The effect of production system on carcass and meat quality in lambs

Uppfödningssystemets påverkan på slaktkroppens och lammköttets kvalitet

Elin Stenberg

Skara 2017

Animal Science

Studentarbete **Nr. 698**
Sveriges lantbruksuniversitet
Institutionen för husdjurens miljö och hälsa

Student report ***No. 698***
Swedish University of Agricultural Sciences
Department of Animal Environment and Health

ISSN 1652-280X

The effect of production system on carcass and meat quality in lambs

Uppfödningssystemets påverkan på slaktkroppens och lammköttets kvalitet

Elin Stenberg

Studentarbete 698, Skara 2017

Advanced E, 30 ECTS, Animal Science, Degree Project in Animal Sceience EX0566

Handledare: Katarina Arvidsson Segerkvist, Instutionen för husdjurens miljö och hälsa, SLU, Box 234, 532 23 Skara
Biträdande handledare: Annika Arnesson, Instutionen för husdjurens miljö och hälsa, SLU, Box 234, 532 23 Skara
Examinator: Elisabet Nadeau, Instutionen för husdjurens miljö och hälsa, SLU, Box 234, 532 23 Skara

Nyckelord: intact male lamb, production system, pH, temperature, lactate

Serie: Studentarbete/Sveriges lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, nr. 698, ISSN 1652-280X

Sveriges lantbruksuniversitet
Fakulteten för veterinärmedicin och husdjursvetenskap
Institutionen för husdjurens miljö och hälsa
Box 234, 532 23 SKARA
E-post: hmh@slu.se, **Hemsida:** www.slu.se/husdjurmiljohalsa

TABLE OF CONTENTS

ABSTRACT

The aim of this study was to evaluate effects of different production models in Swedish lamb production on live weight gain (LWG), carcass quality and meat quality. The experiment included four typical production models for weaned male lambs in Sweden; indoor feeding (group 1), grazing on cultivated pasture (meadow fescue (*Festuca pratensis* Huds.), perennial ryegrass (*Lolium perenne* L.), timothy (*Phlenum pretense* L.*)*, white clover (*Trifolium repens* L.) and red clover (*Trifolium pretense* L.)) with (group 2) or without (group 3) 0.3 kg concentrate supplementation daily per lamb and grazing on semi natural pasture (group 4). Indoor lambs (group 1) were fed grass silage (timothy, red clover and white clover) *ad libitum* and 0.8 kg concentrate daily per lamb. There were 20 intact male lambs per group. Feed samples of silage, concentrate and pasture was taken continuously in connection to weighing of lambs throughout the experiment. The LWG of the lambs were registered as well as pasture height in the different pasture paddocks throughout the experiment. At slaughter, live weight, carcass weight, dressing percentage, carcass conformation, fatness, and blood samples for lactate analysis were registered. Additionally, pH and temperature decline in muscle (topside) during the first 24 hours after slaughter, were measured. The rearing system had an effect on LWG ($P < 0.0001$) where indoor lambs having the highest (377 g/day), followed by cultivated pasture + concentrate (287 g/day), cultivated pasture (245 g/day) and semi natural pasture (212 g/day). Furthermore, lambs on semi natural pasture had lower conformation score ($P = 0.0024$) and fat score ($P < 0.0001$) than the other groups. When comparing at which temperature pH reached 6.0 ($P < 0.0001$), group 1 (19.0°C) had a lower temperature at pH 6.0 compared to the other groups; group 2 (32.6°C), group 3 (32.4°C) and group 4 (35.5°C). This relationship was measured by recording the temperature and pH decrease in the carcass during the first 24 hours after slaughter to indicate the tenderness of the muscle. To have a maximized tenderness there are recommendations that the muscle should enter rigor at approximately 15 °C which indicates that meat from group 2, 3 and 4 could be less tender that meat from group 1. No differences between the four groups were found regarding blood lactate at slaughter, muscle-pH and -temperature at 24 hours after slaughter or muscle-pH at six days post slaughter.

SAMMANFATTNING

Syftet med denna studie var att utreda om olika produktionsmodeller från svensk lammproduktion påverkade tillväxt, slaktkroppskvalitet och köttkvalitet. Experimentet inkluderade fyra typiska produktionsmodeller för avvanda bagglamm i Sverige; på stall (grupp 1), bete på återväxt av åkervall (ängssvingel (*Festuca pratensis* Huds.), engelskt rajgräs (*Lolium perenne* L.), timotej (*Phlenum pretense* L.*)*, vitklöver (*Trifolium repens* L.) och rödklöver (*Trifolium pretense* L.)) med (grupp 2) eller utan (grupp 3) extra tillskottsutfodring utav 0,3 kg kraftfoder per lamm och dag samt en grupp (grupp 4) på naturbete. Lammen på stall (grupp 1) utfodrades med ensilage (timotej, rödklöver och vitklöver) *ad libitum* samt en daglig giva på 0,8 kg kraftfoder per lamm. Det var 20 intakta bagglamm i varje grupp. Foderprover av ensilage, kraftfoder och bete togs kontinuerligt i samband med vägning av lammen under hela experimentet. Levandevikt hos alla lamm registrerades, samt beteshöjden i de olika betesfållorna under hela experimentet. Vid slakt registrerades levandevikt, slaktvikt, slaktutbyte, slaktkroppens form- och fettklassning, blodlaktat samt pH- och temperaturnedgång i muskel (innanlår) under de första 24 timmarna efter slakt. Tillväxten påverkades av de olika uppfödningsmodellerna (P < 0,0001), där lammen på stall hade den högsta dagliga tillväxten (377 g/dag), följt av åkermarksbete med kraftfodertillskott (287 g/dag), endast åkermarksbete (244 g/dag) och naturbete (211 g/dag). Sedermera hade lammen från naturbetet en lägre klassning på både form (P = 0,0024) samt fett (P < 0,0001) än de andra tre grupperna. Likaså sågs skillnad mellan grupp 1 och de övriga tre grupperna vid jämförelse av vid vilken temperatur som pH 6,0 inföll (P < 0,0001), grupp 1 (19,0°C) hade lägre temperatur vid pH 6,0 än de andra grupperna; grupp 2 (32,6°C), grupp 3 (32,4°C) och grupp 4 (35,5°C). Detta samband mättes genom att registrera temperatur och pH sänkningen i slaktkroppen under de första 24 timmarna efter slakt för att indikera muskelns mörhet. För att få ett så mört kött som möjligt finns rekommendationer om att muskeln skall uppnå rigor vid ungefär 15 °C, vilket indikerar att kött från grupp 2, 3 och 4 skulle kunna kan vara mindre mört än kött från grupp 1. Däremot sågs inga skillnader mellan behandlingarna i blodlaktatvärde, muskel-pH efter 24 timmar, muskel-temperatur efter 24 timmar eller muskel-pH efter sex dagar.

INTRODUCTION

Lamb production in Sweden has been increasing and were in 2015 stable with approximately 255 000 lamb slaughtered per year, compared to approximately 173 000 slaughtered lambs in 2000 and 155 000 in 1995. In 2015 there were 306 078 lams and 288 675 ewes and rams in Sweden (Jordbruksverket 2016). The slaughter in 2015 consisted of 255 501 lambs and 33 380 ewes and rams (Jordbruksverket 2015). In 2015, the Swedish sheep and lamb meat production accounted for 30.5% of the total Swedish consumption, which means that two thirds of the total sheep and lamb meat consumption was imported (Jordbruksverket 2016; Lennhard Öberg 2016). To satisfy the consumers' demand of lamb meat, with a consumption of 1.7 kg lamb meat per person, the import of sheep and lamb meat increased a lot both in 2014 and 2015. The Swedish sheep and lamb meat import in 2015 mainly came from New Zealand (30%), Ireland (28%) and the Netherlands (18%). The Swedish Board of Agriculture reports that meat that is imported from other countries within Europe could originate from outside of the EU, due to scantly labeling (Lennhard Öberg 2016). But this does not mean that the Swedish lamb meat production lacks potential, on the contrary, the Swedish consumers have a great confidence in the Swedish animal production when regarding animal welfare. However, the increased consumption, 1.3 kg/person in 2006 and 1.7 kg/person in 2015, of sheep and lamb meat is not reflected in the domestic production (Lennhard Öberg 2016). An increasing demand of high quality lamb meat produced in Sweden results in a need to know how lamb should be reared under Swedish conditions, as the meat has to have a high and consistent eating quality. The eating quality of today's Swedish lamb meat varies which might be due to for example the use of different production systems, different breeds, ages at slaughter and slaughter weights. It has been shown that different feeding diets could affect the meat quality of lamb. Different feeding strategies could be pasture fed lambs contra grain fed lambs, that can affect the meat to appear different in for example flavor but could also have an affect on the glycogen storage of muscles, that after slaughter directly affects the quality of meat (Watkins et al., 2013). To be able to measure differences affected by the different feeding strategies on the lamb meat pH is usually used as an indicator for tenderness. When using pH as an indicator, lamb meat can be tested without being damaged (cut or wasted), which reduces losses of the carcass for quality testing. Since it is a lot of factors affecting the carcass pH, pH ought to vary a lot between different production systems around the world. That is why it is very important to understand how specific production systems as the ones used in Sweden can affect the meat quality in parameters such as carcass pH and temperature after 24 hours. When understanding how the specific production system affects the meat quality, only then can advise be given for the specific conditions. When comparing ultimate pH, it is relevant to have a prospect of what the normal pH in muscle is. Thus, the pH existing in muscle at the time of slaughter and in the beginning of the onset of glycolysis has been shown to be 6.5 in the *M. longissimus* at a temperature of 39.1°C in Dorset wethers (Koohmaraie et al., 1995).

Aim

The aim of this study was to investigate if different production systems affect quality attributes of lamb meat. Models for three, in Sweden commonly used production systems (indoors, cultivated pasture and semi natural pasture) were investigated. Furthermore, it was also investigated whether supplementary feeding of concentrate at pasture affects the meat quality of grazing lambs.

Hypothesis

The hypothesis of this study was that there would be differences in final pH depending on the rearing model. Lambs reared indoors should have the lowest final pH, followed by the group on cultivated pasture with concentrate, only cultivated pasture and then the semi natural pasture group with the highest final pH. This hypothesis was based on that lambs that grew fastest should have developed a better glycogen storage than the ones growing slower.

BACKGROUND

What is meat quality and how can it be measured?

Meat quality is a complex concept that includes a lot of different parameters. These parameters could for example be yield and composition (e.g. muscle size and shape), coulor of the meat, water holding capacity, meat structure, tenderness, juiciness, flavor, smell, chemical composition of the meat and nutritional quality of the meat. It can also include ethical quality, e.g. animal welfare, sustainable and environmental considerations. Methods for analyzing this parameters are for example the Warner-Bratzler method (shear force) for tenderness, the CIELAB-method for colour and sensory tests for flavor, taste and smell (Warris, 2010). In this study the focus will be on final pH and temperature of the meat, as well as the decline in pH and temperature during the first 24 hours after slaughter to measure at which temperature that pH was 6.0. The muschle pH and temperature values are used to indicate the tenderness of meat (Devine et al., 1993). Further meat quality parameters measured in this experiment was pH in meat after six days and the blod lactate value at slaughter to indicate pre slaughter stress.

Muscle becomes meat

At slaughter, it is important that lambs are in a good energy balance, with a sufficient glycogen content in muscle. Glycogen is one way for the body to store energy, and it serves as a buffer to maintain glucose levels between feeding times or under anaerobic physical work. The ATP production with glycogen as substrate is, howerver, less efficient than the normal aerobic ATP production with lipids as substrate. When lambs are slaughtered and stop breathing, the oxygen supply to and in the muscles gets exhausted, which leads to reduced production of ATP in the muscles. Since this process requires oxygen the muscle is forced to degrade glycogen to get energy. When blood sugar is too low the hormone glucagon is released, this hormone activates glycogen phosphorylase which starts the degradation of glycogen to glucose-6-phosphate to restore the blood sugar balance and thereby provide the muscle with energy. When glycogen is degraded, it forms lactic acid which in turn affects the environment of the muscle to become acidic, and the tissue pH drops. If there is enough of glycogen in the muscles at slaughter, glycogen will continue to degrade until the enzyme responsible for the degradation stops working, when all substrate (glycogen) is used. If there, on the other hand, is small amounts of glycogen in the muscle at slaughter, it will lead to a lower than normal drop in pH in the muscle which affects the meat quality (Warris, 2010).

pH of meat and factors affecting it

When discussing meat quality in general one often talks about tenderness and flavor. But which factors are really involved in how the meat quality evolves after the animal is slaughtered? When considering tenderness and water holding capacity, the relationship between these two and the ultimate pH of meat has been investigated for a long time (Boution et al., 1971; Devine et al., 1993; Watanabe et al., 1996). To give an example regarding ultimate pH, seven months old entire male Romney lambs were slaughtered, and the result showed that the most tender meat from their approximately 18 kg carcasses came from meat with an ultimate pH of 5.5-5.7 in the *M. longissimus dorsi* (all muscles mentioned are available in a Latin, English and Swedish dictionary in Annex 1; Devine et al., 1993). This information shows why pH is such an important factor in the whole concept of meat quality. Devine *et al*. (1993) describes how ultimate pH are connected to tenderness by evaluating shear force in meat and how a high ultimate pH gave a higher shear force value and thereby concluded that this meat was less tender. The pH variation

can be traced back to a lot of factors such as stress, feeding, chilling temperature, season and many more, as well as factors of the animal such as age, breed and sex (McGeehin et al., 2001). For a compilation of how different treatements can affect the final pH of lamb meat, see Annex 2.

When taking the two main parameters into consideration, pH and temperature, there are some different recommendations from different associations around the world about muscle pH- and temperature decline after slaughter. When comparing these recommendations between Australia, New Zealand and Scotland there are some minor differences. According to the Meat Standards of Australia (MSA), a pH over 5.7 is categorized as a high ultimate pH. Hence, MSA recommend to strive for an ultimate pH below 5.7 to achieve the best meat quality. MSA also describes how the temperature in the carcass should decrease after slaughter. They recommend a temperature between 8 and 18 °C when the meat enter rigor at a pH of approximately 6.0. These temperatures are referred to non-electrically stimulated animals with an Achilles tendon hanging method (MSA 2015a). Their recommendations also clearly describe that lambs should be in a steady growth phase, growing at least 100 to 150 g/day, two weeks prior to slaughter to have an adequate glycogen storage in their muscles that provides a good pH reduction in carcass after slaughter (MSA 2015b). The Alliance group (New Zealand) recommends a final pH in meat of 5.4 to 5.8 in the *M. longissimus*. According to them a pH of 5.8 to 6.0 is intermediate, while a final pH over 6.0 is considered to be high, which increases the risk of the meat to be less tender (Alliance Group Limited 2010). The recommendations from Scotland, from Quality Meat Scotland, states that pH should drop below 6.0 at a temperature of 12-35 °C. Quality Meat Scotland has not proposed a recommended value for ultimate pH (QMS). In Annex 3, references presenting temperature at pH 6.0 are presented.

pH and meat quality

There are four major quality problems (PSE, DFD, heat shortening and cold shortening) in meat when considering pre-slaughter stress, pH and temperature. Pale, Soft and Exudative (PSE) and Dark, Firm and Dry (DFD) are two quality defects in meat that are a direct effect of stress before slaughter; immediately before and long time before, respectively. These two negative aspects on meat quality refers to the pH at a specific time. PSE is commonly defined as the meat having a pH below 6.0 within the first 45 minutes to 1 hour after slaughter. DFD are on the other hand often defined as the meat having a pH of 6.0 or above after 12 to 24 hours after slaughter (Warris, 2010). When moving on to quality problems depending on the relationship between pH and temperature decline in carcass there are also two major quality problems. These two quality problems are called heat shortening and cold shortening, respectively. Heat shortening refers to that temperature is too high when rigor occurs, this is often described as a high carcass temperature when pH reaches 6.0. Geesink *et al.* (2000) defined heat shortening to occur when the temperature was 35 °C or above when rigor occurred. However, heat shortening is not a major problem in lamb carcasses compared to cold shortening. Cold shortening can occur when carcass temperature is too low at pH 6.0 or when rigor occurs. When considering both cold and heat shortening, Geesink *et al*. (2000) states that the recommendation according to present results are that muscles should be around 15 °C at the onset of rigor to achieve a maximized tenderness in the meat. Thompson *et al*. (2005) states that if the temperature at pH 6.0 in *M. longissimus lumborum* was lower than 10 °C or higher than 30 °C, Achilles tendon hanged carcasses were tougher than carcasses who reached a pH of 6.0 within these temperatures. Thompson *et al*. (2005) also states that the tenderstretched carcasses seemed

less affected (toughness) by the variation in temperature at pH 6.0 compared to Achilles hanged carcasses. So according to Geesink *et al*. (2000) and Thompson *et al*. (2005) the temperature at which the muscle reaches the pH of 6.0 and enters rigor can determine whether the meat quality will be good or bad. Compared to the statements above, van de Ven *et al*. (2013) recommend that pH in *M. longissimus lumborum* should drop below 6.0 between the temperatures of 18 to 35 °C to promote good meat quality. This statement is not fully backed up by other researchers but it shows that even if temperatures are high after pH is below 6.0 that is no guarantee that the meat quality per say is bad. The lower temperature limit was consistent with the results from Toohey *et al.* (2006). Toohey *et al.* (2006), measured at which temperature pH 6.0 in *M. longissimus thoracis et lumborum* occurred in 1197 lamb carcasses. Their result gives an indication on how the situation often occurs in reality. Toohey *et al.* (2006) recommend that pH should reach 6.0 between 18-25 °C. In this study the result showed that at three abattoirs, the proportion of occasions were pH was greater than 6.0 at 18 °C was very high. Their results also point out that occasions where pH were 6.0 in the recommended temperature window was at a very low proportion. Having this results in mind the relationship between temperature and rigor can be hard to accomplish in carcasses in the actual production. On the contrary to the results of van de Ven *et al*. (2013) and Toohey *et al.* (2006), Bouton *et al.* (1972) saw that muscles (*M. longissimus dorsi*) with an ultimate pH of less than 6.2 three days post mortem had a higher incidence of cold shortening. In lambs, Savell *et al*. (2005) recommend that the carcass muscles should not be under 10 °C when pH reaches 6.2 to avoid cold shortening. Heat shortening and cold shortening can thereby be defined as a relationship between temperature and pH at onset of rigor.

Differences in growth and pH between different types of pastures and concentrate levels

Different types of pastures, with different plant growth and energy content could affect the final meat pH after 24 hours. However, Díaz *et al.* (2002) did not find any differences in pH after 24 hours between lambs on oak-wooded pasture versus lamb on sheepfold, which is an enclosed pen with pasture. The daily weight gains were 275 g/day for pasture and 266 g/day for sheepfold. There was no difference between the two groups when looking at pH after 24 hours. This study on the other hand found a difference in pH after 24 hours in lambs slaughtered at different weights. There was a significant difference in pH in the *M. longissimus dorsi* after 24 hours, between low weight animals of 10.6 kg carcass weight with a final pH of 5.51 and the high weight animals with 13.4 kg carcass weight and a final pH of 5.71. These results also showed an increase of dark cutting in meat from lighter carcasses than the heavier ones (Díaz et al., 2002). This results can be compared to McPhail *et al.* (2014) who found that carcasses down to 16 kg had a higher ultimate pH in *M. retus femoris*, *M. longissimus dorsi* and *M. infraspinatus* than carcasses that were up to 28 kg. When further investigating effects of different feeding intensities, on weathers, Campbell *et al.* (2012) found that when comparing a high growth group (280-350 g/day) with a low growth rate group (190-250 g/day), results shows a significant difference in pH between the low growth rate group and the high growth rate group. The low growth rate group had a pH of 5.87 compared to the high growth rate group which had a pH of 5.77. In another study by Pethick *et al.* (2005) they saw a difference in pH after using four different feeding intensities. These lambs had a carcass weight of 19-20 kg. In this experiment lambs were either feed high-energy pellet, moderate-energy pellet, pasture or straw. The results show a significant difference in ultimate pH between the high-energy pellet and straw groups compared with the pasture and moderate-energy pellet groups in all three muscles tested; *M. semimembranosus*, *M. longissimus thoracis et lumborum* and *M.*

semitendinosus. These results show that in this experiment the groups on pasture and moderate-energy pellet had a significantly lower pH in muscles after 24 hours compared to the other groups on high-energy pellet or straw. This are explained by the authors as an unexpected result since the high-energy lambs had a higher glycogen content in muscle. Why this result occurred has not been explained further by this study, they however refer to a metabolic or behavioral origin (Pethick et al., 2005). Unfortunately, no studies could be found were differences in meat quality from lambs grazing on cultivated pasture or semi natural pasture smilar to this study have been conducted.

Differences in growth and pH between different feeding intensities

When comparing different types of feeding intensities between pasture and indoors there has been shown to be both differences and no differences in pH after 24 hours. When comparing one group on pasture with 100 g concentrate and the other group on stall with hay and 200-300 g of concentrate per day, Majdoub-Mathouthi *et al.* (2015) found no significant difference in pH in the *M. longissimus thoracis* after 24 hours. Interesting in this study is that both groups had high ultimate pH, 6.19 for pasture and 6.33 for stall lambs, which the authors referred to be a bit high due to low glycogen levels as an effect of low energy supply (Majdoub-Mathouthi et al., 2015). Priolo *et al.* (2002) on the other hand found results that indicate a tendency for the grass fed lambs to have a higher ultimate pH in the *M. longissimus thoracis et lumborum* than the indoor lambs. The grass fed lambs had a pH of 5.62 when the stall lambs had a pH of 5.57. The results indicate a tendency for the grass fed lambs to have a higher ultimate pH than the indoor lambs. This can be summarized as that there can be a difference in ultimate pH when comparing groups raised on different intensities. The result in Priolo *et al.* (2002) also concludes that there was a tendency for difference in pH between lambs with a high growth rate (238 g/day) with a pH of 5.63 and the low growth rate (185 g/day) lambs which had a pH of 5.57. This could be compared to Díaz *et al*. (2002) where live weight at slaughter affected the pH values. Sylvestre *et al.* (2002) studied the effect of two different housing systems on daily weight gain and found that hay and concentrate resulted in a higher growth rate than only hay, over 250 g/day and lower than 25 g/day respectively. The group with higher growth rate was fed hay *ad libitum* and 900 g of concentrate two times daily. The low growth rate group were fed hay *ad libitum*. The result in this study showed that the concentrate groups grew significantly better than the groups that only got hay. This experiment was conducted on both male and female lambs and the results showed a non-significant differences between sexes for the different treatments (Sylvestre et al., 2002). When considering pH differences between different feeding types Hopkins *et al.* (2005) only examined female lambs but their results are based on low or high intensity of nutrition which is an important factor to account for. The high intensity feeding promotes a more intensive growth per day. Their results show that the final pH in the *M. longissimus thoracis et lumborum* were higher in low intensity lambs with a pH of 5.63, than high intensity lambs with a pH of 5.55. These results can be compared to Young *et al*. (1994) that found a pH difference in the *M. longissimus thoracis et lumborum* ranging between just under 5.4 to just below 6.4 in an experiment with ram lambs on seven different pastures. When considering the prospect of using the same type of pasture and examine the effect of different additional feeds, Velasco *et al*. (2004) did not find any significant difference in pH in the *M. longissimus thoracis et lumborum* and *M. semitendinosis* muscles, between lambs with either additional commercial concentrate or whole barley besides pasture. The pH of the different groups after 24 hours were 5.54 in the concentrate group and 5.66 in the barley group (Velasco et al., 2004). The wide variation in final pH within each treatment in this study could explain that there were no significant difference, even if there was a numerical

difference, between final pH. When comparing the same type of additional feed Majdoub-Mathouthi *et al.* (2013) did not find any difference in pH in the *M. longissimus thoracis* between groups that got either 300 g or 600 g of concentrate combined with a ration of hay.

Difference in pH between breeds, gender and age

It is very common that many different breeds of sheep are existing within the same country or region and are then used in similar production systems. This gives a curiosity to understand whether or not breed has an effect on the pH of meat. This issue has been examined in several studies (Young et al., 1993; Gardner et al., 1999; Sañudo et al., 2003; Teixeira et al., 2005), where the results has pointed towards different conclusions whether or not breed is a factor affecting the decline in muscle pH. When effect of breed was investigated by Gardner *et al.* (1999) the results showed that pure Merino lambs had a significantly higher ultimate pH in the *M. semimembranosus* and *M. longissimus dorsi* than second cross lambs with Merino. These measurements were done under a normal slaughter situation, commercial abattoir, to investigate under normal stress circumstances. When lambs were slaughtered under less stressful conditions in an experimental abattoir, ten minutes after removal from there pen, the results showed no significant difference in final muscle pH between breeds (Gardner et al., 1999). This indicates that the breed Merino are more susceptible to stress and can therefore have an extra sensitive experience from stress that affects the meat quality in form of decline in muscle glycogen that effects the ultimate pH. These results are supported by Young *et al*. (1993) which found a significant difference in pH in the *M. longissimus lumborum* between breeds when comparing Coopwort and Merino lambs. The Coopworth lambs had a mean pH of 5.77 while the Merino lambs had a mean pH of 6.16. This study also investigated how the effect of cross bred lambs with Merino affected the ultimate pH. That experiment showed that pure Merino had the highest final mean pH of 6.37. This number can be compared to the cross breed values; Border Leicester x Merino pH 6.03, Oxford Down x Merino pH 5.95, Suffolk x Merino pH 6.08, Poll Dorset x Merino pH 5.93 and Texel x Merino pH 5.97 (Young et al., 1993).

The effect of gender, age or breed has also been studied (Sañudo et al., 2003; Teixeira et al., 2005). Sañudo *et al.* (2003) examined 2640 lambs, of 22 different breeds from six different countries; France, Greece, Iceland, Italy, Spain and the United Kingdom. The results gave a variation in pH in the *M. longissimus* between 5.44-5.84. This study points out that no significant differences were shown between sex, age, and carcass weight or production system. In this study a pH of 5.8 was considered to be high. Sañudo *et al.* (2003) also points out that they do not agree with the notion that the breed Merino could be considered to have a higher ultimate pH as stated by Young *et al*. (1993) and Gardner *et al*. (1999). When comparing pH after 24 hours with respect to live weight, sex and breed Teixeira *et al*. (2005) found that the impact of sex and breed had a non-significant connection (*M. longissumus thoracis et lumborum)* which supports the results in Sañudo *et al*. (2003). In studies by Sañudo *et al*. (2003) and Teixeira *et al*. (2005), no differences in meat pH in the *longissimus* between genders were found. These results are supported by Okeudo and Moss (2008) that did not find any differences between sexes when comparing castrated males, entire males, vectomised rams and ewes. Their results show that the entire males had an ultimate pH of 5.73, castrated rams 5.67, vectomised ram 5.69 and ewes 5.69 in the *M. longissimus dorsi*. Another study (Johnson et al., 2005) has proved the contrary in their experiment when comparing the ultimate pH in ewes and rams. Their results show that ewes in both experiments with different muscles tested (*M. semimembranosus* and *M.*

longissimus) had a significantly lower ultimate pH of 5.63 and 5.60 respectively, when rams had an ultimate pH of 5.66 and 5.74 in the same muscles respectively (Johnson et al., 2005).

Which time after slaughter is pH usually measured?

To understand the current situation about measuring pH it could be valid to have knowledge about at which time in relation to slaughter that pH has been measured according to some of the studies previously discussed. Measurements of pH had been conducted at 0 hours after slaughter (Koohmaraie et al. 1991; Koohmaraie et al. 1995; Díaz et al. 2002; Velasco et al. 2004), 0.5 hours after slaughter (McGeehin et al., 2001), 45 minutes after slaughter (Díaz et al. 2002; Velasco et al. 2004; Okuedo & Moss. 2008) 1 hour after slaughter (Teixeira et al. 2005; Majdoub-Mathlouthi et al. 2013), 1.5 hours after slaughter (McGeehin et al., 2001), 3 hours after slaughter (Koohmaraie et al. 1991; Koohmaraie et al. 1995), 4 hours after slaughter (McGeehin et al., 2001), 6 and 9 hours after slaughter (Koohmaraie et al. 1991; Koohmaraie et al. 1995), 12 hours after slaughter (Koohmaraie et al., 1991), at least 20 hours after slaughter (McPhail et al., 2014), 24 hours after slaughter (Koohmaraie et al. 1991; Koohmaraie et al. 1995; Watanabe et al. 1996; McGeehin et al. 2001; Díaz et al. 2002; Priolo et al. 2002; Sañudo et al. 2003; Velasco et al. 2004; Pethick et al, 2005; Teixeira et al. 2005; Majdoub-Mathlouthi et al. 2013; Majdoub-Mathlouthi et al. 2015), 48 hours after slaughter (Gardner et al. 1999; Okeudo & Moss. 2008), 7 and 21 days after slaughter (Koohmaraie et al., 1995). Some of these values could appear to be more striking than others. Further McPhail *et al.* (2014) explained the selected value of at least 20 hours with that it should have been a sufficient amount of time to reach the ultimate pH after 20 hours, when electrical stimulation was not used. Other striking measure points were 7 and 21 days after slaughter (Koohmaraie et al., 1995). In that study, pH value after 24 hours was 5.6, compared to 5.6 and 5.7 after 7 and 21 days respectively.

Difference in pH and lactate value between lambs of different stress levels

An introduction to the next highly influencing factor for meat quality, stress and its impact on meat pH is briefly presented by the result of Devine *et al*. (1993). That study showed that entire male lambs of the same age and genetically similar had a significantly different pH decline in the *M. longissimus dorsi* when they got exposed to different stress levels. All animals were slaughtered at 14 months of age. The different treatments lambs were exposed to consisted of different stress levels; low/medium, medium, high and very high stress levels respectively. When animals were exposed to low/medium stress levels they got a mean pH of 5.84, medium stressed lambs had a mean pH of 5.88, high stress a mean pH of 6.29 and the very high stressed a mean pH of as high as 6.38. This results indicate that animals of the same age and genetics can have a negative reaction to stress pre-slaughter which can lead to a higher pH in the carcass muscles compared to if the lamb had been less stressed prior to slaughter (Devine et al., 1993).

Now that the effect of stress was discussed in terms of pH in carcass, it is important to understand that stress is a very complex scenario when handling animals before slaughter. This prospect has been studied quite frequent in experiments that has induced stress of some form to a group of animals, and then compared these results from stressed lambs to lambs of a “control” group without the extra stress induced. This scenario with stress pre-mortem is a very complex problem to understand. An article by Ferguson and Warner (2008) describes the whole prospect of stress within the animal from its transport from the

farm until its arrival at the knocking box. These prospects can be divided into for example increased handling by humans, how animals are transported to the abattoir, arrival to new environments, the impact of food and water deprivation, changes in their social structure and thereby mixing animal groups and how the climate conditions are at the slaughter plant. These external factors influences then further by how the individual animal can handle the new situation, resulting in additional complexity for the understanding of how all this affects the final meat quality (Ferguson & Warner., 2008).

When measuring stress at slaughter lactate is often measured together with other blood components such as cortisol and glucose. Lactate is an indicator of acute stress which can affect the pH fall after slaughter. If the animals have been stressed previous to slaughter the glycogen level in their muscles could have been used to support the energy needed. This decline in glycogen affect the pH decline in muscles since the pH decline is dependent of lactic acid/lactate. Since lactic acid is a derivate from glycogen under anaerobic conditions (Sjaastad, 2010) there are direct effects on pH from a low level of glycogen in muscle. Lactic acid is the end product when glycogen is transformed into glucose during the glycolysis in muscles. To be enable to restore glycogen in muscles both dietary carbohydrates and sufficient amount of time is needed. Time needed for this restoration of glycogen could take up to a couple of days (Sjaastad, 2010). Therefore, it is necessary to feed lambs sufficient amount of feed, before slaughter and to not underestimate the time it takes for glycogen to be regenerated to prevent a good decline in pH in the carcass.

The subject of analyzing lactate values in different experiments are limiting, it is more usual to analyze either cortisol or glucose as parameters of stress within lambs. Articles that describe lactate values when comparing animal groups that have been experiencing different treatments, to trigger a stressed situation for one of the groups are now going to be presented further. The first experiment (Liste et al., 2011) evaluated the lactate value as well as the ultimate pH values in the *M. longissimus* from lambs that had either been transported one hour to the abattoir and then slaughtered, or had the same procedure with transport but were also housed at the abattoir for 12 hours before slaughter. The results from this study shows a significant difference in lactate values between the two groups. The group slaughtered directly upon arrival had a lactate value of 12.91 mmol/L. The group housed for 12 hours at the abattoir before slaughter had a lactate value of 9.64 mmol/L. To include the pH, that were non-significant, to show how this got affected by the two treatments the slaughter upon arrival group had an ultimate pH of 5.65 when the 12 hour housing group had an ultimate pH of 5.68 (Liste et al., 2011). The second experiment (Cotrell et al., 2008) analyzed lactate levels in lambs that had exercised or not exercised before slaughter. One group walked 150 m to the abattoir and was the not exercised value group, the other group got a 15 minutes exercise before slaughter. The exercise consisted of a human walking behind the animals in a special enclosure, only to keep them in motion and not chased. The results points to a significant difference between the two groups. The normal stressed animals had a lactate value of 3.7 mmol/L while the exercised lambs had a value of 13.8 mmol/L. The results did not show a significant difference in ultimate pH measured in the *M. longissimus thoracis et lumborum* (Cotrell et al., 2008). The last experiment (Zhong et al., 2011) composed of four groups of lambs, two groups with six months old lambs and two groups with 12 months old lambs. The two different treatments were no transportation to the abattoir or an eight hour transport to the abattoir. The lactate values had a tendency to differ between treatments. The lactate values for no transportation were 4.24 mmol/L for lambs of six months and 4.20 mmol/L for lambs of 12 months. After

24 hours pH was measured in the *M. longissimus* muscles of these animals which presented a pH of 6.43 and 5.64 respectively. The lactate values for the treatment with an eight hour transportation were 3.15 mmol/L for six months old lambs and 3.32 mmol/L for 12 month old lambs. The pH values for these groups were 6.62 and 5.84 respectively (Zhong et al., 2011).

Current situation in Sweden

The Swedish lamb industry and market has determined that the carcass of lamb should weigh between 16 and 22 kg (Sjödin, 2007). The pricing at slaughter is both based on the carcass weight and meat content. The carcass conformation of the carcass is estimated according to a specific regulatory framework, EUROP. This classification includes 15 classes, with the worst being P- and the best E+. Also the fat content is estimated according to 15 classes, from the 1- being less fat to 5+ being too fat, with the best economical scoring being 3 (Sjödin, 2007). According to a survey conducted at Swedish slaughterhouses (Wallin 2016) the desired carcass weights and fat classification differ between wholesalers and restaurants. In Sweden, the wholesaler desires a carcass weight of 16-23 kg with a fat classification of 2+ to 3 while restaurants want heavier carcasses of around 25 kg with more marbling and a fat classification of 3+ to 4. If looking at the temperature and pH situation at the 20 abattoirs, the final temperature for carcasses is presented to vary between 1-7.5°C. It is not common for the abattoirs to measure pH in carcasses, in this survey, it appears that only one out of 20 participating slaughterhouses measured pH as a standard procedure (Wallin 2016).

MATERIALS AND METHODS

Animals and experimental design

The experiment was performed during the summer and fall of 2016 at Götala Beef and Lamb Research Centre at the Swedish University of Agricultural Sciences (SLU) in Skara, Sweden and at Härlunda Trumpetaregården, Skara, Sweden. In total, 80 crossbred intact ram lambs (Dorset x Fine Wool) where included in the study. The lambs where either 50:50 (36 lambs) or 75:25 (44 lambs) Dorset and Fine Wool, respectively. The lambs where either single, twin or triplett raised. The experiment was approved by the Ethical Committee on Animal Experiments, Gothenburg. The day before lambs were introduced in the study they were weighed, dewormed and divided into four groups of 20 lambs each, with equal numbers of 50:50 and 75:25 Dorset x Fine Wool and equal numbers of single, twin or triplet raised lambs in each group. The live weights at start of the experiment were equal between groups (26.4, 26.8, 26.4 and 26.0 for group 1, 2, 3 and 4 respectively). with an average weight and standard deviation per group as similar as possible between groups to eliminate differences between groups. Each group was then assigned a special feeding treatment and followed that treatment until slaughter. The different groups were; group 1 on stall, group 2 on cultivated pasture with supplemented concentrate daily, group 3 on only cultivated pasture and group 4 on semi natural pasture (Table 1). Concentrate used was Lamm 500 (Lantmännen), granulated mineral was Deltamin Får and the mineral block was Deltamin Får Slick (both from Svenska Foder). The study started at June 29 and went on until October 26. The lambs on semi natural pasture were located at Härlunda and the other three groups, stall and cultivated pastures, were located at Götala.

Table 1. Different feeding strategies for the different groups.

Group	Treatment
Group 1, stall	Silage *ad libitum* + 0.8 kg concentrate/lamb and day
Group 2, pasture	Cultivated pasture + 0.3 kg concentrate/lamb and day (0.4 kg/lamb 28/9-4/10)
Group 3, pasture	Cultivated pasture with no concentrate
Group 4, pasture	Semi natural pasture with no concentrate

Group 1 was housed in an enclosed pen made out of metal gates (Picture 1). The animals had access to water, salt and minerals (Table 4) *ad libitum* in the pen. The bedding was made out of wheat straw and was spread three times a week, normally on Monday, Wednesday and Friday. Water cups were cleaned every other day and minerals were refilled every day. Group 1 was fed a total mixed ration consisting of silage *ad libitum* and a constant amount of 0.8 kg concentrate per lamb and day, to promote an intensive growth (Picture 2). The seed mix for the silage consisted of 76% timothy (*Phlenum pretense* L.), 18% red clover (*Trifolium pretense* L.) and 6% white clover (*T. repens* L.) (Table 2 and 3). The silage was harvested between the 27 and 31 of May and was fertilized at the end of April with manure from cattle, about 30 ton/ha. A blend of formic acid and propionic acid were added to the herbage before ensiling.

Picture 1. Housing of group 1.

Picture 2. Feeding of silage and concentrate for group 1.

Group 2 and 3 were kept in two different enclosed pastures of total 1.0 ha (Picture 3 and 4). These enclosed pastures where made out of electric wire and both groups had protection from rain and sun. Each group on cultivated pasture had access to three grazing paddocks, one at the time. Each group was normally moved once a week to a new paddock (0.3 ha) with fresh pasture in connection with weighing. As the summer of 2016 was quite dry, the cultivated pastures did not grow well enough to provide adequate feeding for these lambs, which led to that four additional paddocks (0.15 ha each) was made at the end of August. The animals were moved to these new pastures for twelve days (26 of august to 7 of September) to let the grass grow in the original paddocks. The two groups on cultivated pasture differed in feeding intensity since group 2 in addition to grass got 0.3 kg of concentrate per lamb and day (Picture 5). Due to low pasture growth, group 2 got 0.4 kg of concentrate per lamb and day between 28 of September to 4 of October to keep a good energy balance in these animals. The lambs on cultivated pasture had daily access to a salt- and mineral block (Table 4). Pasture lambs was given water manually in a tub in each paddock. The seed mix for the cultivated pastures consisted of 50% timothy, 20% meadow fescue (*Festuca pratensis* Huds.), 15% perennial ryegrass (*Lolium perenne* L.) 10% red clover and 5% white clover (Table 2 and 3). The cultivated pasture was fertilized at the 3

of April 2016 with 250 kg of Axan (total nitrogen 27.0%, nitrate nitrogen 13.5%, magnesium 0.4%, sulfur 3.7% and calcium 6.0%) and then at 5 of April with manure from cattle, about 30 ton/ha (1.5 kg N/ton). The field was harvested at 10 of June and the lambs were grazing the regrowth starting at 29 of June. The regrowth was not fertilized after harvest.


Picture 3 and 4. Cultivated pasture for group 2 and 3.

Picture 5. Feeding of concentrate for group 2.

Group 4 (Picture 6) had daily access to pasture, salt and minerals (Table 2, 3 and 4). This group was moved to new pastures at three occasions (31 of August, 8 of September and 11 of October) due to poor pasture quality and growth late in the season. The semi natural pastures were all enclosed by mesh fence normally used for sheep fences in Sweden. Lambs on natural pasture had water in a pond, stream or a tub depending on the different pastures.

Picture 6. Semi natutal pasture for group 4.

Table 2. DM concentration (g/kg), energy concentration (MJ/kg DM) and chemical composition (g/kg DM) in experimental silage (n=3), pastures (n=4) and concentrate (n=1).

	Group 1[1]	Group 2	Group 3	Group 4	Concentrate[2]
Dry matter	297 (31)[3]	233 (33)	228 (22)	223 (39)	878
Crude protein	168 (16.2)	183 (29.3)	168 (16.8)	198 (28.6)	185
Digestible protein	126 (15.0)	140 (27.6)	127 (15.8)	180 (69.6)	-
Metabolisable energy (VOS)	11 (0.3)	12 (0.4)	10 (0.5)	12 (0.3)	13
NDF	507 (16.6)	421 (40.5)	453 (10.7)	396 (31.4)	278
Ash	70 (3.5)	90 (1.7)	83 (8.5)	86 (2.5)	81
Crude fat	-	-	-	-	48[4]
Crude fiber	-	-	-	-	91[4]
Starch	-	-	-	-	238[4]
AAT	-	-	-	-	130[4]
PBV	-	-	-	-	20[4]

[1]*Group 1=indoor feeding with silage, group 2=cultivated pasture with supplemented concentrate, group 3= cultivated pasture only and group 4=semi natural pasture.*

[2]*Concentrate for group 1 and 2.*

[3]*Standard deviation within brickets.*

[4]*Values from feed producer*.

Table 3. Mineral content of the experimental silage, pastures and concentrate (n=1).

	Group 1[1]	Group 2	Group 3	Group 4	Concentrate[2]
Macro minerals (g/kg)					
Calcium	5.5	8.6	8.6	6.3	12.0[3]
Phosphorus	2.9	3.7	3.4	2.7	5.0[3]
Magnesium	1.7	2.1	2.2	2.1	3.0[3]
Potassium	26.0	27.2	27.2	23.8	9.0[3]
Sodium	-	0.3	0.4	<0.2	-
Micro minerals (mg/kg)					
Selenium	-	<0.05	<0.05	<0.05	0.4[3]
Cobalt	-	0.051	0.042	0.041	-
Molybdenum	-	17.4	9.6	7.3	-
Copper	-	6.5	6.3	6.0	-
Iron	-	141	72	89	-
Manganese	-	104	93	440	-
Zinc	-	47	37	46	-

[1]*Group 1=indoor feeding with silage, group 2=cultivated pasture with supplemented concentrate, group 3= cultivated pasture only and group 4=semi natural pasture.*
[2]*Concentrate for group 1 and 2.3*
[3]*Values from feed producer.*

Table 4. Mineral composition of mineral blocks and granulated minerals used in the experiment.

Mineral Stone	Mineral block[1]	Granulated minerals
Calcium (g/kg DM)	130	150
Phosphorus (g/kg DM)	45	45
Ca/P (g/kg DM)	2.9	3.3
Magnesium (g/kg DM)	80	80
Sodium (g/kg DM)	100	90
Sulfur 8 g/kg DM)	-	5
Vitamin A (IU)	-	3 500 000
Vitamin D (IU)	-	800 000
Vitamin E (mg/kg DM)	-	55 000[2]
Zinc (mg/kg DM)	50 000	50 000
Manganese (mg/kg DM)	40 000	40 000
Iodine (mg/kg DM)	2000	2000
Cobalt (mg/kg DM)	400	800
Selenium (mg/kg DM)	450	60[3]

[1]*Mineral block=group 2, 3 and 4. Granulated minerals=group 1.*
[2]*Of which 1500 mg vitamin E was in natural form.*
[3]*Of which 15 mg was selenium yeast.*

Two lambs were taken out of the experiment due to illness; one animal from group 1 and the other lamb from group 2. Their values are not presented in the results. Therefore the total results are based on values from 78 lambs.

Special treatments during the experiment

All animals were dewormed (ivermectin 0.8 mg/ml) at the start of experiment. All animals except group 1 got dewormed again after four weeks and group 4 got dewormed a third time six weeks after the second treatment. A few lambs in group 4 got treated

(formosulfatiazol) against wounds at their heads. This treatment was performed in conjunction with weighing. At two occasions (14/7 and 28/7) an agent (cyromazine) was used to kill maggots in the litter indoor (group 1).

Feed sampling and analyses

Throughout the experiment, silage samples were collected daily and stored at -20 °C until analysis. Before analysis, samples were pooled to obtain representative samples for consecutive 4-week periods. Pasture samples were taken once a week in connection to weighing in all three pasture groups. All pasture analyses were made out of pooled samples from four weeks each. Heights of the cultivated pastures were measured each week in connection with the weighing (Figure 1), just prior to the lambs were released into a new paddock. As seen in figure 1, pasture height for group 2 and 3 was unusually high, in this experiment, around 31 of August, this is explained as measurements preformed in the extra paddocks used for a short time where the pasture height was higher. The same sampling procedure goes for the semi natural pasture, even though the lambs were not moved to a new pasture every week. All pasture samples were stored at -20 °C until analysed at the same time at the end of the experiment.

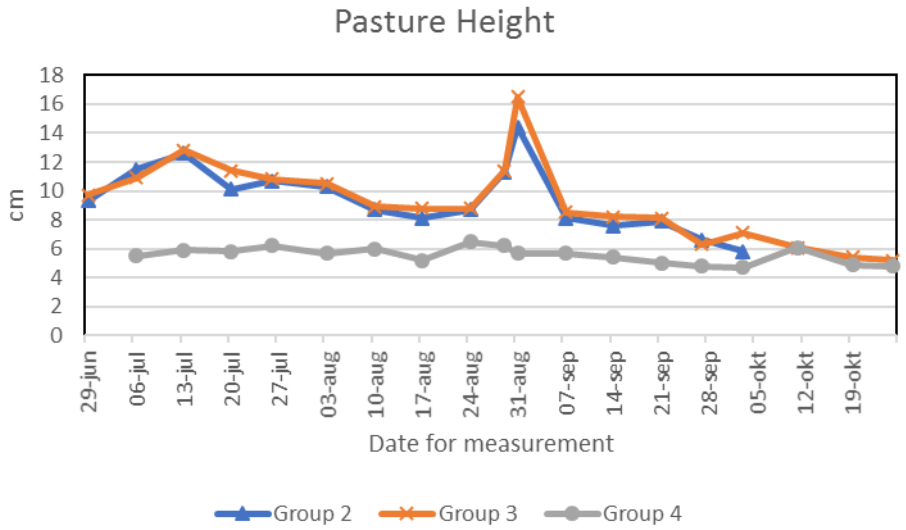

Figure 1. Pasture height (cm), over time for all pastures (group 2, 3 and 4)
**Group 2=cultivated pasture with supplemented concentrate, group 3= cultivated pasture only and group 4=semi natural pasture.*

Feed analyses

Feed analyses was preformed by Optilab in Lidköping. Crude protein was analyzed according to Dumas and digestible protein were calculated using a coefficient for digestibility according to Spörndly. (2003). Ash content was analyzed by combustion in 525 °C. When analyzing the DM, a sample was dried in 60 °C and were then stored in 130 °C overnight. NDF were analyses according to Chai and Udén. (1998) with 100% ND-solution, amylase and sulfite. Metabolisable energy (ME) was determined by incubation in rumen fluid and buffer for 96 hours (Lindgren, 1979) and calculating the ME concentration using the in vitro disappearance of rumen organic matter according to Lindgren. (1983). Cobalt, selenium and molybdenum were analyzed according to NMKL 161 (1998). The other macro and micro minerals were analyzed according to Balsberg-Påhlsson. (1990).

Weighing and body condition scoring of the lambs

All lambs were weighed in a portable scale (Iconix 21) each week. Body condition scoring was used to determine if the animals were being mature enough to go to slaughter or not when looking at body fat. Body condition scoring was performed according to the Swedish standards with 15 classes ranging from 1- to 5+ (Sjödin 2007). In this study, the goal was to slaughter at the score 3. The goal of live weight at slaughter was between 47 to 50 kg.

Slaughter

Due to practical reasons, animals were kept indoors at the farm (Götala or Härlunda) the night before slaughter. They had free access to water and silage until transport to slaughter at Skara Lammslakteri. Animals were transported to the slaughterhouse at approximately 8 am and were transported in a horse trailer driven by staff from SLU. All animals were slaughtered at a commercial slaughterhouse about ten minutes from the research center. The lambs were made unconscious by captive bolt stunning and were then exsanguinated within 6 ± 2 seconds. At slaughter parameters as blood lactate value (at slaughter), slaughter weight and pH- and temperature decline over 24 hours were recorded. Lactate was measured (Lactate Plus device from Nova Biomedical) in blood from the exsanguination procedure. In the first two carcasses the pH and temperature meter (Metler Toledo, Seven2Go pro) was inserted between the third and fourth rib, but due to insecure measurements the meter was inserted in the topside (inner side of the hind leg) in the 71 crcasses left (Picture 7 and 8). Due to technical problems with the meters, pH and temperature were only measured in 73 out of the 80 carcasses. The meter was inserted in the carcass approximately 59 minutes after stunning. The meters were always inserted in the left side of the carcass and were attached in its strap, to the hook, which the carcasses were hanging on or the left hind leg, during the measuring time. The meters were programmed to record both pH and temperature every 10 minutes during 24 hours. After 24 hours, core temperature should be reached in the carcass and nothing more is expected to happen in terms of pH. Between tests the pH and temperature meters were calibrated with buffer solution with pH 4.0 and 7.0. The probes were also cleaned with pepsin solution to prevent protein residues and with ethanol to prevent fat residues. When not in use, the probes were stored in a saturated potassium chloride solution (KCl 3 mol/l).

Picture 7 and 8. Measuring of pH and temperature in carcasses after slaughter.

Statistical analysis

The statistical analysis were performed using Statistical Analysis Software (SAS 9.4, SAS Inst. Inc., Cary, NC, USA). Data were analyzed using Proc Mixed. Production system, with four sub classes, were included as fixed effect and animal were treated as random (20 lambs/treatment) in the statistical model. Tukey's test was used to make parewise comparisons between treatments. Differences with a p-value <0.05 were considered significant.

RESULTS

The rearing system had a significant effect on LWG with Group 1 having the highest LWG (Table 5). Weight at slaughter show a significant difference between groups. Group 1 had the highest weight at slaughter, significantly higher than groups 3 and 4, whereas group 2 had a significantly higher slaughter weight than group 3 (Table 5). Further, Group 4 had lower conformation and fat scores as well as dressing percentage than the other groups. If converting the conformation scoring to the EUROP scale, the different groups had; group 1 had R+, group 2 had R+, group 3 had R+ and group 4 had R. If classifying the scoring for fatness the results gave; group 1 had 3-, group 2 had 3, group 3 had 3- and group 4 had 2+/3- (Table 6). Temperature at pH 6.0 differed between groups, the results show a significant difference in temperature at pH 6.0 between group 1 and the other three groups (Figure 2), were group 1 had a lower temperature at pH 6.0 compared to the other groups (Table 6). There were no differences between groups for blood lactate values, pH values after 24 hours, final temperature after 24 hours or the pH six days after slaughter (Table 6).

Table 5. Live weight (kg) and age of the lambs reared in the different production models at start of the experiment and at slaughter.

Parameters	Group 1[1]	Group 2	Group 3	Group 4	SEM[2]	Significance
Weight at start	26.4	26.8	26.4	26.0	0.65	NS
Weight at slaughter	50.6^{a}	50.3^{ab}	48.3^{c}	48.9^{bc}	0.54	0.0112
Days in experiment	64.7^{d}	82.4^{c}	91.3^{b}	109.1^{a}	2.56	< 0.0001
Growth (g day^{-1})	377^{a}	287^{b}	244^{c}	211^{d}	7.92	< 0.0001

[1]Group 1 on indoor feeding, group 2 on cultivated pasture with 0.3 kg supplemented concentrate per lamb daily, group 3 on only cultivated pasture and group 4 on only semi natural pasture.
[2] SEM = standard error of the mean.
[a-d]Mean values with different superscripts in the same row differ significantly ($P < 0.05$).
NS: non-significant ($P > 0.05$).

Table 6. Carcass and meat quality from lambs reared in the different production models.

Parameters	Group 1[1]	Group 2	Group 3	Group 4	SEM[2]	Significance
Conformation[c]	9.2[a]	8.7[a]	8.7[a]	7.9[b]	0.24	0.0024
Fatness[d]	7.4[a]	7.7[a]	7.4[a]	6.5[b]	0.17	< 0.0001
Dressing (%)	42[a]	42[a]	41[a]	37[b]	0.40	< 0.0001
Lactate (mmol L^{-1})	3.2	3.7	3.2	2.9	0.55	NS
pH after 24h	5.83	5.66	5.77	5.59	0.10	NS
Temperature after 24h (°C)	3.1	3.5	3.2	3.0	0.28	NS
Temperature at pH 6.0 (°C)	19.0[a]	32.6[b]	32.4[b]	35.5[b]	1.80	< 0.0001
pH after 6 days	5.45	5.40	5.45	5.41	0.03	NS

[1]Group 1 on indoor feeding, group 2 on cultivated pasture with 0.3 kg supplemented concentrate per lamb daily, group 3 on only cultivated pasture and group 4 on only semi natural pasture.
[2] SEM = standard error of the mean.
[a-b]Mean values with different superscripts in the same row differ significantly ($P < 0.05$).
NS: non-significant ($P > 0.05$).
[c] According the EUROPE-system where 1=P-, 2=P, 3=P+, 4=O-, 5=O, 6=O+; 7=R-, 8=R, 9=R+, 10=U-, 11=U, 12=U+, 13=E-, 14=E and 15=E+.
[d] According the EUROPE-system where 1=1-, 2=1, 3=1+, 4=2-, 5=2, 6=2+; 7=3-, 8=3, 9=3+, 10=4-, 11=4, 12=4+, 13=5-, 14=5 and 15=5+.

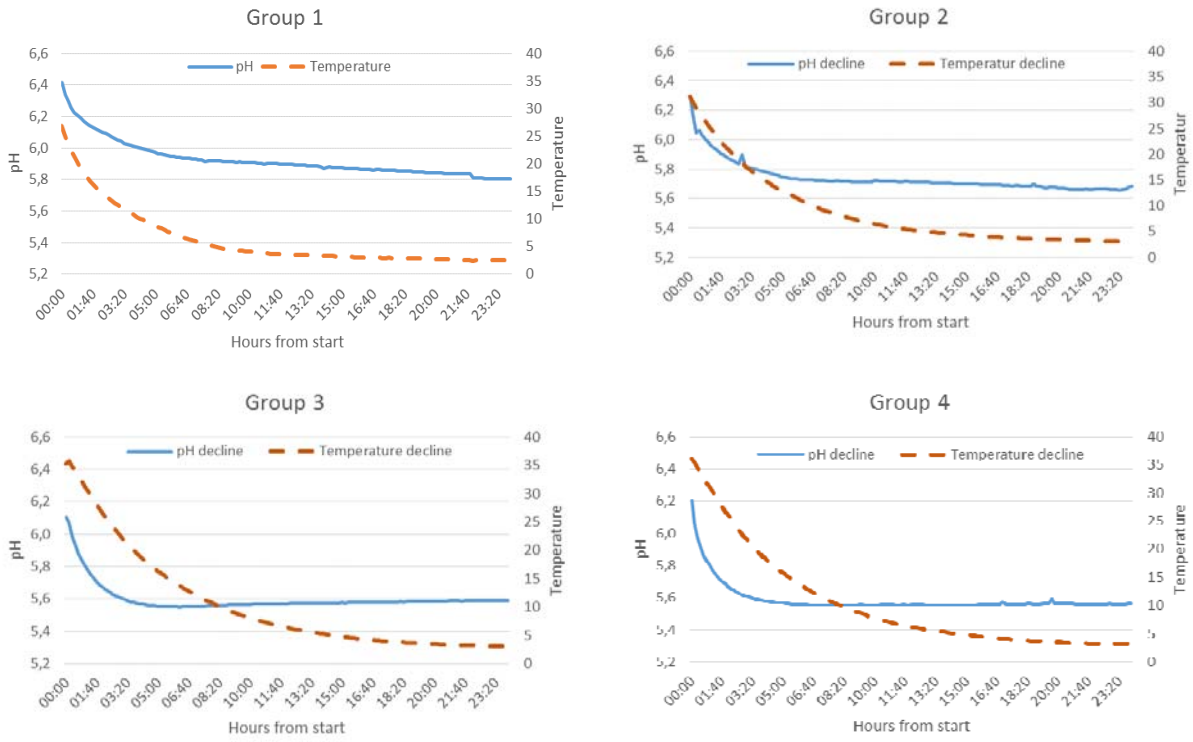

Figure 2. pH and temperature decline during 24 hours from slaughter.
**group 1 on indoor feeding, group 2 on cultivated pasture with 0.3 kg supplemented concentrate per lamb daily, group 3 on only cultivated pasture and group 4 on only semi natural pasture.*

DISCUSSION

Different feeding strategies

In unity to the results of no significant difference in final pH and temperature between different pastures, Díaz *et al.* (2002) found the same results. Growth differences in Díaz *et al.* (2002), were not as high as in this study. This can indicate that there are no differences in final pH and temperature between pasture groups even if the growth intensity varies between groups. The two different groups on cultivated pasture (group 2 and 3) were reared with different feeding intensities, to evaluate if there were any differences in growth, final pH and temperature after slaughter. As shown in the results, there were a significant difference in growth but not in final pH and temperature between these groups. If there would be any differences in final pH and temperature if the intensity differed more between groups, could be a future topic to evaluate. It would also be valuable to investigate the economical profit when comparing these systems. Other studies have shown differences in final pH between groups with different feeding intensities on pasture (Young et al., 1994; Pethick et al., 2005; Campbell et al., 2012), which does not correspond to the results from the different feeding treatments tested in this study. However, these studies have just presented the nutrient content of the feeds very briefly, which makes it hard to compare to this study. Tendency for pasture lambs to have a higher final pH than stall lamb (Priolo et al., 2002), does not correspond to results from this study, even if there are no significant differences, if having the mean values for each group in mind the lambs raised indoor had the highest pH values after 24 hours. It would be interesting to compare different feeding strategies indoor, to evaluate if different treatments such as high energy diet with/without concentrate versus low energy diet with/without concentrate affects final pH. And thereby compare differences in feeding intensity indoors. It could also be interesting to evaluate if there are any differences in meat quality in lambs that does not finish on pasture but are reared indoor until slaughter in late autumn, winter or spring.

Effect of production system on general parameters

The results show that intact lamb rams can be reared under both intensive and extensive conditions and that would not affect the meat quality in terms of final temperature and pH negatively. The same goes for carcass conformation and fatness, a more intensive production such as group 1 and 2 as well as the more intermediate production such as group 3, resulted in carcasses with a significantly higher conformation- and fatness score compared to group 4, which could be profitable for the producer when animals are slaughtered. As expected, feeding intensity had a significant impact on growth per day and days until slaughter between all four groups. The results suggest that although group 3 were reared at lower intensity than groups 1 and 2, this group could finish up for slaughter on only cultivated pasture. This is referred to that there were no significant differences between group 1, 2 and 3 when comparing conformation and fatness of carcasses. The energy content in pasture for group 3 was lower than for group 2, even if samples was taken from the same but different parts of the cultivated pasture. The results could be due to differences in sward composition over the pasture which could influence the nutritional content when measuring at different locations on the same type of pasture. The establishment and proportion of the different species in the mix could therefore have been different in the different locations of the field. Differences in the cultivated pasture that the naked eye could distuinguish was that some parts of the paddocks for group 3 contained a higher concentration of clover rather than grass. Group 4, however, did not finish up for slaughter on only semi natural pasture, according to conformation and fatness of carcasses.

Even if the nutrient content of the semi natural pasture was good according to table 2, it is crusial to understand that the amount of available pasture for group 4 was less than for the other pasture groups (Figure 1). This scenario is important when considering the growth for group 4, that the smaller amount of feed affected the growth potential even if the nutritional content was good and should promote a good growth capacity. One other factor could be the pasture samples from this group. Since they stayed in the same pasture for a longer time and fed on the pasture without letting it regrow in the same extent as the other rotating pasture groups, this contributes to that the pasture samples for this group also contains parts that they did not eat. Or at least what they did not prefere since it was left to take pasture samples of. These samples were diverse and could give a somewhat misleading idea of what nutritional value the pasture had that the lambs in fact grew on. To get this type of animals (group 4) ready for slaughter in the fall, supplement feeding could be a good investment. Alternatively, to advance the lambing season to earlier in the spring to promote an earlier release on pasture.

Effect of production system on pH and temperature

As the results show, there were no significant differences in final pH or final temperature after 24 hours between treatments. This result could indicate that there are no differences in final pH or temperature between feeding intensities such as those in this experiment. Since the production models in the experiment are conducted to evaluate the most common production models in the Swedish lamb meat production, the results indicate that there are no differences in final pH or temperature depending on production model. Although pH is an indicator and not an absolute value for a good meat quality (tenderness), it is still the most used method today and the best way so far to indicate good meat quality since it is non invasive and keeps the meat sellable.

When comparing the results of final pH in this study to earlier research it was shown that most tender meat had a final pH of 5.5-5.7, according to Devine et al. (1993). This statement could indicate that meat from groups 2 and 4 could have more tender meat as there final pH corresponds to the final pH of the most tender meat in Devine et al. (1993). This comparison is interesting since the results are not significant, but in this case, when comparing recommended pH, there are two groups that have better values in final pH, groups 2 and 4. These results indicate that groups 1 and 3 could result in less tender meat. If this is the case it is for future results to show. If tenderness are non-significant between groups that could indicate that the recommended values for final pH in Swedish lamb meat should be within a different interval.

When comparing the results in final pH to recommendations from Meat Standards Australia (MSA; Australia) and the Alliance Group (New Zealand), the values from the current study appears to be quite good. According to MSA, which recommends a final pH of 5.70, group 2 and 4 should contain meat of better quality than groups 1 and 3 which according to MSA both had a final pH that are considered to be too high (MSA 2015a). Further, according to the recommendations from The Alliance group, group 2, 3 and 4 are categorized to have better final pH than group 1 whose value (5.83) is considered to be intermediate (Alliance Group limited 2010). If these recommended values are adaptable onto the Swedish lamb production systems are for future tests to show. These values could be a good overall recommendation for the whole lamb production worldwide, or not acceptable for Swedish breeds and production models. Since the recommendations from other countries differ, it definitely implies that national recommendations for Swedish production are to be recommended for the future. Rather than implement recommendations

from other countries that may not correspond with Swedish circumstances in production. If Sweden should adopt recommendations from another country, which should be chosen? Since the recommendations worldwide are not corresponding, which could be due to differences in for example production system, could there be factors in the Swedish production such as age, breed and so on that provides a necessity for own national recommendations? If so, a final pH value over 5.8, such as in group 1, which is too high according to the MSA recommendations, but intermediated according to the Alliance Group, may not have a negative effect on lamb meat quality in the most common Swedish production systems.

Effect of production system on temperature at pH 6.0

In this study the pH and temperature decline were at first measured between the ribs in the carcasses of lambs that were slaughtered first. The highest proportion of lambs that were slaughtered first were of group 1, which led to that some of the results from this group were measured between the ribs and not in the topside. This could have influenced the low temperature at pH 6.0 for this group. But if that error corresponds to the low temperature mean or not could not be proved.

Considering both the fast drop in pH for group 3 and 4 and the high ultimate pH that occurred in some of the carcasses, both PSE and DFD could have been a problem occurring in meat from the experiment. In the study there were recordings from carcasses that showed both a very fast drop in pH in relation to time after slaughter that corresponds to the characteristics of PSE (pH below 6.0 during the first 45 minutes after slaughter). As well as for DFD where pH should still be over 6.0 in 12-24 hours after slaughter (Warris, 2010). When looking at the other quality problems corresponding to temperature and pH, cold- and heat shortening, could be a problem according to the results of this study. According to the results, group 1 had significantly lower temperature in the muscle when pH reached 6.0. To have a maximized tenderness the muscle should enter rigor at approximately 15 °C (Geesink et al., 2000). This prospect indicates that meat from group 2, 3 and 4 could be less tender that meat from group 1. Geesink *et al.* (2000) also stated that heat shortening occurred more frequent if the temperature were 35 °C or more at rigor. If that is adaptable to conditions in this study, meat from group 4 could have problem with heat shortening. It could on the other hand be interesting to investigate if heat shortening occurred in meat from groups 2 and 3 and thereby either accept the temperature limit of 35 °C or introduce a new recommendation according to the conditions in this experiment. Since there are literature which claim that lower temperature range, as for example 18-25 °C are recommended to prevent quality problems to exist it would be interesting to evaluate if a different temperature range could be recommended when adapting to Swedish production conditions. The prospects above are also supported by van de Ven *et al.* (2013) that recommends a temperature range of 18-35 °C to promote good meat quality. There is also literature that indicate that groups 2, 3 and 4 could have tougher meat than group 1, since these groups are outside the temperature range of 10-30 °C in Achilles tendon hanged carcasses (Thompson et al., 2005). To ensure which temperature range to recommend for Swedish conditions are as indicated earlier, an interesting prospect to evaluate further. As shown earlier, there are a variety of recommendations from different organizations and studies made from different parts of the world. Which recommendations that should be set for the Swedish circumstances of production are once again an interesting problem to solve in the future. Since there are a lot of variations in the international recommendations there could be a variation in what the optimal

circumstances in Swedish production should imply compared to other countries with different production systems.

Effect of production system on pH after six days

Literature reports that pH were measured between 0 hours after slaughter to 21 days after slaughter (Koohmaraie et al. 1995; Okuedo & Moss. 2008; McPhail et al., 2014). The time at which final pH has been measured most frequently were 24 hours after slaughter (Koohmaraie et al. 1991; Koohmaraie et al. 1995; Watanabe et al. 1996; McGeehin et al. 2001; Díaz et al. 2002; Priolo et al. 2002; Sañudo et al. 2003; Velasco et al. 2004; Pethick et al, 2005; Teixeira et al. 2005; Majdoub-Mathlouthi et al. 2013; Majdoub-Mathlouthi et al. 2015). When comparing the pH results after 24 hours the groups 1 to 4 had; 5.83, 5.66, 5.77 and 5.59 respectively. After six days the same groups had a pH of; 5.45, 5.40, 5.45 and 5.41 respectively, there is a difference. With this information in mind, are measurements up to 24 hours after slaughter enough to evaluate the final pH in meat? The results from the present study indicate that the reduction in pH continues even after the first 24 hours after slaughter. These results are not totally unexpected, but the point however is that it could be valuable to make additional measurement of pH in meat even after 24 hours to determine what pH value that piece of meat could be expected to have when it is consumed. When looking at figure 2, it is possible to determine that group 1 and 2 did not reach a plateau in pH value, which group 3 and 4 did. That could indicate that group 1 and 2 had not reached a final pH after 24 hours. Since the values were different, it should be interesting to evaluate at which time after slaughter that the pH decline generally has reached a stable level. If pH continues to drop even after the 24 hours after slaughter it should be valuable to know how much, since this phenomenon then has happened when the meat should be consumed. In disagreement to these results Koohmaraie *et al.* (1995) reports of a slight increase in pH between day 7 (5.6) and 21 (5.7), final pH after 24 hours were 5.6, which provides further evidence that final pH could be measured after 24 hours to give a higher accuracy of the actual pH in meat closer to consumption. Since there are only one report that has measured pH after a longer time than 24 hours after slaughter, and since pH values between 24 hours and six days differed in this study. It would be interesting and probably valuable to investigate this further and see if the decrease in pH are a common problem even after 24 hours or 7 days. It would also be valuable to look for difference in this process between production systems since a lot of the other recommendations regarding pH differ when comparing different studies and recommendations. Therefore it could be more accurate to establish national recommendations rather than imply recommendations from studies made in other production systems.

Effect of production system on blood lactate value at slaughter

Lactate is a parameter indicating so called acute stress. The results show that there were no significant differences in lactate values between treatments. But what does the lactate value actually describe in these situations? The acute stress, yes, but if the animal had been under stress for a longer period of time, these results does not show. In literature it is often described how lactate values are sampled together with cortisol and/or glucose, to get a better indication of how the stress situation in the animal are progressing (Liste et al., 2011). When comparing the lactate values from this study, with values from literature, lactate values from this experiment does not seem high in comparison to the other studies (Cotrell et al., 2008; Liste et al., 2011; Zhong et al., 2011). In fact the lactate levels from this study were very low compared to other studies. If this proves that lambs in this study experienced lower stress levels, in terms of acute stress (Sjaastad, 2010), than previously

conducted tests from lambs referred to as stressed cannot be stated. The low lactate values could, however, indicate that lambs in this study could have been under a low stress level at slaughter. This could furthermore explain a non-significant result between final pH and treatment since there were no significant lactate values in this study either. Since the lactate values were rather low and final pH values are all roughly among the recommended values, glycogen values at slaughter may have been sufficient enough for a favorable pH reduction (Sjaastad, 2010), which could again indicate that the lambs were not physiologically affected by stress at slaughter. When comparing final pH from this study, with the highest final pH of 5.83, with values from stressed animals (Devine et al., 1992), values from this study corresponds to pH values from lambs exposed to low/medium stress according to Devine *et al*. (1992). It is hard to compare stress levels between studies but this could again give an indication of that lambs from this study experienced a low level of stress at slaughter.

CONCLUSION

The four different production models tested in this study; indoor, cultivated pasture with or without supplemented concentrate or semi natural pasture, did not affect meat quality in terms of final pH and temperature in muscle as well as pH six days after slaughter. Parameters that on the other hand were affected by treatment and could be of importance in the actual production were days in experiment, weight at slaughter, growth, conformation and fatness. Lambs reared on cultivated pasture had better carcass classfications (conformation and fatness) than lambs reared on semi natural pasture even if the slaughter wieghts were similar. Even though the nutritional content of the two pastures were similar, the quantity was lower at the semi natural pasture. In addidtion, the parasite burden was higher on the semi natural pasture compared to the cultivated one, which affected the daily weight gain.

FUTURE RESEARCH

If there are other factors that affects meat quality in Swedish lamb are for the future to show. Are one of these factors to measure pH after a longer time post-slaughter? Could the different types of breeds affect pH and therefore meat quality? Or are there differences between sexes in our Swedish breeds? Could electrical stimulation be used as a helpful tool to provide a better meat quality? There are many more questions that needs to be answered where meat quality of Swedish lambs are concerned. If the future strategy is to increase a stable quality of Swedish lamb meat, it is necessary to understand how all production factors affect meat quality in the specific Swedish sheep breeds and under Swedish conditions. Only then will it be possible to rear, slaughter and process Swedish lamb meat with a consistent quality that the Swedish consumer demands.

ANNEX 1

Dictionary (Latin-English-Swedish) over the different muscles in the text.

Latin	**English**	**Swedish**
Musculus infraspinatus	Infraspinatus muscle	Luffarbiff
Musculus longissimus dorsi/ Musculus longissimus thoracis et lumborum	Eye-muscle/longissimus muscle	Ryggbiff + entrecote
Musculus longissimus lumborum	Strip loin	Ryggbiff
Musculus longissimus thoriacis	Cube roll	Entrecote
Musculus semimembranosus	Topside	Innanlår
Musculus semitendinosus	Eye round	Rulle
Musculus supraspinatus	Mock tender, chuck tender, scotch tender or catfish	Bogrulle

ANNEX 2

Table over references for recommended or recorded pH values.

Reference	Treatment/treatments	Final pH	Muscle
Devine *et al.* (1993)	18 kg carcasses	5.5-5.7	*M. longissimus dorsi*
Meat Standards of Australia (MSA 2015a)	Recommendation	<5.7	
Alliance group (Alliance Group Limited 2010)	Recommendation	5.4-5.8	*M. longissimus*
Díaz *et al.* (2002)	Low weight (10.6kg) carcasses High weight (13.4kg) carcasses	5.51 5.71	*M. longissimus dorsi*
Campbell *et al.* (2012)	High growth rate (280-350g/day) Low growth rate (190-250g/day)	5.87 5.77	
Majdoub-Mathouthi *et al.* (2015)	Reared on pasture Reared indoors	6.19 6.33	*M. longissimus thoracis*
Priolo *et al.* (2002)	Reared on pasture Reared indoors (hay + concentrate)	5.62 5.57	*M. longissimus dorsi*
Priolo *et al.* (2002)	High growth rate (238g/day) Low growth rate (185g/day)	5.57 5.63	*M. longissimus dorsi*
Hopkins *et al.* (2005)	Low growth rate High growth rate	5.63 5.55	*M. longissimus dorsi*
Young *et al.* (1994)	Seven different pastures	5.4-6.4	*M. longissimus dorsi*
Velasco *et al.* (2004)	Pasture + concentrate Pasture + barley	5.54 5.66	*M. longissimus dorsi* and *M. semitendinosis*
Young *et al.* (1993)	Coopworth Merino	5.77 6.16	*M. longissimus lumborum*
Young *et al.* (1993)	Purebred Merino Border Leicester x Merino Oxford Down x Merino Suffolk x Merino Poll Dorset x Merino Texel x Merino	6.37 6.03 5.95 6.08 5.93 5.97	*M. longissimus lumborum*
Sañudo *et al.* (2003)	Different ages, breeds, sexes and carcass weight	5.44-5.84	*M. longissimus*
Okeudo and Moss (2008)	Entire rams Castrated rams Vectomised rams Ewes	5.73 5.67 5.69 5.69	*M. longissimus dorsi*
Johnson *et al.* (2005)	Entire rams Ewes	5.66 / 5.74 5.63 / 5.60	*M. semimembranosus* and *M. longissimus*
Liste *et al.* (2011)	High lactate values (12.91 mmol/L) Low lactate values (9.64 mmol/L)	5.65 5.68	*M. longissimus*
Zhong *et al.* (2011)	High lactate: 6 months old High lactate: 12 months old Low lactate: 6 months old Low lactate: 12 months old	6.43 5.64 6.62 5.84	*M. longissimus*

ANNEX 3

Table over references for at which temperature pH was 6.0.

Reference	**Treatment/treatments**	**Temperature (°C) at pH 6.0**	**Muscle**
Meat Standards of Australia (MSA 2015a)	Recommendation	8-18	
Quality Meat Scotland (QMS)	Recommendation	12-35	
Geesink *et al.* (2000)		15	
Thompson *et al*. (2005)	Achilles tendon hanged carcasses	10<°C>30	*M. longissimus lumborum*
Ven *et al*. (2013)		18<°C>35	*M. longissimus lumborum*
Toohey *et al.* (2006)		18<°C>25	*M. longissimus dorsi*
Savell *et al*. (2005)	Avoid heat shortening	10<°C at pH 6.2	

REFERENCES

Alliance Group Limited. July 2010. Research into Lamb Meat Quality. [Brochure]

Balsberg-Påhlsson, A.M. (1990). Handledning i kemiska metoder vid växtetologiska arbeten. 6th edition. (Manual for chemical analyses in plant ecological work). Medelenaden från växtekologiska avdelningen, Lunds Universitet Nr 52. ISSN 0348-2456.

Bouton, P.E., Harris, P.V. & Shorthose, W.R. (1971). Effect of ultimate ph upon the water-holding capacity and tenderness of mutton. *Journal of Food Science,* vol. 36(3), 435-439.

Bouton, P.E., Harris, P.V. & Shorthose, W.R. (1972). The effects of ultimate ph on ovine muscle: water-holding capacity. *Journal of Food Science,* vol. 37(3), 351-355.

Campbell, A.W., Maclennan, G., Lindsay, S., Behrent, M.R., Cheong, I. & Kerslake, J.I. (2012). Brief communication: Exploring the effects of growth rate and meat yield on lamb meat quality. *Proceedings of the New Zealand Society of Animal Production,* vol.72, 150-151.

Chai, W. & Udén, P. (1998). An alternative oven method combined with different tetergent strenghts in the analysis of neutral detergent fiber. *Animal Feed Science and Technology*, vol. 74(4), 281-288.

Cottrell, J.J., McDonagh, M.B., Dunshea, F.R. & Warner, R.D. (2008). Inhibition of nitric oxide release pre-slaughter increases post-mortem glycolysis and improves tenderness in ovine muscles. *Meat Science,* vol. 80(2), 511-521.

Devine, C.E., Graafhuis, A.E., Muir, P.D. & Chrystall, B.B. (1993). The effect of growth rate and ultimate pH on meat quality of lambs. *Meat Science,* vol. 35(1), 63-77.

Díaz, M.T., Velasco, S., Cañeque, V., Lauzurica, S., Ruiz de Huidobro, F., Pérez, C., González, J. & Manzanares, C. (2002). Use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. *Small Ruminant Research,* vol. 43(3), 257-268.

Ferguson, D.M. & Warner, R.D. (2008). Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? *Meat Science,* vol. 80(1), 12-19.

Gardner, G.E., Kennedy, L., Milton, J.T.B. & Pethick, D.W. (1999). Glycogen metabolism and ultimate pH of muscle in Merino, first-cross, and second-cross wether lambs as affected by stress before slaughter. *Australian Journal of Agricultural Research,* vol. 50(2), 175-182.

Geesink, G.H., Bekhit, A.D. & Bickerstaffe, R. (2000). Rigor temperature and meat quality characteristics of lamb longissimus muscle. *Journal of Animal Science,* vol. 78(11), 2842-2848.

Hopkins, D.L., Hegarty, R.S. & Farrell, T.C. (2005). Relationship between sire estimated breeding values and the meat and eating quality of meat from their progeny grown on two planes of nutrition. *Australian Journal of Experimental Agriculture,* vol. 45(5), 525-533.

ISO 15914:2004. (2004). Animal feeding stuffs- Enzymatic determination of total starch content. International Organization for Standardization.

Johnson, P.L., Purchas, R.W., McEwan, J.C. & Blair, H.T. (2005). Carcass composition and meat quality differences between pasture-reared ewe and ram lambs. *Meat Science,* vol. 71(2), 383-391.

Jordbruksverket. *Husdjur efter län/riket och djurslag*. Available: http://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Husdjur__Antal%20husdjur/JO0103G5.px/table/tableViewLayout1/?rxid=5adf4929-f548-4f27-9bc9-78e127837625 [2016-10-24]

Jordbruksverket. (2016) *Marknadsrapport lammkött*. [Brochure] Available: http://www.jordbruksverket.se/amnesomraden/handelmarknad/kottmjolkochagg/marknadenforkottmjolkochagg/marknadenforlammkott.4.449e88113dc95b78dc80001638.html [2016-10-24]

Jordbruksverket. *Slakt av större husdjur vid slakteri.* Available: http://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Animalieproduktion__Slakt/JO0604A3.px/table/tableViewLayout1/?rxid=5adf4929-f548-4f27-9bc9-78e127837625 [2016-09-09]

Koohmaraie, M.,Shackelford, S.D., Wheeler, T.L., Lonergan, S.M. & Doumit, M.E. (1995). A muscle hypertrophy condition in lamb (Callipyge): Characterization of effects on muscle growth and meat quality traits. *Journal of Animal Science,* vol. 74(12), 3596-3607.

Koohmaraie, M., Whipple, G., Kretchmar, D.H., Crouse, J.D. & Mersmann, H.J. (1991). Postmortem proteolysis in longissimus muscle from beef, lamb and pork carcasses. *Journal of Animal Science,* vol. 69(2), 617-624.

Lannhard Öberg, Å. (2016). *Marknaden för lammkött.* Jordbruksverket. http://www.jordbruksverket.se/amnesomraden/handelmarknad/kottmjolkochagg/marknadenforkottmjolkochagg/marknadenforlammkott.4.449e88113dc95b78dc80001638.html

Lindgren, E. (1979). Vallfodrets näringsvärde bestämt in vivo med olika laboratoriemetoder, Report 45. The Department of Animal Nutrition and Management, The Swedish University of Agricultural Sciences, Uppsala, Sweden (in Swedish).

Lindgren, E. (1983). Nykalibrering av VOS-metoden för bestämning av energivärde hos vallfoder. The Department of Animal Nutrition and Management, The Swedish University of Agricultural Sciences, Uppsala, Sweden (in Swedish).

Liste, G., Miranda-de la Lama, G.C., Campo, M.M., Villarroel, M., Muela, E. & María, G.A. (2011). Effect of lairage on lamb welfare and meat quality. *Animal Production Science,* vol. 51(10), 952-958.

Majdoub-Mathlouthi, L., Saïd, B., Say, A. & Kraiem, K. (2013). Effect of concentrate level and slaughter body weight on growth performances, carcass traits and meat quality of barbarine lambs fed oat hay based diet. *Meat Science*, vol 93, 557-563.

Majdoub-Mathlouthi, L., Saïd, B. & Kraiem, K. (2015). Carcass traits and meat fatty acid composition of Barbarine lambs reared on rangelands or indoors on hay and concentrate. *Animal*, vol 9(12), 2065-2071.

McGeehin, B., Sheridan, J.J. & Butler, F. (2001). Factors affecting the pH decline in lamb after slaughter. *Meat Science,* vol. 58(1), 79-84.

McPhail, N.G., Stark, J.L., Ball, A.J. & Warner, R.D. (2014). Factors influencing the occurrence of high ultimate pH in three muscles of lamb carcasses in Australia. *Animal Production Science,* vol. 54(10), 1853-1859.

MSA(b) (Meat Standard Australia). Tips & Tools Meat Standrad Australia. The effect of nutrition and growth on sheepmeat eating quality. [Brochure]

MSA(a) (Meat Standard Australia). Tips & Tools Meat Standrad Australia. The effect of pH on sheepmeat eating quality. [Brochure]

NMKL, 161. (1998). Metaller. Bestämning i livsmedel med atomabsorptionspktrofotometri efter våtuppslutning i mikrovågsugn. NordVal International.

Official Journal of European Communities (OJEC) 1984. Determination of crude oils and fats. Method B. Official Journal of the Europeanm Communities 15, 29-30.

Okeudo, N.J. & Moss, B.W. (2008). Production performance and meat quality characteristics of sheep comprising four sex-types over a range of slaughter weights produced following commercial practice. *Meat Science,* vol. 80(2), 522-528.

Pethick, D.W., Davidson, R., Hopkins, D.L., Jacob, R.H., D'Souza, D.N., Thompson, J.M. & Walker, P.J. (2005). The effect of dietary treatment on meat quality and on consumer perception of sheep meat eating quality. *Australian Journal of Experimental Agriculture,* vol. 45(5), 517-524.

Priolo, A., Micolo, D., Agabriel, J., Prache, S. & Dransfield, E. (2002). Effect of grass or concentrate feeding system on lamb carcass and meat quality. *Meat Science*. vol. 62, 179-185.

Quality Meat Scotland. Scotch Lamb. Lamb eating Quality Summary of good practice. [Brochure]

Sañudo, C., Alfonso, M., Sanchez, A., Berge, P., Dransfield, E., Zygoyiannis, D., Stamataris, C., Thorkelsson, G., Valdimarsdottir, T., Piasentier, E., Mills, C., Nute, G.R. & Fisher, A.V. (2003). Meat texture of lambs from different European production systems. *Australian Journal of Agricultural Research,* vol. 54(6), 551-560.

Savell, J.W., Mueller, S.L. & Baird, B.E. (2005). The chilling of carcasses. *Meat Science,* vol. 70(3), 449-459.

Sjaastad, Ø.V., Sand, O. & Hove, K. (2010). *Physiology of Domestic Animals*. 2nd. ed. Oslo: Scandinavian Veterinary Press.

Sjödin, E., Eggertsen, J., Hammarberg, K-E., Danell, Ö., Näsholm, A., Barck, S., Green, D., Waller, A., Hansson, I., Persson, S. & Kumm, K-I. (2007). *Får*. Stockholm: Natur och Kultur.

Spörndly, R. (2003). *Fodertabeller för idisslare*. Sveriges lantbruksuniversitet, Uppsala: Institutionen för husdjurens utfodring och vård (2003:257).

Sylvestre, M.N., Balcerzak, D., Feidt, C., Baracos, V.E. & Bellut, J.B. (2002). Elevated rate of collagen solubilization and postmortem degradation inmuscles of lambs with high growth rates: Possible relationship with activity of matrix metalloproteinases. *Journal of Animal Science,* vol. 80(7), 1871-1878.

Teixeira, A., Batista, S., Delfa, R. & Cadavez, V. (2005). Lamb meat quality of two breeds with protected origin designation. Influence of breed, sex and live weight. *Meat Science,* vol. 71(3), 530-536.

Thompson, J.M., Hopking, D.L., Souza, D.N.D., Walker, P.J., Baud, S.R. & Pethick, D.W. (2005). The impact of processing on sensory and objective measurements of sheep meat eating quality. *Australian Journal of Experimental Agriculture,* vol. 45(5), 561-573.

Toohey, E.S., Hopkins, D.L., McLeod, B.M. & Nielsen, S.G. (2006). Quantifying the rate of pH and temperature decline in lamb carcasses at three abattoirs in New South Wales. *Australian Journal of Experimental Agriculture,* vol. 46(7), 875-878.

Van de Ven, R.J., Pearce, K.L. & Hopkins, D.L. (2013). Modelling the decline of pH in muscles of lamb carcases. *Meat Science,* vol. 93(1), 79-84.

Velasco, S., Cañeque, V., Lauzurica, S., Pérez, C. & Huidobro, F. (2004). Effect of different feeds on meat quality and fatty acid composition of lambs fattened at pasture. *Meat Science,* vol. 66(2), 457-465.

Wallin, K., Arnesson, A. & Arvidsson Segerkvist, K. (2016). *Lammslakt vid svenska slakterier – en enkätstudie*. Skara: Sveriges Lantbruksuniversitet Instutitionen för husdjurens miljö och hälsa Avdelningen för produktionssystem (2016:41).

Warriss, P.D. (2010). *Meat science: an introductionary text*. 2nd. ed. Oxon: Marston book services LtD.

Watanabe, A., Daly, C.C. & Devine, C.E. (1996). The effects of the ultimate pH of meat on tenderness changes during ageing. *Meat Science,* vol. 42(1), 67-78.

Watkins, P.J., Frank, D., Singh, T.K., Young, O.A. & Warner, R.D. (2013). Sheepmeat flavour and the effect of different feeding systems: A review. Journal of Agricultural and Food Chemistry, vol. 61(15), 3561-3579.

Young, O.A., Cruickshank, G.J., MacLean, K.S. & Muir, P.D. (1994). Quality of meat from lambs grazed on seven pasture species in Hawkes Bay. *New Zealand Journal of Agricultural Research,* vol. 37(2), 177-186.

Young, O.A., Reid, D.H. & Scales, G.H. (1993). Effect of breed and ultimate pH on the odour and flavour of sheep meat. *New Zealand Journal of Agricultural Research,* vol. 36(3), 363-370.

Zhong, R.Z., Liu, H. W., Zhou, D.W., Sun, H.X. & Zhao, C.S. (2011). The effects of road transportation on physiological responses and meat quality in sheep differing in age1. *Journal of Animal Science,* vol. 89(11), 3742-3751.

Vid **Institutionen för husdjurens miljö och hälsa** finns tre publikationsserier:

*** Avhandlingar:** Här publiceras masters- och licentiatavhandlingar

*** Rapporter:** Här publiceras olika typer av vetenskapliga rapporter från institutionen.

*** Studentarbeten:** Här publiceras olika typer av studentarbeten, bl.a. examensarbeten, vanligtvis omfattande 7,5-30 hp. Studentarbeten ingår som en obligatorisk del i olika program och syftar till att under handledning ge den studerande träning i att självständigt och på ett vetenskapligt sätt lösa en uppgift. Arbetenas innehåll, resultat och slutsatser bör således bedömas mot denna bakgrund.

Vill du veta mer om institutionens publikationer kan du hitta det här:
www.slu.se/husdjurmiljohalsa

DISTRIBUTION:

Sveriges lantbruksuniversitet
Fakulteten för veterinärmedicin och husdjursvetenskap
Institutionen för husdjurens miljö och hälsa
Box 234
532 23 Skara
Tel 0511–67000
E-post: hmh@slu.se
Hemsida:
www.slu.se/husdjurmiljohalsa

Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Science
Department of Animal Environment and Health
P.O.B. 234
SE-532 23 Skara, Sweden
Phone: +46 (0)511 67000
E-mail: hmh@slu.se
Homepage:
www.slu.se/animalenvironmenthealth