat and the ratio of beef pixels/fat pixels in the defined surface of rib-eye muscle was calculated to better determine the amount of saleable beef in the muscle (Figure 4.1 left image). In all cases, yield grade at the 10th/11th rib-eye section was assessed retrospectively with a modified formula adapted to the modified image thresholds:

25.1088 + hot carcass weight x 0.002488168 + number of meat pixels - 16.72879
+ meat/fat ratio x 0.4330382 + number of fat pixels 23 x 0.01327071
+ number of meat pixels x 0.001183337 + number of fat pixels 12 x 0.1445752

Rib fat thickness was measured at the same position as the US position (Figure1).

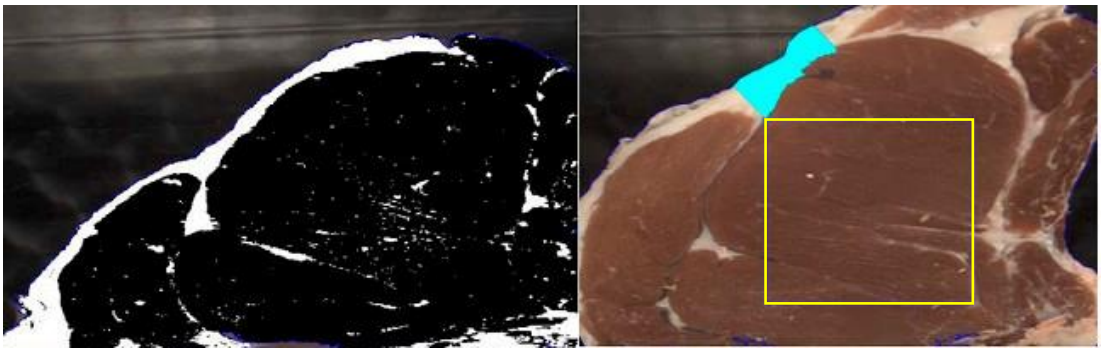

Figure 4.1: Visualisation of the segmentation of meat and fat pixels (left) and the stardized position of the assessment of rib eye fat thickness at the 10th / 11th rib position (right)

4.2.3 Statistical Analysis

After grading in the slaughterhouse, the slaughter data of carcasses was linked with assessed EUROP trade grades and information about breed, weight, age and sex. Statistical analysis was carried out using SPSS (version 19.0, IBM Inc., Ehningen, Germany). EUROP trade grades and fat classes (1 to 4) were conformed numerically from E to P into a 15-point scale, using the upper (+) and lower (-) categories (Schulz and Sundrum, 2019). Pearson correlation coefficients were calculated for marbling score at both positions, EUROP trade grade and fat class, slaughter weight, subcutaneous fat (rib fat thickness) yield grades at both positions and calculated fat/meat ratio determined by the described formula.

4.3 Results

Estimated marbling scores and results from the assessment of main carcass traits are given in Table 4.1. In total, yield grade traits and marbling scores of 170 carcasses were assessed. The

marbling scores ranged from 228 to 803 at the US position and from 200.2 to 942 at the $10^{th}/11^{th}$ rib position. Average marbling scores at the $12^{th}/13^{th}$ rib position

(392) were comparable to those at the $10^{th}/11^{th}$ rib position (385). The differences between the marbling scores at both positions ranged between 139 and 118 marbling points. 107 of the carcasses had higher marbling scores at the $12^{th}/13^{th}$ rib eye section. Only four carcasses were categorized in the different trade classes Prime, Choice or Select, at the two different positions. All in all, the calculated yield grades showed similar results at both positions. Subcutaneous fat was slightly higher at the $10^{th}/11^{th}$ rib position than at the$12^{th}/13^{th}$ rib position.

Table 4.1: Assessed marbling scores and measured carcass traits

	Marbling $10^{th}/11^{th}$ rib position	**Marbling $12^{th}/13^{th}$ rib position**	**YG $10^{th}/11^{th}$ rib position**	**YG $12^{th}/13^{th}$ rib position**	**Subcutaneous Fat $10^{th/}11^{th}$ rib position (cm)**	**Subcutaneous Fat $12^{th}/13^{th}$ rib position (cm)**
Mean	385	392	2.0	2.0	1.12	0.98
Min	200	228	1	1	0.27	0.27
Max	943	803	3.8	3.9	2.57	1.92
SD	76.6	76.8	0.7	0.4	0.52	0.41

SD = Standard deviation

Pearson correlation coefficients of all carcass traits are shown in Table 4.2. Close and significant relations were calculated between marbling scores at the $10^{th}/11^{th}$ and the $12^{th}/13^{th}$ rib position of *M. longissimus dorsi* (r = 0.82** and R = 0.64). The correlation of marbling scores at both positions is highly significant.

Table 4.2: Pearson correlation coefficients of the assessed carcass traits

	Marbling 10. / 11.	**Marbling 12. / 13.**	**age**	**YG 10. / 11.**	**YG 12. / 13.**	**Rib fat 10 / 11.**	**Rib fat 12. / 13.**	**weight**	**EUROP trade**	**EUROP fat**
Marbling 10. / 11.	1.00	0.82**	0.09	0.15	0.04	0.12	0.04	-0.04	-0.48	-0.04
Marbling 12. / 13.		1.00	0.09	0.16	0.10	0.07	0.07	0.03	-0.36	-0.21
Age			1.00	-0.09	-0.12*	0.04	0.15	-0.14	0.27	-0.27
YG 10. / 11.				1.00	00.65**	0.33**	0.46**	0.27**	0.03	-0.41
YG 12. / 13.					1.00	0.37**	0.41**	0.41**	-0.04	-0.52
Rib fat 10. / 11.						1.00	0.37**	0.40**	0.75	-0.52
Rib fat 12. / 13.							1.00	0.17*	0.43	-0.41
weight								1.00	0.64	-0.28
EUROP trade									1.00	-0.36
EUROP fat										1.00

** = $p < 0.01$

* = $p < 0.05$

The distribution of marbling scores at both positions is visualized in Figure 4.2. The mean difference of marbling scores at both positions was 5 marbling points (SD: 46). The differences

between both positions varied between 93 and 193 marbling points. With higher marbling scores (>800), the differences between marbling scores at the two positions increased. In general, the distribution of grading categories Select, Choice and Prime were only slightly influenced by the different positions. In total, 8 carcasses were categorized into different categories according to the rib-eye position. Marbling scores and EUROP fat classes showed no relationship at the German position (r = 0.1) and slightly negative relationships at the US position (r =-0.2). EUROP trade grades and marbling scores showed slightly negative correlation coefficients at the US rib position (r = -0.36) and at the $10^{th}/11^{th}$ rib position (r = -0.04). Furthermore, weak negative relationships were found for subcutaneous fat at both positions and EUROP fat classes (r = -0.41 and r = -0.52).

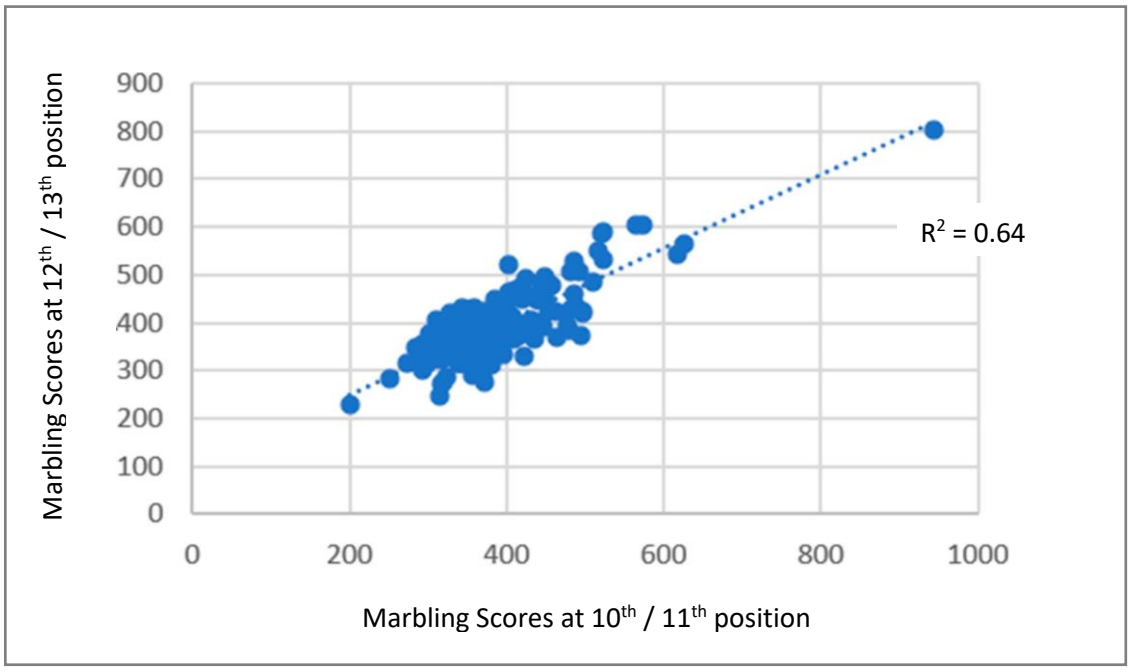

Figure 4.2: Distribution of marbling scores at the 10^{th} / 11^{th} and the 12^{th} / 13^{th} rib-eye position

Discussion

4.4.1 Methodology

The main object of this study was to assess the marbling level of carcasses from young bulls produced for the German beef market. This study included only 174 carcasses of bulls and the selection of the sample was limited. It needs to be increased to a representative sample of German bull carcasses. However, the very heterogeneous nature of the sample enabled comparisons of the results of VIA at different positions in a wide variation of carcasses.

Furthermore, when butchers are not familiar with the different cuts, and when the process line is not adapted to the US rib-eye cutting systems, training for accurate rib-eye cutting is essential.

In the current study, a high number (n = 126) of carcasses could not be assessed because of the lack of cutting routines. In future, this obstacle could be easily solved by adapting the slaughter line and the VIA hardware to focus on the $10^{th}/11^{th}$ rib section and training slaughterers. Other international beef grading systems show that new cuts can be quickly learned and routinely adapted into the slaughter line. To develop and validate a general formula, the VBG 2000 camera has to be adapted to the different size of the $10^{th}/11^{th}$ rib position to reduce the type of placement errors which occurred in the current study and further research has to be conducted. The assessment of marbling scores using VBG 2000 has been validated in earlier studies with high accuracy and repeatability at the 12^{th} rib-eye position (Woerner and Belk, 2008; Moore et al., 2010; Dow et al., 2011; Emerson et al., 2013). VBG 2000 showed close relationships (r = 0.94 and r = 0.84) with the chemical analysis of Intramuscular fat content (IMF) (Vote et al., 2009; Dow et al., 2011). The close correlations of marbling scores at the $10^{th}/11^{th}$ rib-eye position and the $12^{th}/13^{th}$ rib-eye position in this study are in accordance with the results of a recent explorative investigation using VBG 2000 at these two positions (Schulz and Sundrum, 2019). In contrast, Konarska et al. (2017) compared French and Polish beef carcasses at different muscles using near-infrared spectroscopy and image analysis based on Beef Analyzer II Software. The results of trained graders using the USDA marbling scores and the Australian grades reached a lower correlation coefficient (r = 0.53) between the different positions. The authors emphasized that the prediction of marbling at one position might be used for the classification of the entire carcass quality, but the variation of marbling between different positions needs to be considered. Vote et al. (2009) used BeefCam, a technique that is based on VIA (n = 288) to classify Uruguayan beef carcasses at the 10^{th} rib-eye section and explored the use of self-created software to assess marbling scores at the $12^{th}/13^{th}$ rib position. The authors concluded that marbling could not be estimated precisely with the applied equipment. Considering the high correlations of assessed marbling scores at both positions in the current study, VBG 2000 could be easily used to assess marbling scores at the 10^{th} rib with high comparability to the US position, although the threshold borders of rib-eye would have to be adapted to the different rib-eye size at the $10^{th}/11^{th}$ rib-eye position.

4.4.2 Marbling Scores

The marbling scores assessed by VIA at both rib positions in this investigation were slightly higher than marbling scores of young bull carcasses that were assessed at the 10^{th} rib position

using the Australian MSA grading scheme with trained graders (Liu et al., 2020). The comparison of the results with other assessed marbling scores is difficult as there are only a few studies about VIA-assessed marbling scores of young bull carcasses. Carcasses from bulls are mostly classified using EUROP traits or intramuscular fat content. Although VIA marbling scores and the analysis of intramuscular fat content reached high correlations (Emerson et al., 2013; Dow et al., 2011), visual marbling and intramuscular fat content describe different carcass traits. Fiems et al. (2000) investigated very low mean values for the amount of intramuscular fat content at the 8th rib section of *M. longissimus dorsi* for double-muscled bulls (0.9 %) and higher mean values for non-double-muscled bulls of different Belgian breeds (3.0 %) that had higher carcass weights (413 kg) than in the current study. Yang et al. (2006) found low intramuscular fat contents (2.5 %) of German Charolais crossbreeds and German Holstein bulls. In contrast to a recent study (Schulz and Sundrum, 2019), the assessed marbling scores were slightly higher at the 12th/13th rib-eye section. In the same recent investigation (Schulz and Sundrum, 2019), carcasses of young German heifers of different breeds reached slightly lower marbling scores than in the current study assessed with VBG 2000 at the 10th/11th rib-eye position of *M. longissimus dorsi*. However, the authors emphasized the low quality of the German carcasses in comparison to carcasses used in US studies with larger samples (Schulz and Sundrum, 2019). Based on the large number of studies which emphasize that heifers and steers tend to show higher marbling scores than bulls (Harper and Pethick, 2004), these differences may be explained by the very low quality of the assessed carcasses from these particular heifers.

The variation of marbling scores (385 to 942 marbling points) obtained in the current study was higher than that found in other studies (Schulz and Sundrum, 2019). This is mainly due to the targeted heterogeneity of the carcass samples to include beef and dairy cattle of different age and slaughter weight, and deriving from different farms and genotypes. Although the carcasses were heterogeneous, they were all produced for the German beef market and reflect high inconsistency in beef quality. Thus, the need for viable tools to standardly assess and classify the different marbling levels of German carcasses is obvious.

EUROP fat classes showed only weak correlations with the marbling scores at both positions. In accordance with this, a study done by Bonny et al. (2016) indicated that EUROP fat classes were not useful for predicting sensory eating quality traits. In contrast, Schulz and Sundrum (2019) found higher correlations between visually assessed EUROP fat classes and VIA-assessed marbling scores of carcasses from heifers at the 10$^{th/}$11th rib position

(r = 0.40) and the US position (r = 0.36). Konarska et al. (2017) determined slightly lower correlations (r = 0.30) between EUROP fat class and MSA marbling scores of male and female beef and dairy breed carcasses at the 12th/13th rib-eye section. In the current study, EUROP trade grades showed even higher correlations with marbling scores than with EUROP fat classes. Since the relationships between the degree of marbling and the amount of fat of the whole carcass have been discussed at length (Oslage, 1975), weak relations between EUROP fat class and marbling were expected. However, the precision of EUROP fat classes is not sufficiently guaranteed. The current results support the conclusions made by others (Allen, 2010; Bonny et al., 2016; Konarska et al., 2017; Monteils et al., 2017; Liu et al., 2020) that EUROP traits are not suitable for classifying beef quality attributes and need to be modified.

4.4.3 Yield Grades

The European classification system of beef focuses on the estimation of subcutaneous fat and muscling of the carcass. The question arose as to whether this system could be modified to improve classification of European carcasses. At German abattoirs, quantifying KPH-fat and rib-eye size is not part of the routine. Therefore, the parameters describing the yield grade of carcasses using VIA had to be modified and are, thus, not directly equivalent to the results obtained by the US approach. Furthermore, it must be considered that the absence of an accurate rib-eye cut, a necessity for the VIA assessment, hampered the assessment in the slaughter line.

Carcasses assessed in the current study had similar carcass weights to those in recent studies with European beef breeds (Alberti et al., 2008). In contrast, variation of slaughter age was higher than in other studies (Chambaz et al., 2003; Alberti et al., 2008). Although targeted for heterogeneity, the carcasses were randomly chosen in a commercial slaughterhouse and the results represent a typical sample of carcasses produced for the German beef market. Measured rib fat thickness varied widely between the different positions. Rib fat thickness measurements at the 12th rib positions in the current study were slightly higher than in other studies on beef steers (Devitt et al., 2001) and lower than on carcasses on Yearling bulls measured at the 12th rib position. In contrast, rib fat at the 10th rib position was lower than in a comparable study (Devitt et al., 2001). Weak correlations between the measured rib fat thickness at both positions highlighted the variation of fat distribution in muscles, which corresponds with the results in other studies (Konarska et al., 2017).

Calculated correlation coefficients showed positive trends between EUROP trade grade and the yield grade, but weak negative correlations between EUROP fat class and subcutaneous fat at both positions. In contrast, weaker positive relations for measured rib fat and EUROP fat class

for bulls (r = 0.47), heifers (r = 0.5) and steers (r = 0.4) were found by Liu et al. (2020). While a weak relationship between the graded fat class and the measured subcutaneous fat was expected, the results of the current study indicate that the measurement of subcutaneous fat thickness might replace subjective grading of the EUROP fat score. As rib fatness can be easily measured by VIA at the rib-eye positions, the implementation of VIA-measured rib fat in European classification systems would be useful in classifying carcasses in a more objective and reliable way. Correlations between measured subcutaneous fat at both rib positions were lower (r = 0.65) than correlations between marbling scores (r = 0.8), but highly significant. Considering its high precision and the reliable use of VIA as the gold standard in US grading systems, results of measured rib fat thickness may easily supplement the subjective EUROP grading system. However, this does not provide information for predicting the meat quality of carcasses (Konarska et al., 2017).

The current study explored only a few traits that are included in US yield grading. Since the European classification contains different parameters to those used in other international beef grading schemes, a complete adoption of the American system is not necessary. Rather, it is a matter of integrating important parameters, such as marbling and rib fat, into the classification in order to supplement EUROP traits and enrich the information about qualitative aspects of carcasses used in processing and marketing strategies. Classifying the different quality levels may lead to an adapted distribution of carcasses according to the different requirements of the various markets, processors or consumers in the process line (Rahmann et al., 2020).
Considering the fact that other studies already emphasize the high accuracy of VIA in predicting carcass traits (Moore et al., 2010; Dow et al., 2011; Emerson et al., 2013), the implementation of VIA in European classification systems is highly recommendable, if not essential.

Given the standardized use of VIA in international grading systems as well as the importance of qualifying sensory traits of beef carcasses, the need for modification to the European classification system is evident. The given VIA system and other comparable solutions might be usable in different sizes of abattoirs and at different levels of industrialization. Given the long use of VIA in international grading systems, its adaptation to different slaughterhouses might be easy.

The VIA system not only considers EUROP traits such as carcass weight and fat thickness, it also enables, in contrast to the subjective EUROP fat score graders, a highly objective assessment of fat scores at the rib-eye section. Due to its objective assessment of carcass traits, classification and, in a further step, categorization of carcasses could become easier and more

reliable using VIA. Currently, there is insufficient knowledge about meat quality in carcasses of fattened bulls raised in Germany and thus a lack of quality differentiation. This lack, together with the large variation in the composition of German beef, calls for an objective assessment of the quality of every single carcass. This assessment might be undertaken using different methods of assessment, but finally, different evaluation methods need to be comparable. This would provide pertinent information about quality differences and set highly marbled carcasses apart from average quality carcasses.

Further, a standardized assessment of beef quality would allow both better classification of carcasses and differentiation of quality traits during the slaughter line process. As the demand for highly marbled beef increases, the European beef market must produce beef which satisfies demands for various levels of quality.

4.5 Conclusions

The EUROP classification system of beef carcasses does not include the assessment of marbling as a pertinent quality trait. Although further research including larger samples of carcasses from different regions is needed, the results of the current study showed that the VIA-based system can assess the marbling scores of bull carcasses at the 10th rib position of *M. longissimus dorsi* that correspond to the US position. Considering its long use as the gold standard and the high accuracy of VIA in international beef classification, this system could also be a viable solution for the European beef market to assess marbling as well as the conformation score and yield grade of European beef carcasses in a profound and objective way. Modification to the EUROP classification scheme is highly recommended to better differentiate the high variation of beef carcass traits and, consequently, support quality-orientated beef production.

Acknowledgment

Author Contributions: Conceptualization: L.S. and A.S.; methodology: L.S., A.S.; investigation: L.S. and A.S.; data curation: L.S.; writing - original draft preparation: L.S.; writing—review and editing: A.S.; visualization: L.S.; supervision: A.S.; project administration: L.S. and A.S.; funding acquisition:

A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This project was funded by Block Stiftung “Pro Qualität 5 522125”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons of the involved companies.

Acknowledgments: This project was highly supported by Block House and the Block Foods Stiftung. The authors would like to express their gratitude to K. H. Kraemer, T. Naber and L. Reese (Block House) who shared their valuable experience and lead to this research. All of this research was carried out with the VBG 2000 system and software by e+v. This software and statistical formula was created and validated by A. Abomoharam, R. Rothe and H. Eger. R. Heisterkamp (Danish Crown, Teterow) supported this research in the Danish Crown abbatoir.

Conflicts of Interest: The authors declare no conflict of interest.

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5 Marbling Scores of Beef Can Be Increased by Purposive Feeding Regimes

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Abstract

The aim of the study was to assess possible impacts of different feeding regimes on the marbling score of beef. Feeding regimes included a high protein diet (HP), enriched with UDP 5 in the finishing phase of beef cattle, a high energy diet (HE), enriched with starch during the so-called marbling window (< day 250), and the combination of both regimes. In the first feeding trial, 122 Uckermärker heifers were allocated during the finishing phase into three groups. Animals in the control treatment were offered a control diet (CD) with a low UDP content, while the two experimental treatments received diets with either a moderate (MP) or a high portion (HP) of UDP. In a second trial, 192 heifers were allocated after weaning into four treatments. In two feeding groups the diet was enriched with energy during the marbling window while the other two groups received a control diet. In the finishing phase, one of the two experimental and control groups was fed with a high UDP 5 diet (HP) or with the control diet (CD), previously offered in trial I. Marbling scores of carcasses were assessed using image analysis for rib eye measurements. The design of the experiment was based on the hypothesis that an energy-enriched diet during the marbling window supports an increase in marbling scores, assuming that the adipocytes are filled with fatty acids that derive from undegraded glucoplastic amino acids in UDP 5 fraction. Carcasses showed significantly higher marbling scores when the heifers were fed with moderate and high UDP 5 diets in the finishing phase. The values even increased when the heifers received a diet enriched with energy during the marbling window after weaning. Presumably, this feeding regime is suited to support the differentiation of stem cells to adipocytes during this phase. The results of both trials gave reasons to conclude that the marbling score in beef cattle can be particularly increased by a high energy feeding in the marbling window combined with high portions of UDP 5 in finishing phase as part of a purposive feeding regime.

Keywords: beef quality**;** Video Image Analysis; marbling scores; heifers

5.1 Introduction

Marbling describes the visual distribution of intramuscular fat content within a muscle cross-section and is highly correlated to sensory traits of beef such as juiciness, tenderness and meat flavor (Cheng et al., 2015). Marbling of beef is generally accepted as the best determiner of sensory beef quality and therefore became an integrated part of many international beef grading systems (Polkinghorne and Thompson, 2010; Cheng et al., 2015). However, marbling is still not considered as a classification parameter in the European beef grading system, despite consumers showing an increasing awareness of the relevance of marbling for the taste of roasted beef (Hocquette et al., 2014). The degree of marbling is influenced by various factors such as sex, genotype, and age of the animal at slaughter. For example, carcasses of heifers and steers generally show higher marbling scores than carcasses of bulls (Harper et al., 2004; Hocquette et al., 2009). With regard to genotype, numerous studies have shown that less muscular beef breeds tend to have higher marbling scores or intramuscular fat content (IMF) than highly muscular breeds. Moreover, there are reasons to assume that one of the most important factors to increase marbling is a feeding strategy purposely designed to support the adipogenesis of cattle within the different fattening periods (Hocquette et al., 2009). The role of myogenesis and adipogenesis in muscle and fat cell development has been described by Du, et al. (2013). Intramuscular adipocytes have their origin in common mesenchymal stem cells or progenitor cells. Differentiation into various cells with different functions such as fibroblastic and myogenic cells can be influenced by the availability of appropriate substrates in the sensible phases of the development.

In cattle, adipocytes in muscles develop mainly during the marbling window between late gestation and day 250 after birth (Du et al., 2010). In the further course of growth and liveweight gains, these cells can be filled with substrate which they can transform into and store as fatty acids, inducing a hypertrophy of the cells (Leibel et al., 1989; Hocquette et al., 2014). To produce beef with a high content of intramuscular fat, feeding regimes are required that increase the differentiation of adipocytes, which increase their volume in the finishing phase when being filled with fatty acids (Harper et al., 2004). However, such feeding regimes have to be implemented with caution in order to prevent an over-acceleration of fat into the subcutaneous and visceral fat tissues, which would counteract the aim of producing a lean carcass.

On the other hand, various insights into the effects of protein supply on intramuscular fat content have been gained in pork production. For instance, Essen-Gustavsson et al. (1994) and D'Sousa et al. (2003) revealed that a deficiency of essential amino acids (Isoleucine, Leucine,

Lysine, Methionine, Phenylalanine, Threonine, Tryptophan and Valine) may increase intramuscular fat content in pigs. Other studies showed that combining comparably low levels of essential amino acids with a high level of glucoplastic amino acids (Alanine, Arginine, Asparagine, Aspartic acid, Cysteine, Glutamic acid, Glutamine, Glycine, Histidine, Methionine, Proline, Serine and Valine) caused a significant increase in the intramuscular fat content of pork without increasing the subcutaneous fat content of the carcass (Sundrum et al., 2000; Sundrum et al., 2011). The authors assumed that the surplus of glucoplastic amino acids was transformed into fatty acids in intramuscular adipocytes but not into subcutaneous adipocytes. This hypothesis was confirmed, among others, by Hu et al. (2017), who were successful in increasing the intramuscular fat content of pigs without simultaneously increasing subcutaneous fat by supplementing diets with arginine and glutamic acids.

The results of such specifically adapted feeding regimes in fattening pigs raised the question whether the effect of increasing hypertrophy of adipocytes by increasing the supply of glucoplastic amino acids within UDP 5 (rumen undegradable protein in crude protein (CP) assuming a passage from the forestomach of 5 % per hour) could also apply for beef cattle. So far, little is known about options to affect performance and carcass characteristics of beef cattle in the fattening period through different protein sources (Sami et al., 2009; Duarte et al., 2011). In ruminants, impacts of crude protein on the intermediary metabolism are leveled out by fermentation processes of the microbes in the rumen. Thus, a direct effect of protein content is most likely to be expected in the amount of undegradable protein (UDP 5) in the rumen.

It was hypothesized that an energy supply during the marbling window (up to day 250) in combination with an increased UDP 5 supply in the later finishing fattening period of heifers might lead to increased intramuscular fat storage translated into a higher marbling score without provoking increased back-fat thickness. Therefore, two different feeding trials were conducted. The first focused on the effect of UDP 5 supplementation in the finishing phase. In the second trial, animals were supplied with an energy enriched diet during the marbling window. The effect of this feeding regime was assessed separately and in combination with an increased UDP 5 supply in the finishing phase of heifers.

5.2 Materials and Methods

5.2.1 Experiment design

The trial was conducted in two steps. An overview of the experiment design is given in Figure 5.1. Both trials were conducted with Uckermärker heifers due to an industrial beef quality program referring to regional beef breeds.

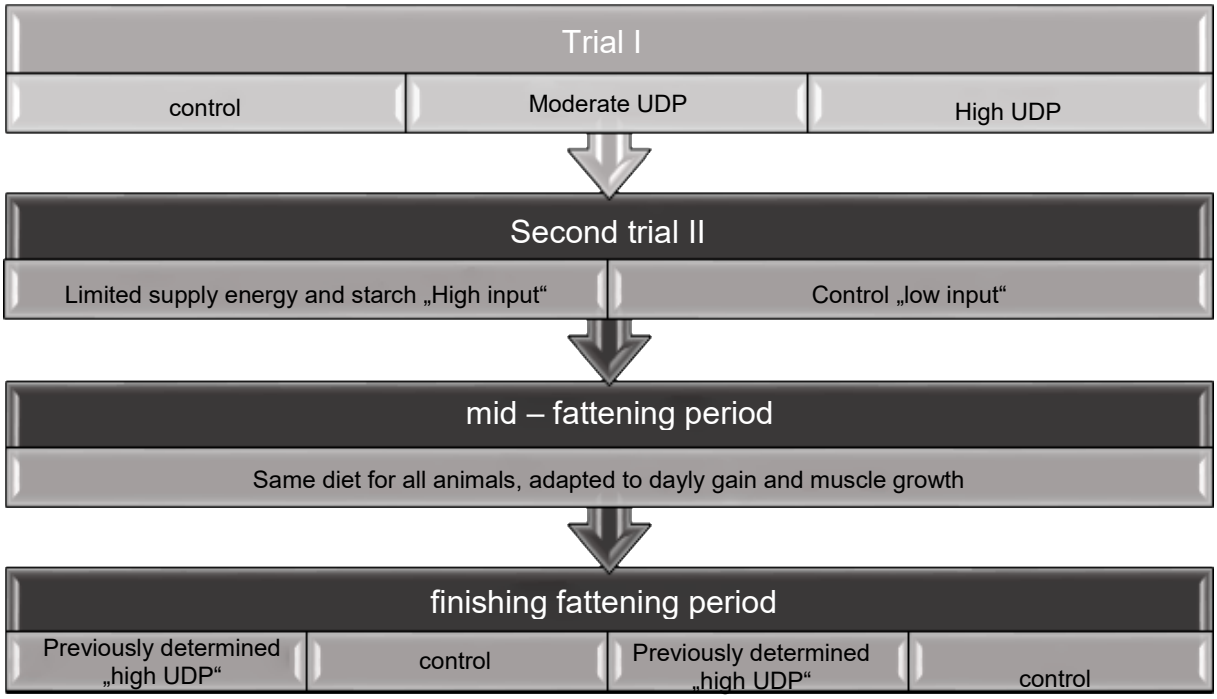


Figure 5.1: Visualization of experimental set up of trial I and trial II.

Before the beginning of the trial, all animals were fed with the same maize-based diet. Trial I was set up as a precursor test to assess the effect of different portions of UDP 5 in the diet during the finishing fattening phase on the marbling score. 122 Uckermärker heifers were randomly allocated into three treatments and fed with isocaloric diets that differed in their UDP 5 content (Table 5.1).

Table 5.1: Dry matter diet ingredients and chemical composition of three feeding groups in the trial I (finishing fattening period).

Ingredients	Control (CD) (n = 42)	Moderate UDP (MP) (n = 39)	High UDP (HP) (n = 41)
Grass silage (kg)	5.5	2.5	1
Maize silage (kg)	4	5.5	4
Faba beans (kg)	1.2	--	--
Alfalfa pellets (kg)	--	1.5	4
Lupine (kg)	--	1	0.5
Rape seed meal (kg)	--	--	1
Mineral premix	0.2	0.2	0.2
Total (kg)	10.9	10.7	10.7
Chemical Composition			
MJ ME	106	108	109
Crude protein CP (g)	1378	1435	2162
UDP 5 (g / animal / day)	313	382	704
UDP % of CP	22.6	26.6	32.6
Crude fiber CF (g / animal / d)	2571	2380	2117

Composition of maize silage: 11.0 MJ ME/kg DM | 69 g CP/kg DM | 19.3 g UDP 5/kg DM/28 % UDP 5/kg CP | GAA*: 56.7 g/16 g N
Composition of grass silage: 8 MJ ME/kg DM | 132 g CP/kg DM 26,.,4 g UDP /kg DM/20 % UDP 5/kg CP | GAA: 69.2 g/16 g N
Composition of alfalfa pellets : 9.4 MJ ME/kg DM | 253 g CP/kg DM 91.1 g UDP 5/kg DM/36 % UDP 5/kg CP | GAA: 56.7 g/16 g N
Composition of lupine: 13.6 MJ ME/kg/DM 346 g CP/kg DM | 72.6 g UDP/kg DM/21 % UDP 5/kg CP | GAA: 70 .4 g/16 g N
Composition of rape seed 13.3 MJ ME/kg DM | 569 g CP/kg DM | 199.1 g UDP 5/kg DM/35 % UDP 5/kg CP | GAA: 64.9 g/16 g N
Composition of faba beans: 14.8 MJME/kg DM | 376 g CP/kg DM | 94 g UDP 5/kg DM/18 % UDP 5/kg CP | GAA: 63.9 g/16 g N .

*) GAA: amount of glucoplastic Amino Acids in total feeding diet (including Alanine, Arginine, Aspartic Acid, Glutamine, Glycine, Histidine, Methionine, Proline, Serine, Valine, calculation among nutrition values of Heuzé et al. (2016; 2017; 2018; 2019; 2019a).

All diet ingredients were analyzed for chemical composition and UDP 5 content. The finishing fattening period started at the mean age of 450 days and lasted until the mean age of 600 days. At the start of the finishing period, ultrasonic assessment of back-fat thickness was carried out at the 10^{th} – 13^{th} rib position of *M. longissimus dorsi*. Live weights were assessed in an interval of 6 to 8 weeks.

To meet the energy requirements, the protein source of the control group was replaced by faba beans, which contain only low amounts of UDP 5.

In trial II, 192 Uckermärker heifers were allocated after weaning during the so-called marbling window (day 180 - day 250) into two feeding treatments. Diets of these treatments are presented in Table 5.2.

Table 5.2: Different feeding groups of trial II during marbling window (day 180 – day 250) with ingredients and chemical composition in dry matter**.** Dry matter diet ingredients and chemical composition of three feeding groups in trial II during marbling window (day 180-day 250)

Ingredients	Low Energy (LE) (n = 92)	High Energy (HE) (n = 100)
Grass silage (kg)	4.0	1
Maize silage (kg)	3.0	5.0
Rape seed meal (kg)	0.5	1.0
Faba beans (kg)	--	1.0
Mineral premix (kg)	0.2	0.2
Total:	7.6	8.1
	Chemical composition	
MJ ME	71.6	81.1
Crude protein	1019.5	1377.0
Crude fiber	1821.6	1423.4
Fat (g)	135.8	282.2
starch	920.3	1952.2

Composition of maize silage: 11.0 MJ ME/kg DM ǀ 69 g CP/kg DM ǀ 19,3 g UDP 5/kg DM ǀ 28 % UDP/kg CP
Composition of grass silage: 8 MJ ME/kg DM ǀ 132 g CP/kg DM ǀ 26, 4 g UDP 5/kg DM ǀ 20 % UDP/kg CP
Composition of lupine: 13.6 MJ ME/kg/DM ǀ 346 g CP/kg DM ǀ 72.6 g UDP 5/kg DM ǀ 21 % UDP/kg CP
Composition of rape seed meal: 13.3 MJ ME/kg DM ǀ 569 g CP/kg DM ǀ 199.1 g UDP 5/kg DM ǀ 35 % UDP/kg CP
Composition of faba beans: 14.8 MJME/kg DM ǀ 376 g CP/kg DM ǀ 75 g UDP 5/kg DM ǀ 18 % UDP/kg CP .

The first group “High Energy” (HE; n = 100) was fed with an energy diet (81MJ ME) enriched with starch. The control group “Low Energy” (LE; n = 92) was fed a diet with a lower energy content (71.6 MJ ME). In the second period (mid - fattening), animals of both groups were fed according to their needs and growth with the same grass silage based diet.

During the final fattening period, the groups of the HE and LE treatments were each sub-divided into two groups: one with a high UDP 5 amount, which had been identified as effective in trial I (HP), and a control group (LP) with a low amount of UDP 5 (Table 5.3).

Table 5.3: Different feeding groups of trial II during the finishing fattening period . Dry matter diet ingredients and chemical composition of feeding groups in trial II in the finishing fattening period.

Ingredients	Control (HE – LP and LE – LP)	High UDP (HE – HP and LE – HP)
Grass silage (kg)	5.4	1.0
Alfalfa pellets		4.0
Maize silage (kg)	4.5	4.0
Rape seed meal (kg)	--	1.0
Faba beans (kg)	0.2	--
Lupine (kg)		0.5
Mineral premix (kg)	0.2	0.2
Total:	10.3	10.7
	Chemical composition	
MJ ME	105	110
Crude protein	1259	2001
UDP 5	286	679
UDP 5 % of CP	23	34
Crude fiber	2191	2327
GAA*) (g/kg DM)	277	439

Composition of maize silage: 11.0 MJ ME/kg DM ǀ 69 g XP C/kg DM ǀ 19.3 g UDP 5/kg DM ǀ 28 % UDP/kg CP ǀ GAA*: 56.7 g/16 g N
Composition of grass silage: 9.7 MJ ME/kg DM ǀ 166 g CP/kg DM ǀ 35.2 g UDP 5/kg DM ǀ 15 % UDP/kg CP ǀ GAA: 69.2 g/16 g N
Composition of alfalfa pellets : 9 MJ ME/kg DM ǀ 204 g CP/kg DM ǀ 91.1 g UDP 5/kg DM ǀ 29 % UDP/kg CP ǀ GAA: 56.7 g/kg DM
Composition of lupine: 13.6 MJ ME/kg/DM ǀ 348 g CP/kg DM ǀ 72.6 g UDP 5/kg DM/21 % UDP/kg CP ǀ GAA: 56.7 g/16 g N
Composition of rape seed meal 13.3 MJ ME/kg DM ǀ 569 g CP/kg DM ǀ 199.1 g UDP 5/kg DM/35 % UDP/kg CP ǀ GAA: 64.3 g/16 g N
Composition of faba beans: 14.8 MJME/kg DM ǀ 376 g CP/kg DM ǀ 75 g UDP/kg DM ǀ 18 % UDP 5/kg CP ǀ GAA: 63.9 g/16 g N .

*) GAA: amount of glucoplastic Amino Acids (including Alanine, Arginine, Aspartic Acids, Glutamine, Glycine, Histidine, Methionine, Proline, Serine, Valine, Tryptophane) calculation among nutrition values of Heuzé et al. (2017, 2018, 2019). Characterization of diets: low energy vs. high energy diets (LE and HE) and low UDP vs. high UDP diets (L_UDP and H_UDP)

At the start of the finishing period, ultrasonic assessment of back-fat thickness was carried out at the 10^{th} – 13^{th} rib section of *M. longissimus dorsi*. The animals were weighed every 6 to 8 weeks from day 180.

5.2.2 Assessment of amounts of amino acids in feeding groups

The assessment of the amounts of glucoplastic amino acids in the different feeding groups was based on the nutritional tables of feeding ingredients created by Heuzé et al. (2017, 2018 2019).

The following formula was used:

$$GAA^{1}\ (g/kg\ DM) = AA^{2}\ (g/16g\ N)/100 * UDP\ 5\ (g/kg\ DM) * XP\ (g/)\ kg\ DM.$$

[1]= Glucoplastic Amino Acids
[2]= Amino Acid

A chemical analysis of the amino acid profiles of various feeding ingredients was not carried out.

5.2.3 Slaughtering process

In both trials, the heifers were slaughtered at the mean age of 630 ± 48 days in the same abbatoir. Carcasses were graded according to EUROP criteria by trained graders. Pathological findings of all carcasses were assessed by the same veterinarian on all slaughtering days at the abattoir immediately after slaughtering in a standardized process.

5.2.4 VIA – Analysis to assess marbling scores in both trials

Marbling scores and back-fat thickness of the rib eye of all carcasses were assessed using the Video – Image Analysis (VIA) system VBG 2000 (e+v, Oranienburg). VBG 2000 is based on a camera and lighting system that photographs the rib eye area at fixed points such as spinal channel, ribs and surface of meat. As the VBG 2000 system was initially created for the grading of US beef carcasses, the system uses the official numerical USDA Marbling Scores "Practically Devoid" (0 – 99), "Traces" (200 – 299), "Slight" (300 – 399), "Small" (400 – 499), "Modest" (500 – 599), "Moderate" (600 – 699) and "Slightly Abundant" (700 – 799). Carcasses were ribbed, and marbling and rib-fat thickness were assessed in either the left or right carcass halves at the $10^{th}/11^{th}$ rib eye position of *M. longissimus dorsi*. As the size of the camera was created for the assessment of marbling at the $12^{th}/13^{th}$ rib position, digital thresholds had to be modified and adapted to the 10^{th} rib eye section with the VIA creator after slaughterhouse (Schulz and Sundrum, 2019; Schulz and Sundrum, 2021).

5.2.5 Statistical Analysis

Statistical analysis was carried out with IBM SPSS20 and Microsoft Excel. Possible differences between the marbling scores of the different feeding groups were analyzed using one-way ANOVA analysis. As the analysis of variance showed significant differences between the groups, LSD post hoc test was applied (multiple comparison of means). Pearson correlation coefficients were calculated for the traits EUROP trade grade and EUROP fat class, marbling in left and right carcass halves, slaughter weight and VIA-assessed back-fat thickness. EUROP

grades were transformed numerically in relation to the upper (+) and lower (-) categories of EUROP (Schulz and Sundrum, 2019). Carcasses were weighed at the slaughterhouse.

5.3 Results

5.3.1 Results of Trial I

Slaughter data of carcasses from different feeding groups of trial I is presented in Table 5.4.

Table 5.4: Carcass data including slaughter weights and EUROP classification of trial I animals differentiated by feeding diet

Ingredients		**Control (CD)**	**Moderate UDP (MP)**	**High UDP (HP)**
Average Slaughter weight (SD)		352.6 (23.7)	354.4 (24.6)	356.9 (23.4)
No. of carcasses classified in EUROP trade classes				
	U	7	6	10
	R	35	33	31
No. of carcasses classified in EUROP Fat classes				
	2	--	1	--
	3	23	23	27
	4	19	14	14
	5	--	1	--
Ultrasonic back-fat thickness before feeding trial start in mm				
	Min	10.5	9.6	10.5
	Max	16.4	16.9	23
	Mean	13.4	13.1	13.4
VIA assessed subcutaneous fat of rib eye in mm				
	Min	10.5	7	7
	Max	30	30	40
	Mean	16.2	16.2	18.5

At the beginning of trial I, all animals showed a similar back-fat thickness before the finishing fattening period in all groups. The highest variation of slaughter weights revealed in the group with the highest UDP 5 amount (Mean 356.9, 284 kg to 403 kg SD: 23.7). The highest variation in EUROP fat classification was found in the moderate UDP 5 diet group. Most U - classified carcasses appeared in the high UDP 5 group. Mean values of back-fat thickness differed between the experimental groups but were similar between the control and the moderate UDP 5 diet group. The highest variation of VIA - assessed back-fat thickness at the rib eye position

was found in the high UDP 5 diet group. Results of ANOVA emerged no significant differences in carcass weights and rib-fat between the groups. Pearson correlation coefficients showed only weak correlations (r = 0.1) between marbling scores and rib - fat thickness. No significant correlation (r = -0.005) was detected between the visually - assessed EUROP fat class and VIA - assessed back - fat thickness.

Marbling scores and live weight development of trial I

Live weight development of animals and marbling scores of trial I are presented in Figure 5.2a and 5.2b.

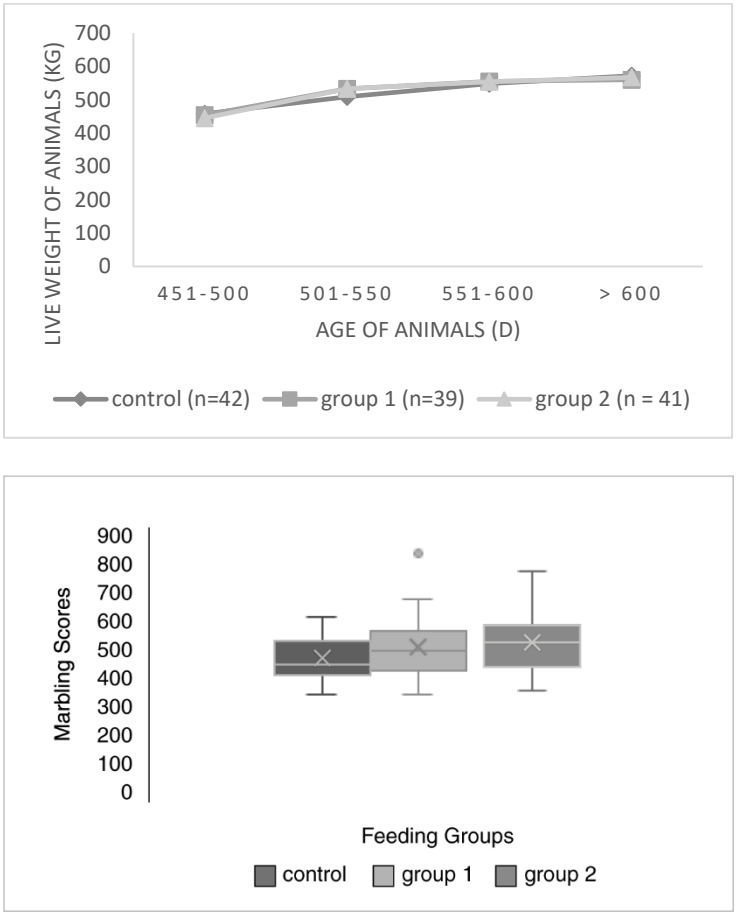


Figure 5.2: Live weight development during the finishing fattening period in trial 1 (a) and marbling scores of carcasses in trial I (b) differentiated by feeding group (group 1: moderate M_UDP diet; group 2: High H_UDP diet)

The highest marbling scores were found in the group of heifers fed the H_UDP diet (Mean 512.9: SD:85.0), followed by those animals supplied with the M_UDP diet (509.2: SD: 109.3). In contrast, the animals in the control group achieved the lowest values (Mean: 478.4: SD: 85.0). The highest variation of marbling scores occurred in the MP diet group.

In CD, 87.8 % of halves of carcasses were graded as Choice or better (> 400), 86.8 % in group I and 93.7 %. in group II. The results of ANOVA showed significant differences between all three groups ($p < 0.05$). General significant differences ($p < 0.05$) between the CD and MP treatments, and between the CD and HP diet treatments were explained by the LSD post hoc test.

5.3.2 Results of Trial II

Slaughter data of carcasses in trial II is shown in Table 5.5.

Table 5.5 Carcass data including slaughter weights and EUROP classification of heifers in trial II differentiated by the feeding regime.

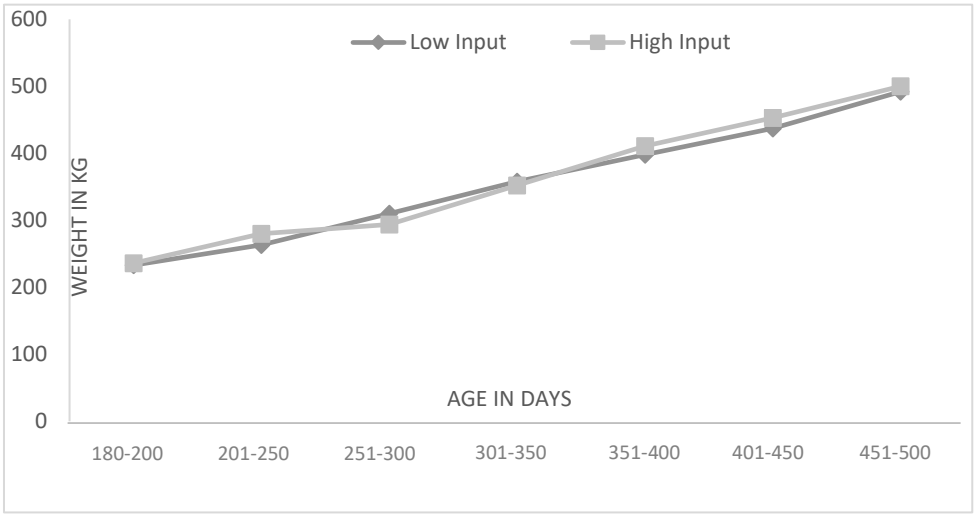
	Low Energy		High Energy	
	Group I LE-LP *(n = 50)*	**Group II LE-HP *(n=42)***	**Group III HE-LP (n = 51)**	**Group IV HE-HP (n = 49)**
Average Slaughter weight in kg (SD)	342.6 (19.6)	342.1 (16.7)	330.7 (23.4)	352.1 (19.5)
No. of carcasses classified EUROP trade classes				
U	18	20	20	32
R	32	22	31	17
No. of carcasses classified in EUROP Fat class				
2	1	2	3	17
3	44	28	36	32
4	5	12	12	--
Ultrasonic back-fat thickness before late fattening period in mm (SD)	26.3 (3.4)	26.5 (4.1)	24.1 (4.2)	20.4 (4.4)
VIA assessed subcutaneous fat of rib eye in mm	Min: 1 Max: 24 Mean: 11	Min: 6 Max: 37 Mean: 16	Min: 0.3 Max: 34 Mean: 13	Min: 3 Max: 29 Mean: 15

Carcasses of heifers fed with a low-energy diet during the marbling window had similar mean slaughter weights. In contrast, carcass weights of the high energy groups ranged from 330 kg to 252 kg. The highest mean slaughter weights were reached by the animals of the HE – HP treatment, while the HE – LP group gained the lowest slaughter weights. ANOVA and LSD post hoc test revealed significant differences between all groups except between LE – LP and

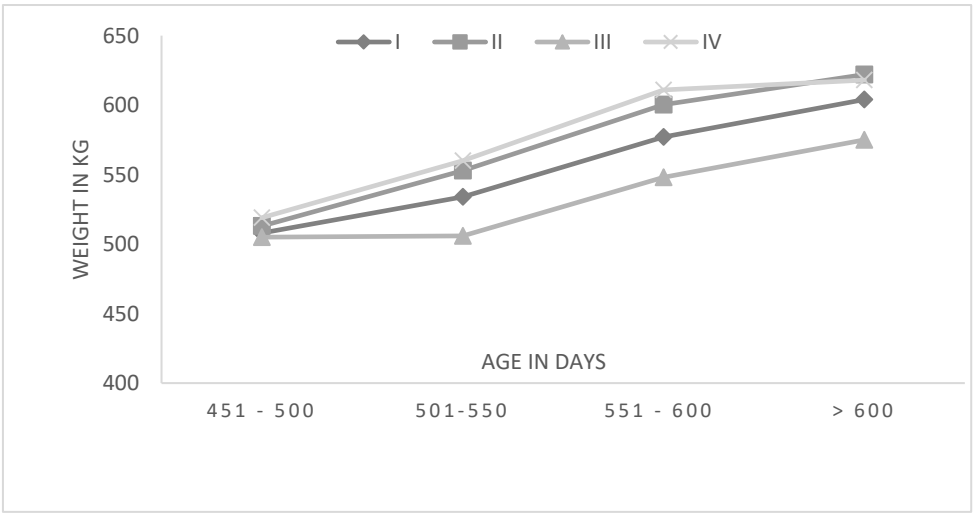
HE – HP , and LE – HP and HE – LP for the rib-fat trait. Calculated ANOVA results for the comparison of slaughter weights between all groups showed no significant differences.

Live weight development of animals in trial II

Live weight development of animals in trial II is presented in Figure 5.3a and 5.3b.



a)



b)

Figure 5.3: Live weight development of animals in Trial II in the HE and LE treatment from day 180 - 250 (a) that were then separated (b) into Treatment I: HE - LP, Treatment II: HE - HP, Treatment III: LE - LP and Treatment IV: LE - HP from day 450 - 600.

During the marbling window, the fattening animals of HE treatment averaged higher daily gains in live weight (1221 g/day) than those of the low energy treatment (1084 g/day). After day 250, the LE group reached slightly higher live weights than the HE treatment. At the age of 450 days, all animals had similar mean live weights of 505 kg (LE) and 513 kg (HE). After

separating the animals into subgroups, HP treatments averaged higher live weights than the LP treatments. During the whole finishing fattening period, HE - LP reached the lowest live weights. At the end of trial, animals in this group achieved a mean live weight of 575 kg. In contrast, the mean live weights of the other treatments differed only slightly between 622 kg (LE – HP), 618 kg (HE – HP) and 604 kg (LE – LP).

Marbling scores of carcasses in trial II

Variation of assessed marbling scores of trial II is visualized in Figure 5.4.

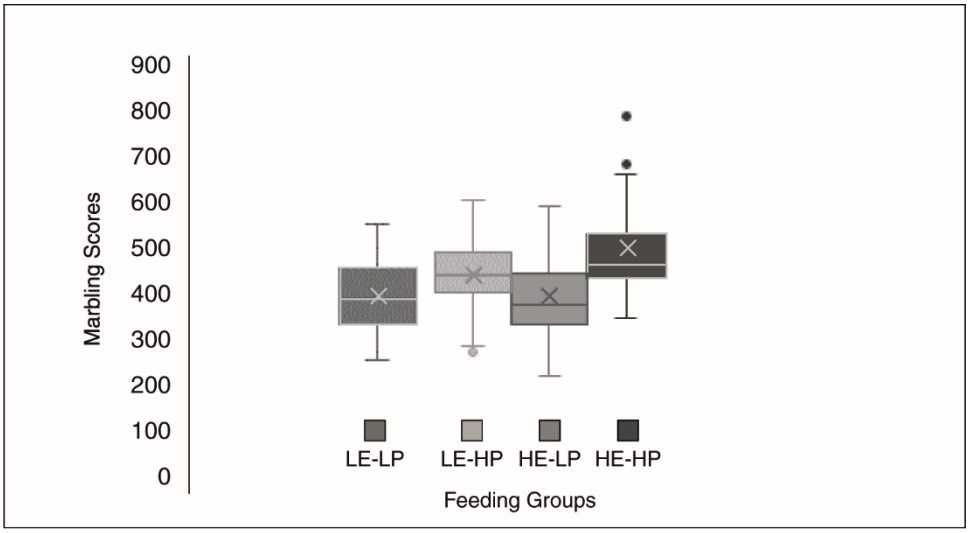


Figure 5.4: VIA assessed marbling scores in trial II *) Treatment LE - LP: Low Energy – Low UDP (n = 50) Treatment LE-HP: Low Energy High UDP (n = 42) | Treatment HE - LP: High Energy – Low UDP (n = 51) | Treatment HE-HP: High Energy – High UDP (n = 49)

Mean marbling scores of the assessed rib eyes reached 387 (SD: 75.7) in treatmet I (LE - LP), 442 (SD: 67.1) in treatment II (LE – HP), 393 (SD: 78.8) in treatment III (HE – LP) and 480 (SD: 79.1) in treatment IV (HE – HP). Highest variations of marbling scores were found in treatment IV (HE– HP) (345-787) and treatment II (LE – HP) (270.7 - 605). Graded halves of heifer carcasses from treatment IV (HE – HP) also achieved the highest number (88.6 %) of Choice (> 400 marbling score), followed by treatment II/LE – HP) (76.2 %), treatment IV (HE – HP) (48 %) and treatment I (LE – LP) (42.7 %). In trial II, results of ANOVA showed significant differences in marbling scores between treatments ($p < 0.05$). The subsequent post hoc test showed significant differences (<0.05) between all treatments except between treatment I (LE – LP) and treatment III (HE – HP).

The results of the calculated Pearson correlation coefficients of the carcass traits and marbling scores differentiated by halves are given in Table 5.6.

Table 5.6. Pearson correlation coefficients of different carcass traits

	Marbling left	Marbling right	VIA back-fat left	VIA back-fat right	EUROP trade grade	EUROP fat class	carcass weight
Marbling left	1.0	0.8	0.3	0.1	0.2	-0.2	0.2
Marbling right		1.0	0.3	0.1	0.2	-0.2	0.3
VIA back-fat left			1.0	0.7	0.2	-0.4	0.2
VIA back-fat right				1.0	0.1	-0.3	0.1
EUROP trade grade					1.0	-0.2	0.5
EUROP fat class						1.0	-0.2
Carcass weight							1.0

Highest correlations between left and right halves of carcasses were revealed in VIA-assessed marbling scores. Visually-assessed EUROP fat class showed negative correlations with all other traits. Apart from EUROP trade grade, carcass slaughter weights showed only weak relationships to marbling scores.

5.4 Discussion

5.4.1 Marbling grades

Marbling of beef is influenced by various factors. The current study aimed to validate the potentials of purposive feeding regimes to improve the development of marbling in heifers. Actually, European beef carcasses are graded and paid using the EUROP grading scheme that focuses mainly on muscularity and subcutaneous fat. The calculated correlations showed no relation between subjectively assessed EUROP trade grades and fat classes. Weaknesses of subjective EUROP grading have been discussed at length (Monteils et al., 2017) and evidenced by various studies (Bonny et al., 2016; Schulz and Sundrum, 2019; Liu et al., 2020; Schulz and Sundrum 2021). Therefore, EUROP traits are no appropriate indicators of sensory beef quality attributes.

In Germany, beef cuts, and therefore the standardized position to assess marbling scores, are different from those in the US. Variation of marbling within different muscles has been investigated by Konarska et al (2017). To compare the quality and the slaughter value of different beef carcasses, a standardized measuring position is highly recommended. To make use of the VIA system VBG 2000, which is accepted as the standard procedure in the US to assess marbling scores (USDA, 2006), the assessment of marbling scores at the German cutting

position at the 10th rib position was validated with reference to the US cutting position. In recent studies, high correlations (> 0.8) between the 10th rib and 12th rib position were established for VBG 2000 marbling scores in heifers and bulls (Schulz and Sundrum 2019; Schulz and Sundrum, 2021). Thus, the assessed marbling scores and VIA-assessed back-fat thicknesses of the current study can be classified as reliable even though the VBG2000 camera was initially created for the 12th rib eye section.

The trials were carried out with Uckermärker heifers, a beef breed chosen for the industrial beef market. Heifers tend to marble more highly than bulls (Hocquette et al., 2009; Park et al., 2018). Nevertheless, effects of the presented feeding diets have to be validated in further studies encompassing bulls and/or steers as well as other breeds of cattle.

5.4.2 Level of assessed marbling scores

Studies, in which the levels of beef quality of European beef carcasses were assessed, are limited and therefore also the possibility of comparing marbling scores. In a recent study, the mean VIA-assessed marbling scores of other beef samples of heifer carcasses at the 10th/11th rib section of *M. longissimus dorsi* carcasses were lower (Schulz et al., 2019) than marbling scores of the current sample. Carcasses in the current study derived from one farm and were thus more homogeneous. Liu et al. (2020) determined average marbling scores of 330 and average carcass weights of 305 kg by using the Australian Meat Standards at the 10th rib position of *M. longissimus dorsi* in 129 carcasses of young heifers of different European breeds under 32 months. Rezac et al. (2014) gathered data of more than 13,000 US cattle in feedlots including steers and heifers and reported mean VIA marbling scores of 433 at the 12th/13th rib of *M. longissimus dorsi*.

5.4.3 Effect of feedings regime in the final fattening period

In both trials, hypertrophic effects during the finishing fattening period were supported with high UDP diets during the finishing fattening period. The high UDP feeding diet investigated in trial I led to significantly higher marbling scores and was validated by the results in trial II. Carcasses of the High Energy and high UDP 5 diet reached higher marbling scores than the Low Energy and High UDP 5 groups. The results are in accordance with those of previous studies (Harper et al., 2004; Hocquette et al., 2009). Results of feeding trials with pigs gave reason for the assumption that an acceleration of intramuscular fat by increasing the supply with non-essential amino acids might also be achieved in beef cattle. Hu et al. (2017) found that the supply of arginine and glutamic acid diets led to increased intramuscular fat contents in

carcasses of finishing pigs. Hyuen et al. (2007) indicated interactions between lysine and leucine for the accretion of IMF in pigs and suggested that the ratio of essential and non – essential amino acids might play an important role in increasing IMF. In general, carcasses of trial II animals had slightly lower marbling scores than carcasses in trial I but were still higher than marbling scores of comparable studies (Liu et al., 2020).

In contrast, Duarte et al. (2011) found no significant effects of different levels of UDP 5 (48.8 % and 27.2 % of crude protein) and no interaction of UDP 5 with high or low energy level in carcass traits of twenty Zebu crossbred heifers fattened in feedlots. In this study, the diets included mainly different amounts of soybean meal and very high amounts of maize silage and corn grains. The authors emphasized that the duration of their feeding trials (each feeding period 28 days) might have been insufficient to show significant effects of UDP 5 on quality characteristics of carcasses.

The different UDP 5 diets in the finishing fattening period were offered for at least 150 days. There are reasons to suggest that increased supplies of glucoplastic amino acids are used as substrates for intramuscular fat storage (hypertrophy) during the finishing fattening period. This effect was repeated and therefore validated in the two feeding trials.

The high amount of UDP 5 in the current feeding diets was achieved by the supply of heat-treated alfalfa pellets, lupines and rape-seed meal. In these diets, lupines contributed the highest amount of glucoplastic amino acids (70.4 g/16 g N), while alfalfa provided a higher amount of UDP 5. The given results suggest that the effect of intramuscular fat cell hypertrophy might be induced by an increased amount of glucoplastic amino acids in UDP 5. They also demonstrate that the feeding groups with high calculated amounts of glucoplastic amino acids show significantly higher marbling scores than those with lower glucoplastic amino acids.

The number of Choice graded carcasses in the different groups varied more widely in trial II than in trial I. As carcasses in group HE_H_UDP (High energy and High protein in the finishing fattening period) reached significantly higher marbling scores than the other treatments, the effect on heifers of a purpose-designed feeding regime with a high UDP 5 amount deriving from the combination of alfalfa–pellets, rape-seed meal and lupine was confirmed. Sami et al. (2010) found similar intramuscular fat contents (IMF) (2.2 % IMF to 2.5 % IMF) in carcasses of Simmental bulls that were fed with other protein sources such as lupine, rape-seed meal and soybean meal. Blanco et al. (2010) investigated effects of different diets on carcass composition in a small sample of Spanish bulls fed diets containing alfalfa (n = 21). Catrileo et al. (2014) compared Holstein Friesian bulls fed with concentrated diets containing high amounts of lupine (n = 14) with forage-fed bulls and detected significant effects on IMF in the former (1.94 % and

0.9 %, respectively). They found highest IMF in carcasses of those animals that were fed with alfalfa grazing as main protein source in the first fattening period and combined with a concentrate-based diet in the finishing fattening period. However, these studies focused on the supply of crude protein, whereas the UDP 5 content was not analyzed and information about the amount of glucoplastic amino acids was missing.

5.4.4 Effect of feeding regime during the marbling window

The results of the study show that effects of supply with energy during the marbling window increased marbling grades of beef carcasses. The heifers in the current study were fed with a high or low energy diet from an age of 180 – 250 days. This period includes only the last period of the marbling window as defined by Du et al (2013). Moreover, the role of the marbling window has been mainly investigated in studies involving Angus and Wagyu or crossbreds of these breeds (Wertz et al., 2001; Corah et al., 2007). Pyatt et al. (2005) assessed influences during the marbling window until day 250 in Simmental steers. So far knowledge about the influences of marbling window in beef cattle is limited and it is not clear, if different genotypes influence the role of marbling window. The trials in the current study were carried out with heifers of a large-framed beef breed which tend to show higher muscularity than Angus or Wagyu in the early fattening period. Further research might explore the feeding effects on marbling window during an earlier age of animals to investigate if the effects can be validated or broadened. Assessed rib eye fat was similar among the animals of the different feeding groups in trial I but differed between the feeding groups in trial II. However, due to the reduced quality of grass silage, these feeding groups received a high amount of maize silage during the marbling window. This suggests that the subcutaneous back-fat thickness might be reduced by an optimized density of energy involving high quality feed ingredients.

5.4.5 Effect of combined feeding regimes

In the second trial, a significant effect of the combination of a high energy diet during the marbling window period and a high UDP 5 diet in the finishing fattening period emerged. This supports the hypothesis that IMF development results from a balance between hyperplasia and hypertrophy (Hocquette et al., 2014), but also increases due to the adipocytes growing in volume (Hocquette et al., 2009). Park et al. (2018) reported that hypertrophy represents a larger contributor to IMF than hyperplasia after day 250. When aiming to increase marbling through feeding strategies, the effects of both need to be considered. The marbling scores in group low energy and high UDP 5 were lower than in group high energy and high UPD 5, which possibly suggests that the combination of both feeding strategies could lead to highest marbling scores.

It was suspected, that an increased energy supply during the marbling window (up to day 250) in combination with an increased UDP 5 supply in the later finishing fattening period of heifers might lead to increased intramuscular fat storage without provoking increased back-fat thickness. Our study affirms the role of the marbling window (Du et al., 2013) combined with a high UDP 5 amount in the finishing period in increasing marbling.

Li et al. (2014) investigated effects of diets differing in energy amount during the marbling window and portions of crude protein (11.9 % and 14.3 %) in the later fattening period on Angus x Chinese Xiangxi yellow steers (n = 23) and heifers (n = 24). The authors revealed higher IMF content in the rib eyes of animals fed with a high energy diet (28.4 % and 27.7 % IMF) than those supplied with a low energy diet (18.5 % and 22.4 % IMF). The crude protein in the later fattening periods did not influence intramuscular fat content. However, this study focused on the role of crude protein in increasing intramuscular fat content without considering the UDP 5 content.

To produce beef with high marbling scores, the feeding regime proved to be a relevant factor in influencing the accumulation of intramuscular fat cells that are later filled with substrate to increase in volume during the late fattening period. Therefore, a feeding diet aimed at increasing marbling should consider these two effects of adipogenesis. Due to the complexity of purposive feeding of fattening heifers, it has to be emphasized, that practical strategies must consider more than one of the main parameters that influence marbling to obtain high sensory beef quality. The current study was carried out with Uckermärker heifers. In general, heifers are expected to reach higher marbling scores than bulls (Hocquette et al., 2009) and Uckermärker heifers also have the tendency to produce carcasses with high muscularity. While marbling scores in the feeding group high energy and high UDP 5 differed significantly from the other groups , the results indicate potentials to improve marbling scores by a purposive feeding regime.

5.5 Conclusions

Purposive feeding regimes provide options to improve the quality of beef. The results of the study revealed that a combination feeding regimes which considers the effects of both high energy input during the marbling window and a high amount of UDP 5 in the finishing period of heifers have the highest potential to increase marbling scores in beef. Further studies are required to assess the potentials of feeding regimes on the level and the variation of marbling scores under different initial and boundary conditions.

Author Contributions: Conceptualization, L.S.; methodology, L.S.; validation, L.B..; formal analysis, L.S., E.S..; investigation, L.S., A.P., L.B. A.S..; resources, L.S., L.B, A.P., A.S..; data curation, L.S., A.P.; writing—original draft preparation, L.S.; writing—review and editing, L.B., A.P., E.S., A.S.; visualization, L.S., supervision, A.S.,; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript."

Funding: This research was funded by Stiftung Block as part of the research project Pro - Qualität grant number 5522125.

Institutional Review Board Statement: This study was carried out in accordance with the Head of Department Landesamt für Arbeitsschutz, Verbraucherschutz und Gesundheit (LAVG) Brandenburg respecting the animal ARRIVE guidelines of animal welfare and was officially stored with identification number 2340-40-2019.

Acknowledgments: This work was part of the project "Pro – Qualität" that was funded by the Stiftung Block. The authors would like to express their gratitude to K.-H. Krämer, T. Naber, L. Reese, O. Renn and D. van der Reith. All of this research was carried out with the VBG 2000 system and software of e+v, Oranienburg. This software and statistical formula were created and validated by A. Abomoharam, R. Rothe and H. Eger.

Conflicts of Interest: The authors declare no conflict of interest.

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6 General Discussion

One of the main aims of this thesis was to assess the variation of marbling and intramuscular fat content of beef and, in a second step, to validate possible influencing factors that enable an increase in marbling or intramuscular fat content as determining parameters of sensory beef quality. The different studies focused on different samples of beef carcasses to explore influences of breed (study I), age and gender (study II and study III) and tried to validate specified feeding strategies (study III) as possible factors influencing intramuscular fat content or marbling.

The heterogeneous level of intramuscular fat content within a homogeneous genetical structure was illustrated in study I. Although samples of this study derived from animals of one breed which were fed more or less extensively on different farms, the heterogeneous structure of this population with its different origins genders and ages of animals was expressed in the IMF results. It could be demonstrated that homogeneous genetic structures do not consequently lead to a high or low beef quality. In this study, beef from steers and heifers showed higher values in intramuscular fat content than beef samples from bulls. This is in accordance with other studies that described the influences of gender and an early castration on intramuscular fat content and marbling (Harper and Pethick, 2004; Hocquette et al., 2009; Li et al., 2014; Park et al, 2018).

Although an early castration of bulls or choosing heifers might increase marbling, the results of study II (young bulls) and III showed that the same or a high degree of marbling cannot be expected per se in carcasses of the same sex. The marbling scores of young bulls varied widely as they derived from different farms and were thus fed in different ways. The assessed marbling scores ranged from very low to very high (200 to 942 at the 10^{th} rib cross section). Additionally, the carcasses of young bulls were from different breeds. In study II, variation of marbling scores emerged although carcasses derived exclusively from bulls. In German beef production, bulls represent the highest number of animals slaughtered and yet the quality level of German beef carcasses is widely unclear. Results in study II show tendencies in German beef quality as the sample in this study was produced for typical German beef production, but the sample does not represent all beef carcasses of young bulls.

In study III, meat was analyzed from heifers of the same breed that were all slaughtered at a similar age. The main objective of this study was to validate feeding as a possible influencing factor on marbling. While the marbling scores did show a certain degree of variation, the results indicated that this variation might be reduced by specified feeding strategies. Furthermore, this

study validated a significant effect of using a defined feeding strategy to increase marbling. Therefore, it is assumed that a purposive feeding strategy is one of the main parameters to increase marbling scores of beef. Hocquette et al (2009) mentioned a high number of studies showing that increasing marbling or IMF by nutritional strategies is highly complex (Bindon, 2004). Mostly, different feeding diets result in changes in backfat thickness or the fat of the whole carcass. The revealed significant differences in the feeding trials of study III suggest a relevant strategy when trying to increase marbling. However, although results of this study showed increases in marbling scores, the variation of possible influences that might affect feeding strategies nevertheless remains present.

Although variation of marbling scores in the feeding was reduced, the marbling values were by no means the same. Therefore, it has to be emphasized that marbling or intramuscular fat content are always subjected to a certain degree of variation due to the high variation of possible influencing factors that can only be reduced but not removed by optimizing the parameters that influence these traits. In order to produce high-quality beef with high intramuscular fat content or marbling it is necessary to consider and steer the interactions between the genetic base, gender, age and liveweight of animals, management and feeding.
A retrospective assessment of the carcasses is a prerequisite for a purposive optimization of the various influencing factors of beef quality. Evidence about the actual variation of the sensory quality trait marbling or intramuscular fat contet is necessary to modify internal resources and factors such as feeding regime and the choice of genetics in the context of production.

All the studies of this thesis included specified samples of beef. It has to be emphasized that the investigation of the given feeding strategies was carried out on young heifers of a special beef breed. The effect of these feeding strategies on marbling scores of bulls or steers was not considered and has to be validated in further research. Additionally, the choice of other breeds such as Angus or beef breeds commonly used in Germany, such as Limousin and Charolais, also needs to be investigated.

Furthermore, the effect of age has to be considered. Heifers in the feeding trial were, due to commercial conditions, slaughtered at a specified age. But as intramuscular fat content is known to increase with increase of age (Hocquette et al., 2009), the prolongation of the fattening period of different animals might also have influences on marbling scores. Terler et al. (2016) found higher intramuscular fat content in heavier (760 kg vs. 690 kg) and longer fattened Simmental steers during a fattening period. Chung et al. (2018) summarized different studies that suggest

possible effects of an extended fattening period on intramuscular fat content but emphasized that possible increases in back fat thickness have to be considered.

At the same time, however, the present results also illustrate that only evidence of the quality level in the form of marbling or IMF allows valid statements about the sensorial quality level of beef carcasses. Currently, there are hardly any valid statements about the sensory quality level of German beef carcasses and therefore, comparability is not given. Thus, the need of a standardized method to assess quality traits of beef is evident and has been reported by other studies (Bonny et al., 2016; Monteils et al., 2017; Liu et al,.2020). Only the evidence of higher quality can lead to consistently higher pricing and thus to increased value creation on the industrial beef market.

As the chemical analysis of IMF requires the destruction of the beef sample (Cheng et al., 2015) and is therefore not usable in the industrial slaughter line, the use of VIA methods that assess marbling in a reliable way without destroying the carcass might fit the conditions in German slaughter lines. Should marbling become standardized in the classification of carcasses, farmers and butchers of smaller cattle populations, such as the RHV, with less organization of slaughtering processes, could get evidence using IMF analysis to compare their quality of beef.

Furthermore, VIA systems and the classification of marbling are already practiced in international classification or grading schemes so these systems might be easily adapted to the German slaughter line. In study II, the first exploratory results from Schulz and Sundrum (2019) were furthered to validate and adapt a VIA method standardized in other countries for the standardized assessment of marbling in the German industrial slaughter line. This study focused on the assessment of marbling at the 10^{th} rib position of *M. longissimus dorsi* but as there is no standardized position for ribbing carcasses, and only a few studies about marbling in different muscles (Konarska et al., 2017), further research including other positions and more samples might be useful to standardize VIA methods. Hocquette et al. (2009) emphasized that the variation of intramuscular fat within muscles, between individuals and among different cuts always has to be considered when comparing marbling or intramuscular fat content at different positions of carcasses.

VIA assessment of marbling of beef carcasses is described as ready for use (Craigie et al., 2012). Other studies focus on the feasibility of international beef classification systems with European carcasses (Bonny et al., 2016; Liu et al., 2020). Although the VIA system that was used in study II is able to assess marbling scores at the 10^{th} / 11^{th} rib position of *M. longissimus dorsi* with high reference to the US position in young bulls and heifers (Schulz and Sundrum,

2019), research about the validation of beef samples with expected higher marbling, such as Wagyu or Angus heifers and steers, is required. Furthermore, the validation of the calculation of yield grades at this position requires further research and is not completed so far.

The results of study I are in accordance with other studies which suggest that beef from heifers and steers might have higher amounts of intramuscular fat than beef from bulls. Additionally, the feeding trials in study III, were carried out with heifers, that showed high marbling levels. Heifers in particular, but also steers and carcasses from beef breeds that are generally known to show higher marbling, are graded lower in the EUROP grading system due to a lower muscularity, of the carcasses than those of bulls. Furthermore, the feeding strategy that was carried out in study III risks leading to heavier carcasses with higher subcutaneous back fat thickness. As carcasses with higher muscularity and lower subcutaneous fat are favored in the EUROP grading scheme, farmers may hesitate to increase the amount of protein in the fattening finishing period and to produce beef from heifers and steers as well as less-muscled beef breeds. But results of study III show that it is possible to produce carcasses with relatively high muscularity as well as increase marbling by purposive feeding strategies.

The results of study II and study III demonstrate that EUROP traits are not linked to marbling scores. These results are in accordance with other studies (Bonny et al., 2016; Liu et al.,2020). As the EUROP grading system has been criticized for a long time (Brinkmann, 2008; Bonny et al., 2016; Monteils et al., 2017), the need of an objective grading system that is able to classify carcasses according to sensory beef quality attributes is evident. To increase the production of higher marbled beef, carcasses with higher marbling need to be remunerated with higher prices than carcasses with lower marbling. Especially as carcasses with higher muscularity tend to have lower marbling (Alberti et al., 2008; Hocquette et al., 2009), the EUROP grading scheme inherently ignores sensory beef quality. Therefore, beef producers have no encouragement to produce high quality beef. In addition, beef carcasses are not compared or even differentiated by quality attributes. Such an assessment of sensory quality traits of beef and an adapted distribution of the differently graded carcasses does already take place in numerous international classification systems (Polkinghorne and Thompson, 2010) and is accepted by consumers and producers. Furthermore, comparability of the carcasses and their slaughter value is given. In view of the continuing low prices for German beef, the aim of beef production should be the distinguishment of proven quality beef products on the market and to generate high added value. A pricing system that considers the degree of marbling could support the production and the optimized distribution of highly marbled beef in Germany. Furthermore, the

choice to fatten less-muscled animals such as heifers and steers or animals of smaller breeds that tend to show higher marbling such as Angus and Wagyu (Park et al., 2018) could be enabled through a special pricing system focusing on marbling, provided these animals show increased marbling scores that were assessed independently and by a profound method.

Due to the complexity and the high number of possible influencing factors that might affect sensory beef quality, it has to be emphasized that the regulation of all parameters has to be considered to produce high quality beef. It is suggested that all possible influences on marbling interact during the fattening period of animals. Furthermore, the physiological state of animals and the production and management strategies of each farm might have influences on the product quality of beef. Further influences such as quality of diet ingredients or the health state of animals might also have impacts on the quality level of beef or at least on daily gain and production traits of animals (Rezac et al., 2014; Rheinhart et al., 2015).

Therefore, when producing beef, a holistic approach which includes optimized feeding, management and slaughtering processes might lead to reduced variation of marbling scores in beef and thus to a higher number of quality beef carcasses. These factors need to be validated and optimized consequently throughout the whole process line due to the high number of possible and very variable influences in the final beef products. In total, the retrospective assessment of the end product “meat carcass” remains the most effective method to validate and evaluate strategies to increase beef quality.

7 General Conclusion

The results of this study illustrate the great variability of sensory beef quality traits such as marbling and IMF. It was shown that marbling or the amount of intramuscular fat of beef may be affected by the interactions between different influencing factors such as feeding, age and gender, and in a limited way by genetic traits. On the one hand, variation emerges due to the high number of possible influencing factors on marbling but also among the trait itself. It is not possible to expect a high or consistent level of marbling or intramuscular fat content by optimizing only one of the factors that influence marbling in standardized strategies. Considering the given results, it is suggested that there are a few different possibilities to increase marbling and thus the sensory quality of beef. But all of these possibilities require a target-oriented and holistic approach that respects the initial and boundary conditions of beef production within the whole slaughter line. Therefore, it is necessary to validate data and strategies through evidence-based statements.

It was found that a purposive and needs-based feeding strategy involving a supply of high energy during the marbling window and a high supply of UDP amounts in the later fattening period is suitable to increase marbling. Therefore, the intramuscular fat content of beef might be highly influenced by feeding regimes. But results of this study have to be validated and adapted to other conditions and samples. Overall, the production of high-quality beef requires defined and purposive strategies in management and feeding of beef cattle. In addition to this, the industrial slaughter line needs objective measuring methods to validate the quality of each beef carcass. Therefore, the adaption of the EUROP classification scheme has to be realized. There are already functioning and objective international measurement systems that might be easily adapted to the German process line (Monteils et al., 2017) which would enhance comparability of carcasses.

Due to the current lack of quality differentiation, and without any objective assessment method of beef, consumers have no guarantee for the final sensory quality level of beef. Considering the long use of beef quality classification in international grading systems, the successful marketing of German beef also requires evidence-based assessment of carcass traits data to ensure an optimized processing including higher values throughout the whole process line and to lead, in the long term, to an increase in beef quality as well as an optimized distribution of beef carcasses with different levels of quality.

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