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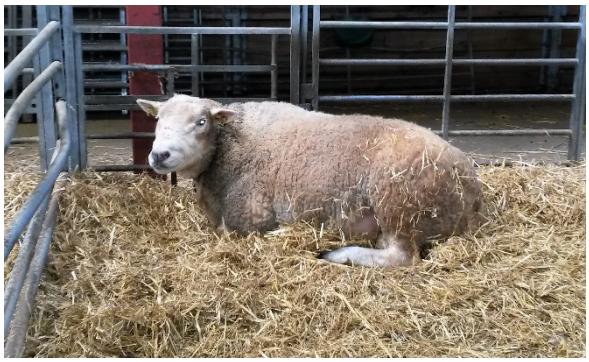
Susanna Hedlund

Skara 2017

Animal Science



Studentarbete **Nr. 706**
Sveriges lantbruksuniversitet
Institutionen för husdjurens miljö och hälsa

Student report ***No. 706***
Swedish University of Agricultural Sciences
Department of Animal Environment and Health

ISSN 1652-280X

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Susanna Hedlund

Studentarbete 706, Skara 2017

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

Huvudhandledare: Elisabet Nadeau, Institutionen för husdjurens miljö och hälsa, SLU, Box 234, 532 23 Skara

Biträdande handledare: **Peder Nørgaard**, Department of Large Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 3, 1870 Frederiksberg C, Denmark.

Examinator: Katarina Arvidsson-Segerkvist, Institutionen för husdjurens miljö och hälsa, SLU, Box 234, 532 23 Skara

Nyckelord: forage, maturity, particle breakdown, rumination, wether

Serie: Studentarbete/Sveriges lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, nr. 706, 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

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Förord

Det här är ett examensarbete som ingår i agronomprogrammet inriktning husdjur och omfattar 30 hp. Arbetet är gjort som en del i det större projektet ”Helsädesensilage och gräsensilage till får skördade vid olika mognadsstadier – effekt på konsumtion, foderselektion och foderutnyttjande”. Projektet pågick 2013 - 2014 och finansierades av Stiftelsen Svensk Fårforskning, Agroväst Nöt- och lammköttsprogram och Fåreafgiftsfonden, Dansk fåravl.

Jag vill tacka mina handledare Elisabet Nadeau och Peder Nørgaard för deras tålamod och engagemang för att hjälpa mig. Jag vill även tacka Annika Arnesson, Frida Dahlström, Jonas Dahl och Karin Wallin för deras hjälp med provtagningar och hantering av djuren, samt Anna Magnusson för hjälp och sällskap vid utförandet av studien. Jag vill också tacka Jan-Eric Englund, Institutionen för biosystem och teknologi, SLU Alnarp, för statistisk rådgivning. Avslutningsvis vill jag tacka min familj och mina vänner som har stöttat och uppmuntrat mig för att detta arbete ska bli färdigt.

Summary

Sheep in Sweden are generally kept on pasture when suitable and fed with a diet consisting mainly of forage, composed mainly by grass, when kept indoors. Lamb production in Sweden is steadily growing and with that the interest of different feedstuff to get a profitable production. Whole-crop barley silage has a high content of nutrients and a higher digestibility in comparison to whole-crop spring-sown wheat and oat.

The aim of this experiment was to study the effect of whole crop barley silage and grass silage harvested at different maturity stages on consumption, chewing behaviour and faecal particle size in sheep. The silages used were two grass silages harvested May 31 and June 30 and two whole-crop barley silages harvested at heading stage June 30 and at milk stage July 18. Eight wethers were divided into two 4 x 4 Latin Squares (four wethers and four periods) with one group fed forage only and the other group fed forage an rapeseed meal as protein supplementation. Each period was four weeks where the wethers were fed *ad libitum* during the first three weeks and during the fourth week they were fed restricted with 80% of *ad libitum*. At the end of the trial, all wethers had been fed all diets. During the restricted period they were kept in metabolic cages where all faeces were collected and their chewing patterns were registered. The live weight of the wethers, the body condition score and the feed intake was continuously measured throughout the trial. Samples of feed and faeces were collected daily during the restricted period.

The dry matter intake as percentage of live weight was lower for grass silages compared to the barley silages ($P < 0.01$). No difference between the maturity stages was found regarding dry matter intake. The intake of neutral detergent fibre increased with advancing maturity of the grass silages, but this could not be seen for the whole-crop barley silages ($P < 0.001$). Time spent chewing ranged from 629 to709 minutes per day, time spent ruminating ranged from 475 to 542 minutes per day and time spent eating ranged from 141 to 175 minutes per day. This is in line with other studies. The particle size in faeces was effected by forage type ($P < 0.05$). The proportion of large particles was higher in wethers fed whole-crop barley silage harvested at milk stage compared to the other silages ($P < 0.05$).

In conclusion, no large differences between the four treatments were found suggesting that whole-crop barley silages could be a suitable equivalent to grass silage in lamb production given that it is not harvested too late.

Sammanfattning

I Sverige hålls får på bete så länge det är möjligt och när de hålls inomhus utfodras de till största delen med grovfoder, oftast till största delen bestående av gräs. Lammproduktionen i Sverige växer stadigt och med det ökar också intresset för alternativa fodermedel för att få en så lönsam produktion som möjligt. Helsädesensilage av korn har ett högt näringsinnehåll och en hög smältbarhet i jämförelse med vårvete och havre.

Syftet med studien var att studera helsädesensilage av korn och gräsensilage skördade vid olika tidpunkter och deras effekter på konsumtion, tuggningsbeteende och partikelstorlek i träck hos får. De två gräsensilage som användes var skördade den 31 maj samt den 30 juni och de två helsädesensilagen av korn var skördade vid axgång den 30 juni respektive mjölkmognad den 18 juli. Åtta kastrerade baggar fördelades på två 4 x 4 romerska kvadrater (fyra baggar och fyra perioder) med en grupp som utfodrades med enbart grovfoder och en grupp som fick proteintillskott i form av rapsmjöl. Varje period var fyra veckor där baggarna under de första tre veckorna fick vänja sig vid fodret med fri tillgång och den fjärde veckan utfodrades de restriktivt med 80 % av vad de åt när de hade fri tillgång. När försöket var slut hade samtliga baggar blivit utfodrade med samtliga foder. Under perioden med restriktiv tillgång hölls baggarna i metabolismburar från vilka all träck samlades upp och där tuggningsbeteendet kunde mätas. Levande vikten av baggarna, hullbedömningar och foderintag mättes under hela försöket. Foderprover och träckprover togs dagligen under den restriktiva perioden.

När torrsubstansintaget mättes som procent av djurens levande vikt var intaget lägre av gräsensilagen i jämförelse med kornhelsädesensilagen ($P < 0,01$), men någon skillnad mellan skördetidpunkterna gick inte att se. Fiberintaget ökade med ökad mognadsgrad vid skörd för gräsensilagen, men däremot inte för kornhelsädsensilage ($P < 0,001$). Totala tuggningstiden var 629-709 minuter per dag, den totala idisslingstiden var 475 till 542 minuter per dag och den totala ättiden var 141 till 175 minuter per dag. Detta resultat stämmer överens med andra liknande, studier. Partikelstorleken i träck påverkades av vilket grovfoder som baggarna utfodrades med ($P < 0,05$). Proportionen av stora partiklar i träcken var större hos baggar som utfodrades med kornhelsädesensilage skördat vid mjölkmognad jämfört med de andra ensilagen ($P < 0,05$).

Skillnaderna mellan de fyra fodertyperna är inte så stora, vilket betyder att kornhelsädesensilage skulle kunna vara en lämplig ersättare till gräsensilage förutsatt att det inte skördas för sent.

Introduction

With a steadily growing number of sheep, the sheep industry in Sweden has been increasing for the last twenty years. In 2015 there were more than 595 000 sheep in Sweden, compared to around 400 000 in the early 1990's (Yearbook of Agricultural Statistics, 2016). The trend is towards bigger herds with more animals. The average herd in 2015 was 32 ewes, compared to 17 in 1990 (Yearbook of Agricultural Statistics, 2016). According to Kumm (2009) bigger herds give the opportunity of a more effective and profitable lamb production.

To minimize feeding costs forage is the major feedstuff used for sheep in Sweden and grazing is often used for as long periods as possible. Traditionally grass silage is used. Harvest date of grass silage has a major impact on the nutritive values of the silage. As the grass matures the lignification of the grass increases while the crude protein decreases (Fogelfors, 2011). Lately there has been an interest in investigating the use of different forages, for example whole-crop silages, compared to the traditional grass silage. Barley or other cereals are often used as nursing crops for leys. Cereals could be harvested early as whole-crop silage when the farmer needs some extra forage. It is possible to use different kinds of cereals in the making of whole crop silages. According to a study done by Nadeau (2007) barley and triticale have higher nutrient content, digestibility and also better fermentation characteristics than other cereals such as oat and wheat.

For ruminants it is of importance, not only that the feed contains enough nutrients, but that it contains enough structural material for the rumen to work properly (De Boever *et al*., 1990). However, too much fibre gives a decreased feed intake and gives a forage with lower energy content, which in turn affects the productivity of the animal in a negative way (Mertens, 1997). Because of this, it is important to get a forage that fulfils the requirements of the animal, with the right amount of energy, protein and fibre. One important aspect that influence the energy, protein and fibre concentrations of a plant is the maturity stage of the plant (Frame and Laidlaw, 2011).

A ruminant spends between two and nineteen hours a day chewing. Chewing is of importance since it reduces the feed into smaller particles making it easier for the microbes in the rumen to access the feed for degradation (Sjaastad *et al*., 2010). The total chewing time is divided between eating and rumination, where ruminating time often is the greater of the two. The time differs between different feeds offered and different feeding strategies (*ad. libitum* etc). (Mertens, 2007) How long time the animal spends chewing can be measured by different techniques, for example observations or measurements of jaw movements. Chewing is one of the factors that affect the particle size of the faeces.

Hypothesis

The hypothesis of this study is that a late harvested forage will cause a longer time spent chewing and larger particle size in faeces. It is also hypothesised that an early harvested whole-crop barley silage will be comparable with grass silages when it comes to chewing times and particle size in faeces.

Aim

The aim was to study the effect of whole crop barley silage and grass silage harvested at different maturity stages on consumption, chewing behaviour and faecal particle size in sheep.

Literature review

When keeping livestock the general aim is for the animal to produce something, such as meat or milk. The performance of the animal is affected by type of feed and how it is fed. Things such as nutrient content of the forage, the intake of the animal, the digestibility of the feed and how well the nutrients are absorbed by the animal are factors that will affect the production of the animal (Mertens, 2007). Forage is one of the major costs in the sheep industry in Sweden (Kumm, 2009) suggesting that a good forage increases the chances to have a profitable production.

Composition of forage

The composition of forage is usually described by its dry matter (DM) content. The DM content can be divided into different nutrient groups:

- Cell wall:
    - Acid detergent fibre (ADF): cellulose and lignin
    - Hemicellulose
    - Pectin
    - Protein
- Cell content:
    - Water soluble carbohydrates (WSC)
    - Proteins
    - Peptides
    - Lipids
    - Vitamins
    - Organic/nucleic acids
    - Minerals

(Frame and Laidlaw, 2011)

When looking at the composition of a forage there are different things to take into consideration. For ruminants, one important part is the structural properties of the forage, i.e. the fibre part (McDonald *et al*., 2011). Fibres in forage are usually measured as neutral detergent fibre (NDF). The NDF mainly consists of lignin, cellulose and hemicellulose, which are considered to be the plant cell wall components (McDonald *et al*., 2011). A drawback with the NDF system is that it only shows the chemical properties of the fibre, not particle size and density, which also has an impact on the animal (Mertens, 1997).

The amount of fibre in the diet of a ruminant is of importance for the rumen to work properly. According to Mertens (1997) too low NDF concentrations cause altered rumen fermentation which in turn can cause a variety of different symptoms. Too high NDF concentrations decrease the energy density in the ration and reduce the productivity of the animal (Mertens, 1997). When the amount of fibre is high enough the animal is chewing sufficiently, producing enough saliva to buffer the rumen and keeping the pH from getting too low (Mertens, 1997).

Chewing activity in ruminants

Chewing is of importance as it decreases the size of the feed and make it possible to swallow, but it also increasing the surface of the feed. The increased surface makes the feed easier to process and makes it easier for the microbes in the rumen to get access to the feed for degradation

(Sjaastad *et al.*, 2010). The chewing activity in ruminants can be divided into eating and ruminating, where eating is the first step of the process and ruminating is where the animal process the feed further on. During rumination the feed can be chewed several times until the particles are small enough to pass from the reticulorumen to the omasum. This means that more easily digested feed will not need to be ruminated as much as more fibrous and coarse material which can be ruminated several times and, therefore, spend longer time in the reticulorumen (Sjaastad *et al*., 2010).

According to Mertens (1997) chewing activity per kilogram of DM is affected by the characteristics of the animal (breed, size etc.), the level of intake and the properties of the feed (fibre content, other chemical contents, DM content, particle size etc.). Palatability of the feed is also an important factor when it comes to feed intake. However, palatability is hard to measure in a quantitative way as it is affected by many different factors, such as properties of the feed and state of the animal (Baumont, 1996).

The chewing behaviour of housed sheep is depending on the feeding management system (how many times feed is offered, when feed is offered and to what amount etc.). According to a review by Baumont *et al.* (2000) the usual feeding behaviour of small ruminants during a day at pasture is two longer grazing periods. This is also a common feeding strategy when sheep are kept indoors. During a meal, the rate of eating and chewing is highest in the beginning of the eating period and declines during the period (Baumont *et al.*, 2000).

Time distribution of eating and rumination

According to Sjaastad *et al.* (2010) approximately one third of a ruminant´s day is spent ruminating. In a study by Dutilleul *et al.* (2000) they observed that yearling female sheep fed grass hay *ad libitum* spent almost twice as much time ruminating compared to eating.

A mean eating time of 436 min/kg of NDF intake was observed in a study by Jalali *et al.* (2012a) where they gave pregnant ewes grass silage of different harvest times *ad libitum*. They also observed that the total time spent eating ranged from 348 to 405 minutes per day compared to the total time spent ruminating that ranged from 283 to 345 minutes per day. Total time spent chewing was 800-861 minutes per day. When looking at time as minutes per kg of DM intake (DMI), eating ranged from 199 to 281 min/kg DM intake, ruminating from 193 to 282 min/kg DM intake and total time chewing from 349 to 530 min/kg DM intake.

Factors affecting rumination and eating

The physical properties of a feed influence rumination as well as the chemical properties. In a study by Hadjigeorgiou *et al*. (2003) they used the same rye-grass hay but chopped it into different sizes (13.29 mm, 7.26 mm and 0.69 mm) and fed it to sheep and goats. They could see that chopping length influenced the time spent ruminating. In their study the shortest length (0.69 mm) caused the longest rumination time. Chopping length did not influence the number of rumination cycles per day. They also observed that the shortest length of the forage caused the lowest number of ingestive jaw movements. However, when they combined the eating time with the rumination time, they did not see any differences between the different chopping lengths (Hadjigeorgiou *et al.*, 2003).

When looking at the chewing time De Boever *et al.* (1990) observed that sheep spent longer time ruminating than cattle per kg DM intake. They could also see that the numbers of chews per minute were higher for sheep compared to cattle. The differences were even bigger when the feed was of poor quality or with long straw instead of chopped straw. Jalali *et al.* (2012b) found that ruminating time, eating time and total chewing time per kg of DM intake differed between sheep, goats and llamas. For example, they found that sheep had a longer total chewing time in minutes per day compared to goats. This is important to keep in mind when looking at studies done on different ruminants.

In a study on heifers, Schulze *et al.* (2014) reported that a decreased feeding level resulted in a decreased proportion of eating time in relation to ruminating time. When the animals were fed 90% of *ad libitum* eating was 30% of the total chewing (i.e. eating and rumination). When the feeding level was decreased to 50% of *ad libitum* the percentage of eating was down to 10% of the total chewing. Time spent ruminating ranged from 270 minutes per day to 460 minutes per day. In their study the total chewing time per day was never higher than 10 hours. They also observed that restricted feeding caused more rumination time per kg DMI.

According to Dutilleul *et al.* (2000) the chewing behaviour in sheep is also affected by the season (i.e. day length and mean temperature) and time within the day. For example, the sheep spent longer time eating when the daylight was 610 minutes long and the mean temperature 10.9 °C compared to when the daylight was 550 minutes long and the mean temperature 7.2 °C.

The influence of NDF on chewing

Rumination seems to increase with higher fibre content (cell-wall content). In a study on steers using diets with different fibre concentrations, McLeod and Smith (1989) reported a higher number of chews per bolus and a higher number of total chews per day in steers fed high fibre diets. They did not see any differences in eating time between the different forages. The different fibre concentrations of the feed in their study was created by separating the stem and leaf fractions of the same grass hays and feeding them separately (McLeod and Smith, 1989). The intake of forage NDF seems to be what affect the daily total eating, chewing and ruminating time (Jalali *et al*., 2012a).

Schulze *et al*. (2014) reported an increased daily eating time with a higher NDF content of the forage fed to heifers. Also, the eating time per kg DM intake increased when the NDF content increased. However, the eating time per kg of NDF intake was not affected by a higher NDF content. A higher NDF content increased the total rumination time in minutes per day as well as rumination time per kg of DM intake for the heifers in the study. To obtain a higher NDF value of the feed Schulze *et al.* (2014) used grass-clover silages harvested at different regrowth stages.

Methods of measuring chewing activity

There are different ways of measuring the chewing activity in animals. For example, measurements can be done by using visual and video recordings or different types of sensors such as measuring jaw activity by pressure oscillations, muscle activity by electric voltage oscillations or sound measurement from the mastication processes. McLeod and Smith (1989) used intra-oesophageal pressure to measure the chewing activity. Dutilleul *et al* (2000) used sponge-filled rubber balloons under the lower jaw to measure air pressure. Nørgaard and Hilden (2004)

described a method where the principle was to use a magnet relative to a small Hall sensor which both are placed in a soft rubber tube surrounding the mouth of the sheep.

Particle size in faeces

The faecal particle size is influenced by the effectiveness of the tooth of the animal, chewing behaviour, quantity of feed eaten and physical structure of the feed (Pérez-Barbería & Gordon, 1998). The particle size found in faeces is a sign of the particle size of the feed that leave the rumen. Faeces is the greatest loss of ingested nutrients in an animal (Mertens, 2007). Particles with a size larger than 1 mm are considered to be selectively retained in the rumen. An average of 2.4 percentage of the faeces particle DM was found to be larger than 1 mm in pregnant ewes feed grass silage harvested at different maturity stages (Jalali *et al.*, 2012a; Table 1).

Factors affecting faecal particle size

The NDF fraction of the forage seems to affect the faecal particle size in sheep. Jalali *et al*. (2012a) concluded that less lignified forage NDF particles were degraded into smaller and thinner particles compared with more lignified forage NDF, making the particle size negatively correlated with NDF digestibility (Jalali *et al.*, 2012b). Jalali *et al.* (2015) observed that the proportion of large particles in faeces (particles larger than 1.0 mm) increased with a higher NDF intake per kg of body weight. They also observed that an increased maturity stage of the forage resulted in an increased faecal mean particle size and DM percentage. The advancing maturity stage also decreased the proportion of small particles in the faeces (Jalali *et al.*, 2015).

Table 1. The range of faecal particle size in sheep fed different forages in a few different studies.[1]

Particle size	Jalali *et al.* (2012b)	Jalali *et al.* (2012a)
Pore size, 0,0 mm (bottom) (%)	16-20	14.1-20.3
Pore size, 0.106 mm (%)	35-43	31.7-50.4
Pore size 0.212 mm (%)	29-39	20.4-41
Pore size 0.5 mm (%)	7-9	5.5-11.4
Pore size 1.0 mm (%)	0.8-0.9	0.9-1.3
Pore size 2.36 mm (%)	0.3-0.6	0.9-1.6
Pore size >1.0 mm (%)	1.1-1.5	1.8-2.9
Particle size (mm) Most frequent	0.21-0.25	0.11-0.26
Particle size (mm) Geometric mean (GPS)	0.18-0.2	0.18-0.23
Particle size (mm) Arithmetic mean (APS)	0.25-0.27	0.26-0.31
Particle size (mm) Median value (MPS)	0.23-0.27	0.21-0.29
Particle size (mm) 95 percentile value	0.41-0.42	0.55-0.66

[1]Forage used by Jalali *et al.*, 2012b was grass hay and grass seed straw fed to female mature, non-pregnant, non-lactating sheep, goats and llamas. Forage used by Jalali *et al.*, 2012a was grass silage harvested at different maturity stages fed to pregnant ewes.

Animal species and size of the animal have an impact on the faecal particle size. For instance, Jalali *et al*. (2015) found that cattle generally had a larger mean particle size, a lower faeces DM content and a lower proportion of small particles in the faeces compared to sheep. Jalali *et al*.

(2015) also found that DM content in faeces for growing animals were lower and they had a higher proportion of small particles in the faeces compared to adult animals.

Methods of measuring particle size in faeces

The methods of measuring particle size in faeces might differ a bit in technique. As described in Jalali *et al.* (2012b) dry sieving is done to show the spread of particle size in the faeces. The samples are freeze dried and separated into different fractions by using sieves with different size of square holes. Jalali *et al.* (2012a) described the technique of simple wet sieving which shows the particle length of the larger faecal particles. By putting the faecal sample on a sieve with a pore size of 2.36 mm and pour water on the sieve, the larger particles were collected and measured on a graph paper and divided into groups depending on size.

Grass silage

Grass silage is the most commonly used forage in Swedish lamb production. In a review by Keady *et al.* (2013) the major factors affecting the digestibility of grass silage are harvest date, sward type, silage fermentation, fertilizer nitrogen application and wilting.

Maturity stage of the grass

Grass in temperate climates such as Sweden starts to grow in the spring when the temperature reaches 4-6 °C. It starts with a growth of the leaf, followed by the stem, then the flowering head and finally the formation of the seed (McDonald *et al*., 2011). In general, the lignification of a grass increases, while the crude protein (CP) concentration decreases as the grass matures (Fogelfors, 2011). With a delayed harvest date, there is a decline in digestibility of the grass but an increase in herbage yield (Keady *et al.*, 2013).

Effects on digestibility and feed intake

In a study with dairy cows a decreased DM intake was correlated with an increased maturity (Rinne *et al.*, 2002). Jalali *et al.* (2012a) and Nadeau *et al.* (2016) reported a higher DM intake of early harvested grass silage compared to late harvested grass silage in pregnant and lactating ewes. Nadeau *et al.* (2016) also found that pregnant and lactating ewes had a greater performance when fed grass silage harvested early, compared to grass silage harvested at a later maturity stage. Rinne *et al.* (2002) found a linear decline in digestibility of NDF and CP with advancing maturity stages in grass.

Effects on chewing activity

In a study by Jalali *et al.* (2012a) eating time, ruminating time and overall chewing time per kg of DM intake increased at advancing maturity stages of the grass. However, no increase was seen when expressing the chewing time per kg of NDF intake. Schulze *et al*. (2014) reported that rumination time increased when NDF concentrations of the grass silage increased.

Effects on faecal particle size

Jalali *et al*. (2012b) found that early harvested grass silage resulted in thinner faecal particles compared to more mature grass silage harvested later. The most frequent, arithmetic and geometric mean and median particle size values were lower for early harvested grass silage compared to late harvested grass silage. The same was true for arithmetic and geometric mean and median width values of the faecal particle size.

Whole crop barley silage

Whole crop cereal silages are silages made using the whole crop, both stalk and ear. According to a study by Nadeau (2007) whole crop barley silage had a higher nutrient content, digestibility and fermentation qualities compared to whole crop silage from spring-sown wheat and oat. When introducing whole crop barley silage to dairy cows fed grass silage Ahvenjärvi *et al*. (2006) could not observe any difference in the DMI compared to only feeding grass silage. They could see a decrease in milk yield with a higher proportion of barley silage, but that could have been explained by the lower nitrogen values of the whole crop barley silage compared to the grass silage, for which no compensation was made.

Maturity stage of the crop

Maturity stage of the crop influences a number of things such as composition of the plant, intake of the animal and the ensiling process. Compared to grass, advancing maturity of whole-crop cereals will not only cause an increased fibre concentration by stalk development, the cereal also will develop ear resulting in increasing amounts of starch. The total DM yield of the cereal will increase as well when the plant matures (Khorasani *et al*., 1997). The sugar content of the cereals decrease when the plant matures as it becomes polymerised into starch in the ear (Khorasani *et al*., 1997; Nadeau, 2007). In contrary to grass silage, NDF decreases with maturity in the later part of the development of the plant even though the NDF concentration in leaves and stems increases (Khorasani *et al*., 1997). This can be explained by the increased ear:stalk ratio as the ear contains great amounts of starch (Nadeau, 2007). Nadeau (2007) found that the ear:stalk ratio increased by 163% with advanced maturity.

Hargreaves *et al.* (2009) observed that the earlier whole-crop barley was harvested, the lower was the yield. When the plant is more mature, the DM content of the plant increases (Hargreaves *et* al., 2009; Khorasani *et* al., 1997). Hargreaves *et al*. (2009) observed that the fermentation process of whole-crop barley silage was restricted when the DM content of the silage was close to 400 g/kg. Khorasani *et al.* (1997) reported an increase in DM content from 13% at boot stage to 41.9% at soft-dough stage. A higher DM content also caused a stiffer stem, which makes the forage harder to pack, causing more oxygen to stay in the silage. This gives a higher risk of getting problems with the hygienic quality.

Effects on digestibility and feed intake

Bolsen and Berger (1976) found that the crude fibre digestibility decreased as stage of maturity increased in both whole-crop wheat silage and whole-crop barley silage. They also observed that the DM digestibility was affected by the stage of maturity of the plants. Whole-crop silages harvested at milk stage had lower DM digestibility compared to those harvested at boot or dough stage (Bolsen and Berger, 1976). A study done on whole-crop barley by Hargreaves *et al.* (2009) showed a declined estimated digestibility (neutral detergent cellulase digestibility, NDCD) and a decline in the concentrations of crude protein and WSC when the crop matured while the starch concentration increased when the crop matured (Hargreaves *et al.*, 2009).

The stage of maturity seems to affect the voluntary intake of the animal. According to a study done by Bolsen and Berger (1976) lambs fed silages harvested at milk stage consumed less compared to those fed silages harvested at boot or dough stage. It is not only the maturity stage

that influences the intake, the cutting length of barley silage has been shown to affect the feed intake in steers (Soita *et al*., 2002). In their study they showed that feeding short cut whole crop barley silage with a theoretical cutting length of 4.7 mm increased the DM intake in steers compared to feeding long cut silage with a theoretical cutting length of 18.8 mm. Rustas *et al.* (2010) found that chopping whole crop barley silage to a theoretical cutting length of 20 mm compared to unchopped whole crop barley silage increased the DMI of silage harvested at the dough stage, but not at the heading stage.

Effects on chewing activity

Rustas *et al*. (2010) reported that steers had longer durations of their eating cycles when they were fed whole crop barley silage harvested at dough stage compared to silage harvested at heading stage. They also observed a longer effective chewing time per kg NDF intake when the steers were fed barley silage harvested at dough stage compared to heading stage.

Effects on faecal particle size

Rustas *et al* (2010) showed a larger proportion of small particle sizes in faeces from steers when they were fed whole crop barley silage harvested at heading stage compared to dough stage. The early harvested (heading stage) whole crop barley silage had approximately the same content of NDF and ADF as the late harvested (dough stage) silage, but the lignin content was somewhat higher at the dough stage.

Material and Methods

Animals and housing

Eight castrated rams (the term wether will be used throughout the text) were used for the study. The wethers were breed crosses (maternal line: Swedish Finewool/Dorset, paternal line: Texel). They were about two years old, and had previously been used in a similar study, which made them accustomed to the equipment used. Average live weight at the start of the study was 88 kg (SD 5.3). Average body condition score (BCS) was 3.4 (SD 0.21). The average live weight for wethers in the unsupplemented group was 88.0 kg (SD 6.56) and the body condition score were 3.4 (SD 0.30). In the supplemented group the average live weight were 87.4 kg (SD 4.08) and body condition scores were 3.5 (SD 0). The study was conducted January-May 2014 at Götala Beef and Lamb Research Centre, Swedish University of Agricultural Sciences (SLU), Skara, Sweden.

Forages

Two different forages harvested at different maturity stages were used in the study. Early harvested grass silage (EG) harvested May 31, late harvested grass silage (LG) harvested June 17, whole crop barley silage harvested at the heading stage (WCBH) on June 30 and whole crop barley silage harvested at the milk stage of maturity (WCBM) on July 18. Forages were harvested, wilted and ensiled in round bales using salt-based additives; Kofasil LP (sodium nitrite, hexamine, sodium benzoate) for the grass and Kofasil Ultra K (sodium nitrite, hexamine, potassium sorbate, sodium benzoate, sodium propionate, Addcon Europe GmbH) for the whole crop silage. After at least 4 months of storage, the silages were chopped to a length of approximately 40 mm, mixed well and then frozen prior to the trial. Before feeding, the silages were well thawn.

Experimental design

The different silages made four treatments. All wethers were fed all silage treatments using two 4 x 4 Latin Squares (Tables 2 and 3). By the end of the experiment all animals had been fed all different silages. For one of the Latin Squares (i.e. for four wethers) 150 g of untreated rapeseed meal (Lantmännen Lantbruk) was added to all the treatments to evaluate the effect of protein supplementation on intake (Table 3).

Treatment 1: Whole crop barley silage harvested at the heading stage of maturity (WCBH)
Treatment 2: Whole crop barley silage harvested at the milk stage of maturity (WCBM)
Treatment 3: Early harvested grass silage in spring growth (EG)
Treatment 4: Late harvested grass silage in spring growth (LG)

Table 2. The Latin Square (1) for wethers fed silage only.

	Wether 1	Wether 2	Wether 3	Wether 4
Period 1	Treatment 1	Treatment 3	Treatment 4	Treatment 2
Period 2	Treatment 2	Treatment 1	Treatment 3	Treatment 4
Period 3	Treatment 3	Treatment 4	Treatment 2	Treatment 1
Period 4	Treatment 4	Treatment 2	Treatment 1	Treatment 3

Table 3. The Latin Square (2) for wethers fed silage and rapeseed meal.

	Wether 5	Wether 6	Wether 7	Wether 8
Period 1	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Period 2	Treatment 3	Treatment 1	Treatment 4	Treatment 2
Period 3	Treatment 2	Treatment 4	Treatment 1	Treatment 3
Period 4	Treatment 4	Treatment 3	Treatment 2	Treatment 1

Table 4. Housing condition, feeding procedure and recording for each period.

Week	Housing	Feeding	Recordings
Week 1	Individual pen	*Ad libitum*	Adaptation to new silage for two weeks
Week 2	Individual pen	*Ad libitum*	
Week 3	Individual pen	*Ad libitum*	Recording of intake
Week 4	Metabolic cages	80% of *ad libitum*	Adaptation to restricted intake for 3 days followed by recordings of chewing and collection of faeces during the last four days of the period.

Each treatment period was four weeks (28 days) long, where the wethers were allowed to become adapted to the feed for two weeks, followed by one week of feed intake measurements, when the wethers were fed at *ad libitum* (Table 4). During this period the animals were kept individually in pens of 6 m^2 bedded with straw. At start of the last week of each period, week 4, the wethers were moved to individual metabolic cages (1.5 * 0.8 m) that allowed urine and faeces to be collected separately and individual registration of chewing activity. The amount of feed during this period was 80% of the amount consumed *ad libitum*. The amount of rapeseed meal was 120 g/day during the restricted period. The feed was given once daily at 8:00-9:00. The collection week started with an adaptation period of three days when the wethers were adapted to the restricted intake levels, followed by four days of registrations of feed intake, chewing and total collection of faeces and urine. In this thesis, results on intake, chewing, and faeces particle size distribution from the last four days at restricted intake are presented. The faeces were collected in plastic buckets under each cage and sampled for particle size determination (Table 4).

Sample collection

Animals were weighed and body condition scored before and after each period of restricted intake.

During the period of restricted intake, when the wethers were in the metabolic cages, feed samples were taken daily from Monday until Thursday. Feed samples were collected at around 08:00-09:00 each morning at the same time as the animals were fed. Approximately 200 grams of feed were collected from each batch used to feed the wethers. If there were any refusals the next morning they were collected as well. Samples of the rapeseed meal were taken once each period. All samples were frozen right after they were taken until analysis of chemical composition were done.

Faeces from the plastic buckets under the cages were collected each morning from Tuesday until Friday during the period of restricted period. Any residual faeces in the metabolic cages were

scraped down into the plastic bucket before it was emptied, to make sure that all faeces were collected. If there were any wool or feed in the plastic bucket with the faeces it was removed. All faeces were put in plastic bags marked with date and number of the wether. The samples were weighed on a scale and then frozen right away until further analysis could be done.

Analyses of samples

Analyses of forages

Samples of the daily feed and any refusals from the restricted period were thoroughly thawn. The DM content of the samples were then determined by weighing 150 g of each sample in aluminium trays. For any refusal samples where the amount was less than 150 g the amount available were weighed. The samples were dried in 60 °C for 20 hours and then weighed for DM determination. An average DM from each feed for each period were calculated and used to calculate the daily DM intake of the wethers.

The rest of the feed was mixed into one sample of each feed for each period, giving four samples for each forage. These samples were thoroughly mixed and from each of them 200 g were taken and sent to LKS mbH, Lichtenwalde, Germany and to the Department of Animal Nutrition and Management, SLU Uppsala, Sweden for nutrient analyses and fermentation characteristics (Tables 5 and 6).

Analyses of CP, NDF, ADF and acid detergent lignin (ADL)

The feed was analysed at LKS mbH, Lichtenwalde, Germany for CP, NDF, ADF and ADL and crude ash. The CP content of the feeds was determined by using the Kjeldahl nitrogen determination procedure and by calculating the CP content by total N x 6.25. To get the NDF, ADF and ADL values of the forages the Fibre Technology method, excluding sodium sulphite, according to Van Soest *et al*. (1991) was used.

Analyses of crude ash and in vitro organic matter digestibility

At the Department of Animal Nutrition and Management, SLU, Uppsala, Sweden the feed samples were analysed for ash and *in vitro* OM digestibility according to the VOS method (Lindgren 1979; Lindgren 1983). To determine the crude ash content of the forages the samples were dried at 525 °C for 16 hours. To determine *in vitro* OM digestibility, 0.5 g samples were incubated at 38 °C for 96 hours in 49 ml buffer and 1 ml rumen fluid (Lindgren 1979; Lindgren 1983). The content of metabolizable energy (ME) was calculated form the VOS value (Lindgren, 1988).

Table 5. Characteristics of silages from samples taken during the restricted period, as mean and standard deviation (SD; n=4).

	WCBH		WCBM		EG		LG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Dry matter (%)	36.3	5.56	36.0	6.03	36.6	4.70	34.2	3.33
Crude ash (% of DM)	5.7	0.23	5.1	0.22	10.8	1.03	5.9	0.12
In vitro organic matter digestibility[1]	83.7	0.88	81.1	0.85	87.7	0.49	77.3	0.52
ME[2] (MJ/kg DM)	10.8	0.15	10.5	0.15	10.8	0.18	9.8	0.09
Crude protein (g/kg DM)	105	2.4	83	2.1	190	1.8	116	4.1
aNDFom[3] (g/kg DM)	471	17.2	444	11.6	472	5.1	573	4.1
ADFom[4] (g/kg DM)	259	10.74	240	10.1	302	4.8	341	9.1
ADL[5] (g/kg DM)	22	0.8	27	2.1	26	1.8	42	7.2

[1]*in vitro* organic matter digestibility measured with the VOS method (Lindgren 1979; Lindgren 1983).

[2]ME = metabolizable energy

[3]aNDFom = neutral detergent fibre on ash-free basis using amylase in the analysis.

[4]ADFom = acid detergent fibre on ash-free basis.

[5]ADL = acid detergent lignin

Analyses of WSC, acids, ethanol and pH

Content of WSC, lactic acid, acetic acid, propionic acid, butyric acid and ethanol as well as pH of the silage were analysed at the Department of Animal Nutrition and Management, Uppsala, Sweden. Content of WSC was assessed by a simplified enzymatic method according to Larsson & Bengtsson (1983). Lactic acid, acetic acid, propionic acid, butyric acid and ethanol were assessed with HPLC -applications for agricultural and animal science according to Ericson & André (2010). The pH was determined in juice squeezed from the silage using a pH-meter Metrohm 654 (Herisau, Schweiz).

Table 6. Fermentation characteristics of the silages as means and standard deviations (SD; n=4).

	WCBH		WCBM		EG		LG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
pH	4.21	0.033	4.23	0.096	4.20	0.005	4.23	0.094
Ammonia-N (% of tot N)	7.0	0.39	5.9	0.61	11.1	1.61	8.3	0.65
WSC[1] (% of DM)	15.4	1.94	12.6	0.14	0.71	0.55	5.60	0.55
Lactic acid (% of DM)	5.19	0.319	3.94	0.482	8.82	1.208	4.97	0.488
Acetic acid (% of DM)	1.72	0.081	0.63	0.044	2.18	0.356	1.20	0.043
Propionic acid (% of DM)	0.09	0.023	<0.04	0.001	0.07	0.005	<0.05	0.004
Butyric acid (% of DM)	<0.05	0.003	<0.04	0.001	<0.07	0.005	<0.05	0.004
Ethanol (% of DM)	0.17	0.031	0.80	0.144	0.44	0.065	0.36	0.152
2,3-Butandiol (% of DM)	<0.05	0.003	0.29	0.109	<0.07	0.005	<0.05	0.004
1,2-Propandiol (% of DM)	<0.05	0.003	<0.04	0.001	0.13	0.011	<0.05	0.004

[1]WSC = water soluble carbohydrates

Analyses of faecal particle size

Faeces samples were collected daily for each wether during the four days of the restricted period (week 4) in the metabolic cages. Samples were pooled for each wether for each period giving four samples for every wether and 32 samples in total. The DM analyses were done on all faeces

samples at SLU, Skara. DM was determined by putting 150 g of faeces from each wether in aluminium trays that were dried in 60 °C for 48 hour and then weighed again.

From the pooled faeces samples from each weather each period, 200 g were weighed and sent to the University of Copenhagen for analysis of particle size. Each of three subsamples of 4 g faeces were placed in nylon bags with a pore size of 0.01 mm before addition of 4 ml soap per bag. After 30 minutes, the bags with contents were gently massaged in order to dissolve soap into the faeces. The bags with faeces and soap were washed at 40 °C colour wash for 2 h and centrifuged at a spin of 700 per min in a regular washing machine. The residual contents from the three bags were transferred into an aluminium tray per faeces sample by use of distilled water. The aluminium trays were kept in a deep freezer for 1 h before freeze-drying in a HETOSICC CD8 Freeze dryer for 48 hours. The residual amounts of freeze-dried faeces particle was defined as particle dry matter (PDM) as described by Jalali *et al.* (2012b).

The PDM was sorted into six sieving fractions of 2.36 mm, 1.0 mm, 0.5 mm, 0.212 mm, 0.106 mm and the bottom bowl (0.0 mm) by use of a Retsch AS200 sieve shaker. The particles on the top sieve were brushed to the below sieve fraction and the residues were stirred for 2 minutes. This procedure was then repeated for all sieving fractions as described by Jalali *et al.* (2012b). Residues from each sieve were collected and weighed, and the proportion of particles retained on each sieve was estimated. The arithmetic mean particle size (APS), the geometric mean particle size (GPS), the median particle size (MPS) and the 95 percentile value were estimated from the proportions of particles in the individual sieving fractions as described by Jalali *et al.* (2012b).

Chewing activity

The chewing activity of each wether was recorded for 96 h continuously from before the morning meal on day 3 in week 4 until after removal of residual silage before the morning meal on day 7 by use of a special chewing halter (Nørgaard and Hilden, 2004). A Hall censor placed on top of the nose of the wether measured the jaw movement (JM) oscillations (JMO). The wethers had used the chewing halter prior to the trial. The chewing halter was connected to a data logger by a wire surrounded by a flexible metal tube (Figure 1). The data logger box was placed on top of the experimental cages. The data logger sampled the JMO values at 40 Hz and stored the values on a memory card (1 or 2 GB Compact Flash), which was replaced once every day prior to feeding

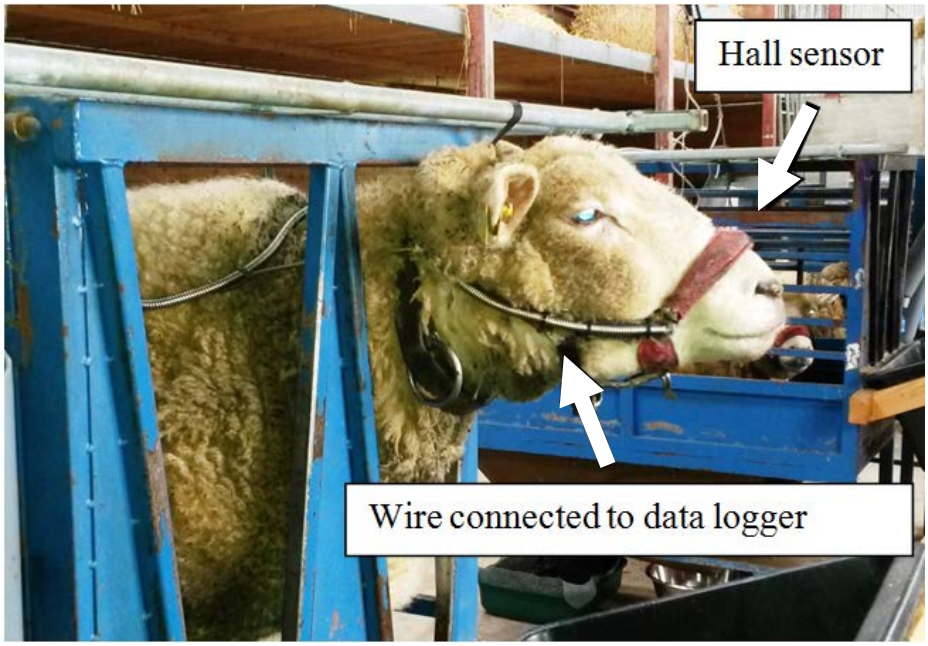

Figure 1. Picture of a wether equipped with a chewing halter.

The chewing behaviour at the late part of the morning meal and during one to two rumination periods were done for 2 days per experimental period for each wether.

Chewing variables

The time and amplitude value of the individual JM were identified from JMO as described by Nørgaard and Hilden (2004). The individual JM were clustered into crude chewing cycles where one cycle was the chewing time for one mastication and ending with a short pause in JM. The cycles were further clustered into crude periods of eating and rumination where one period was considered to consist of continuous cycles. Periods of idling or licking were filtered out based on manual observation and plots of JM oscillations, using the principles described by Schleisner *et al.* (1999).

The basic chewing rate (BCR) within each cycle was calculated as the reciprocal of the most frequent time interval between successive JM given in JM/s. The duration of an effective chewing cycle was defined as the time from the first JM to the final JM, added the reciprocal BCR value of each crude chewing cycle, and subtracted pauses in mastication. The daily time spent eating and rumination was estimated as the accumulated duration of the eating and rumination periods, respectively. The daily chewing time was estimated as the time spent eating plus time of rumination. The effective daily eating and rumination times were calculated as accumulated effective cycles and periods of eating behaviour and rumination, respectively. Total effective chewing time equalled effective eating plus effective rumination time. Characteristics of rumination were evaluated from the duration of rumination cycles, rumination periods, number of JM per rumination cycle and number of rumination cycles per kg of forage NDF.

Statistical analyses

To analyse the data from feed intake, particle size and chewing the PROC MIXED procedure in SAS (ver. 9.3) were used. The statistical model for the duplicated 4 x 4 Latin Square was:

$Y_{ijkl} = \mu + F_i + S_j + (FS)_{ij} + P_k + B_{l(j)} + C_{m(ijkl)} + e_{ijkl}$

Where Y_{ijkl} = observed response, μ = overall mean, F_i = effect of forage (i = 1 to 4), S_j = effect of supplementation of protein (l = 1 to 2), $(FS)_{ij}$ = interaction between forage and supplementation of protein, P_k = effect of period (k = 1 to 4), $B_{l(j)}$ = random effect of sheep nested within supplementation of protein (j = 1 to 8), $C_{m(ijkl)}$ = effect of carry over between periods for the combination of ijkl (m = 1 to 4) and e_{ijkl} = residual error.

No significant carry over effect or interaction between forage and supplementation of protein were found and therefore $C_{m(ijkl)}$ and $(FS)_{ij}$ were excluded from the model. When significant effects were shown at $P \leq 0.05$ in the *F*-test, pairwise comparisons were done between the least square means with Tukey-Kramer adjustment. When $P \leq 0.05$ the pairwise difference was declared significant. The pairwise differences were stated as a tendency to significance at $0.05 < P \leq 0.10$ and with asterisks for $*P \leq 0.05$, $**P < 0.01$, $***P < 0.001$ in the tables.

Results

Forages

Weight of wethers and DMI

Weights of the wethers (Table 7) fed the EG diet were lower than of those fed the barley silage diets. Forage and total DMI in kg/day were higher for wethers fed the barley silage diets compared to EG. Also, wethers fed WCBH had higher forage and total DMI than LG. The DMI of both the forage and of the whole diet in percentage of live weight was higher for the whole crop barley silages than for the grass silages. The maturity stage of the silages did not influence the forage or total DMI (Table 7).

Table 7. Mean weights of wethers and daily forage and total intake (forage and rapeseed meal) during the intensive period at 80% of *ad libitum* intake. LS means averaged over protein supplementation (n = 8).

	Experimental Diets[1]					
	WCBH	WCBM	EG	LG	SEM	*P* - value
Mean live weight of wethers (kg)	99.0^{a}	98.4^{a}	95.8^{b}	97.8^{ab}	2.519	**
Forage DM[2] intake (kg/day)	1.87^{a}	1.85^{ab}	1.57^{c}	1.66^{bc}	0.061	***
Total DM intake (kg/day)	1.94^{a}	1.92^{ab}	1.64^{c}	1.73^{bc}	0.061	***
Forage DM intake (% of LW[3])	1.91^{a}	1.89^{a}	1.64^{b}	1.70^{b}	0.047	**
Total DM intake (% of LW)	1.97^{a}	1.96^{a}	1.71^{b}	1.77^{b}	0.047	**
Forage NDF[4] intake (g/day)	882^{ab}	822^{bc}	743^{c}	952^{a}	30.1	***
Total NDF intake (g/day)	901^{ab}	841^{bc}	762^{c}	972^{a}	30.1	***
Forage NDF intake (% of LW)	0.90^{ab}	0.84^{bc}	0.78^{c}	0.97^{a}	0.022	***
Total NDF intake (% of LW)	0.92^{ab}	0.86^{bc}	0.80^{c}	0.99^{a}	0.022	***
Forage ADF[5] intake (g/day)	496^{b}	452^{b}	486^{b}	578^{a}	21.0	***
Forage ADL[6] intake (g/day)	42.3^{b}	48.6^{b}	40.9^{b}	66.3^{a}	3.95	***

[1]WCBH = whole-crop barley silage at heading stage of maturity, WCBM = whole-crop barley silage at milk stage of maturity, EG = early harvested grass silage, LG = late harvested grass silage; SEM = standard error of the mean [2]DM = dry matter; [3]LW = live weight; [4]NDF = neutral detergent fibre; [5]ADF = acid detergent fibre; [6]ADL = acid detergent fibre; **$P < 0.01$, ***$P < 0.001$; [a,b,c]LS means with different superscripts within the same row differ ($P < 0.05$).

Intakes of NDF, ADF and ADL

The NDF intake of forage and of total diet in kg per day and in % of live weight were higher for wethers fed the LG diet compared to wethers fed WCBM and EG diets (Table 7). Wethers fed the EG diet had lower NDF intake than those fed the WCBH diet. Forage intakes of ADF and ADL were higher for the LG diet than for the other diets, which did not differ. Advancing maturity stage of the grass silages increased the NDF, ADF and ADL intakes. For the barley silages no difference in fibre intake could be seen by advancing maturity stage (Table 7).

Chewing data

Chewing patterns for eating

No effects of diets on eating time in minutes per day and per kg of DM and NDF intakes were found (Table 8).

Table 8. Eating activity of wethers fed different forage diets at 80% of *ad libitum* intake. LS means averaged over protein supplementation (n = 8).

	Experimental Diet[1]					
	WCBH	WCBM	EG	LG	SEM	*P* - value
Total eating time (min/day)	168	141	164	175	22.8	n.s.
Total effective eating time (min/day)	128	109	131	150	17.6	n.s.
Number of periods/day	32.3	25.4	33.5	26.2	4.04	n.s.
Total number of cycles/day	189	149	155	133	25.2	n.s.
Total number of JM[2]/day	11231	9765	10825	13289	1549	n.s.
BCR[3] (JM/s)	1.97[a]	1.95[a]	1.87[b]	1.91[ab]	0.033	**
Total eating time/forage DMI[4]	89.0	76.6	106	106	12.6	n.s.
Total eating time/DMI	86.4	74.3	101	103	12.4	n.s.
Total eating time/forage NDFI[5]	189	171	224	186	26.2	n.s.
Total eating time/NDFI	186	168	218	183	25.6	n.s.
Total effective eating time/ forage DMI	68.3	59.1	84.5	91.1	10.16	n.s.
Total no. JM/forage DMI	5968	5328	6963	8094	887	n.s.
Total no. JM/period	354[b]	408[ab]	316[b]	531[a]	42.3	**
Total no. JM/effective eating time	88.1	90.1	82.8	89.2	2.67	0.098
Effective eating time/cycle	44.4[b]	44.9[b]	50.3[b]	69.0[a]	5.25	**
Number of JM/cycle	65.7[b]	67.6[b]	69.5[b]	103.1[a]	8.75	**
Intercycle time (sec)	14.9	15.2	17.4	14.0	1.41	n.s.
Effective eating time/period	4.02[b]	4.49[ab]	3.84[b]	5.93[a]	0.431	**

[1]WCBH = whole-crop barley silage at heading stage of maturity, WCBM = whole-crop barley silage at milk stage of maturity, EG = early harvested grass silage, LG = late harvested grass silage; SEM = standard error of the mean
[2]JM = jaw movements; [3]BCR = basic chewing rate; [4]DMI = dry matter intake; [5]NDFI = neutral detergent fibre intake
P* < 0.01, n.s. = non-significance;*** [a,b]LS means with different superscripts within the same row differ (*P* < 0.05).

Basic chewing rate was higher for the barley silages compared to the EG diet. The total number of jaw movements per period was higher for the LG diet compared to the WCBH and EG diets. There was a tendency towards a higher total number of jaw movements per effective eating time for the WCBM diet compared to the EG diet (*P* = 0.098). The effective eating time per cycle and the number of jaw movements per cycle were higher for the LG diet compared to the other treatments, which did not differ. Furthermore, the effective eating time per period was longer for the LG diet compared to the WCBH and EG diets (Table 8).

Chewing patterns for rumination

No effects of diets on rumination time in minutes per day and per kg of DM and NDF intakes were found (Table 9). The number of rumination periods per day were higher for the EG diet compared to WCBM. There was a tendency towards a higher basic chewing rate for WCBH compared to EG and LG ($P = 0.089$). In addition, there was a tendency towards a higher number of jaw movements per period for WCBH compared to EG ($P = 0.098$). Likewise, there was a tendency towards a higher number of jaw movements per effective rumination time for WCBH compared to EG and LG ($P = 0.088$).

Table 9. Rumination activity of wethers fed different forage diets at 80% of *ad libitum* intake. LS means averaged over protein supplementation. (n = 8).

	Experimental Diet[1]					
	WCBH	WCBM	EG	LG	SEM	*P*-value
Total rumination time (min/day)	542	477	475	503	33.7	n.s.
Total effective rumination time (min/day)	460	401	396	419	32.0	n.s.
Number of periods per day	17.8^{ab}	16.8^{b}	21.6^{a}	18.7^{ab}	1.11	*
Total number of JM[2]/day	46827	39042	38119	39894	3275.9	n.s.
BCR[3] (JM/s)	1.74	1.70	1.64	1.63	0.048	0.089
Total rumination time/forage DMI[4]	292	265	311	309	28.5	n.s.
Total rumination time /DMI	282	256	299	299	28.1	n.s.
Total rumination time / forage NDFI[5]	619	592	659	538	57.1	n.s.
Total rumination time /NDFI	604	579	643	529	56.5	n.s.
Total effective rumination time / forage DMI	248	223	260	257	25.6	n.s.
Total no. JM/forage DMI	25288	21928	24956	24473	2564.2	n.s.
Total no. JM/period	2659	2344	1854	2207	217.0	0.098
Total no. JM/effective rumination time	102.0	100.0	96.0	95.5	2.82	0.088
Effective rumination time / cycle	44.0	42.9	42.1	42.2	2.86	n.s.
Number of JM/cycle	74.5	71.2	67.2	66.7	4.39	n.s.
Intercycle time	7.96	8.75	8.79	8.64	0.348	n.s.
Effective rumination time / period	26.1	23.6	19.4	23.2	2.05	n.s.

[1]WCBH = whole-crop barley silage at heading stage of maturity, WCBM = whole-crop barley silage at milk stage of maturity, EG = early harvested grass silage, LG = late harvested grass silage; SEM = standard error of the mean
[2]JM = jaw movements; [3]BCR = basic chewing rate; [4]DMI = dry matter intake; [5]NDFI = neutral detergent fibre intake
*$P < 0.05$, n.s. = non-significance; [a,b]LS means with different superscripts within the same row differ ($P < 0.05$).

Total chewing patterns

No effects of diets on total chewing time in minutes per day and per kg of DM and NDF intakes were found (Table 10).

Table 10. Total chewing activity of wethers fed different forage diets at 80% of *ad libitum* intake. LS means averaged over protein supplementation. (n = 8).

	Experimental Diet[1]					
	WCBH	WCBM	EG	LG	SEM	*P*-value
Total chewing time (min/day)	709	624	639	678	37.4	n.s.
Total effective chewing time (min/day)	588	513	527	569	34.1	n.s.
Number of periods/day	50.1	42.9	55.2	44.9	4.47	n.s.
Total number of cycles/day	826	711	719	738	33.0	0.084
Total number of JM[2]/day	58058	49406	48943	53183	3369.9	n.s.
BCR[3] (JM/s)	1.88[a]	1.84[ab]	1.78[b]	1.79[b]	0.036	*
Total chewing time/forage DMI[4] (min/kg)	381	344	417	415	31.7	n.s.
Total chewing time/DMI (min/kg)	368	335	400	402	31.2	n.s.
Total chewing time/forage NDFI[5] (min/kg)	808	768	883	724	63.0	n.s.
Total chewing time/NDFI (min/kg)	790	753	861	712	62.1	n.s.
Total effective chewing time/ forage DMI (min/kg)	316	284	344	348	28.1	n.s.
Total no. JM/forage DMI	31256	27455	31920	32567	2719.8	n.s.
Total no. JM/period	1221	1189	917	1254	112.9	n.s.
Total no. JM/effective chewing time	99.0	98.3	92.5	93.7	2.69	n.s.
Effective chewing time/cycle	42.8[ab]	42.4[b]	44.0[ab]	46.8[a]	2.17	*
Number of JM/cycle	70.5	69.0	67.9	72.6	3.51	n.s.
Intercycle time (sec)	9.36	10.0	10.2	9.56	0.56	n.s.
Effective chewing time/ period	12.3	12.1	9.90	13.4	1.07	n.s.

[1]WCBH = whole-crop barley silage at heading stage of maturity, WCBM = whole-crop barley silage at milk stage of maturity, EG = early harvested grass silage, LG = late harvested grass silage; SEM = standard error of the mean [2]JM = jaw movements; [3]BCR = basic chewing rate; [4]DMI = dry matter intake; [5]NDFI = neutral detergent fibre intake; **P* < 0.05, n.s. = non-significance; [a,b]LS means with different superscripts within the same row differ (*P* < 0.05).

There was a tendency for a higher total number of cycles per day for WCBH compared to the other treatments (*P* = 0.084). Basic chewing rate was higher for WCBH compared to the grass silage diets, which did not differ. The effective chewing time per cycle was longer for LG compared to WCBM (Table 10). No effects could be seen of the supplementary rapeseed meal on eating, rumination or total chewing.

Particle size in faeces

The DM content of faeces was lower for the whole crop barley silages compared to the grass silages (Table 11). The EG diet had the highest DM content of the faeces.

Table 11. Faecal dry matter and particle size characteristics from wethers fed different forage diets at 80% of *ad libitum* intake. LS means averaged over protein supplementation. (n = 8)

	Experimental Diet[1]					
	WCBH	WCBM	EG	LG	SEM	*P* - value
Dry matter (%)	36.0^{c}	35.2^{c}	47.3^{a}	41.6^{b}	1.32	***
Bottom (0.0 mm) (%)	21.4^{c}	15.2^{d}	38.1^{a}	27.8^{b}	0.84	***
Lowest sieve (0.106 mm) (%)	31.9^{b}	28.6^{b}	39.4^{a}	39.1^{a}	1.01	***
Lower sieve (0.212 mm) (%)	37.7^{b}	43.3^{a}	18.5^{d}	28.0^{c}	0.73	***
Middle sieve (0.5 mm) (%)	8.06^{b}	11.7^{a}	3.19^{c}	4.53^{c}	0.527	***
Upper sieve (1.0 mm) (%)	0.77^{ab}	0.93^{a}	0.67^{ab}	0.43^{b}	0.119	*
Upper most sieve (2.36 mm) (%)	0.16	0.34	0.11	0.094	0.087	n.s.
GPS[2] (mm)	0.28	0.27	0.28	0.29	0.016	n.s.
APS[3] (mm)	0.41	0.39	0.41	0.43	0.032	n.s.
Most frequent PS value (mm)	0.41	0.39	0.41	0.42	0.031	n.s.
MPS[4] (mm)	0.41	0.39	0.41	0.43	0.031	n.s.
PS[5] in 95 percentile	0.45	0.42	0.45	0.48	0.046	n.s.
PS smaller than 0.2 mm (%)	53.3^{c}	43.8^{d}	77.5^{a}	66.9^{b}	1.07	***
PS smaller than 0.5 mm (%)	91.0^{b}	87.1^{c}	96.0^{a}	94.9^{a}	0.66	***
PS smaller than 1 mm (%)	99.1^{ab}	98.7^{b}	99.2^{ab}	99.5^{a}	0.17	*

[1]WCBH = whole-crop barley silage at heading stage of maturity, WCBM = whole-crop barley silage at milk stage of maturity, EG = early harvested grass silage, LG = late harvested grass silage; SEM = standard error of the mean [2]GPS: geometric mean particle size; [3]APS: arithmetic mean particle size; [4]MPS: median particle size; [5]PS: particle size; *$P < 0.05$***$P < 0.001$, n.s. = non-significance.; [a,b,c,d]LS means with different superscripts within the same row differ ($P < 0.05$).

The highest proportion of the smallest particles (bottom, less than 0.106 mm) was found in EG followed by LG, WCBH and WCBM in descending order (Table 11). The whole crop barley silages had a lower proportion of particles in the range of 0.106 mm and 0.212 mm compared to the grass silages. In the lower sieve (particle size of 0.212 to 0.5 mm) all four forages differed from each other in the descending order WCBM, WCBH, LG and EG. In the middle sieve (particle size from 0.5 to 1.0 mm), the highest proportion was found in WCBM, followed by WCBH, which had a higher proportion of particles than the grass silage diets. The WCBM had a higher proportion of particles in the upper sieve (from 1.0 mm to 2.36 mm) than the EG (Table 11).

The accumulative proportion of particles smaller than 0.2 mm was highest for EG, followed by LG, WCBH and WCBM (Table 11). The grass silage diets had the highest accumulative proportion of particles smaller than 0.5 mm and the WCBH had higher accumulative proportion of faeces particles smaller than 0.5 mm than the WCBM. The WCBM also had lower accumulative proportion of particles smaller than 1.0 mm than LG (Table 11).

Advancing maturity of the plant seemed to have some effect on the faecal particle size. For example, the accumulative proportion of particles smaller than 0.2 mm was higher for the early harvested forages, both for the barley silages and for the grass silages (Table 11).

There was a tendency towards a smaller geometric mean particle size for the wethers fed rapeseed meal (0.27 mm) compared to the wethers without rapeseed (0.30 mm; $P = 0.086$). The arithmetic mean particle size also had a tendency to be smaller for the wethers fed supplemental rapeseed meal (0.38 mm) compared to those who were not fed rapeseed meal (0.44 mm; $P = 0.064$). The results were similar for the most frequent value (0.38 mm and 0.44 mm; $P = 0.069$) and the median particle size (0.38 mm and 0.44 mm; $P = 0.066$). The 95 percentile particle size was smaller for the wethers fed rapeseed meal (0.40 mm) compared to those who were not fed rapeseed meal (0.50 mm; $P = 0.045$).

Discussion

Results by De Boever *et al* (1990) suggest that it is not possible to compare sheep and cattle right off when it comes to their eating habits. This is important to keep in mind as many of the studies reviewed in this paper are done on cattle. There are many similarities, but for example sheep spend longer time eating and ruminating per kg of DMI than cattle and sheep also have a higher number of chews per minute (De Boever *et al.,* 1990). Jalali *et al*. (2015) could also observe a difference when comparing small ruminants such as sheep, goat, llamas and cattle to each other.

Dry matter intake

The DMI (both forage and total) of EG was lower than for the barley silages. When DMI was measured as percentage of live weight the intake of the grass silages were lower compared to the barley silages. There were no differences between the maturity stages within forage type. In other studies such as Jalali *et al.* (2012a) and Nadeau *et al.* (2015) they showed a decrease in intake of forage DM as the maturity of the forage increased. However, those studies were done on ewes in late pregnancy and lactation, respectively. Rinne *et al.* (2002) observed a decreased DMI with an increased maturity in a study on dairy cows fed grass silages of different maturity stages. Furthermore, Bolsen and Berger (1976) fed whole crop barley silage harvested at boot, milk and dough stage to growing lambs and observed that the intake of the lambs decreased with advanced maturity stage of the whole-crop barley. A number of things could explain the fact that maturity stage did not affect DMI in this study. One important factor is the animals that used in this study. The animals in this study were mature wethers, compared to most of the other studies that used either growing animals, pregnant animals or lactating animals. This means that the animals in this study only have a low capacity for deposition of energy into body stores compared to growing animals.

Fibre intake

When comparing whole-crop barley silages to grass it is important to acknowledge the difference in morphology of the plants. The ear of the whole-crop barley contains a lot of starch and not that much NDF, compared to the stem and leaves that have a much higher NDF content which increases with advanced maturity (Khorasani *et al.,* 1997). The WCBM does not have the highest proportion of NDF in total, but the stem and leaf fraction of the diet could have a higher NDF content. However, in this study the wethers were fed 80% of *ad libitum* and ate both stem, leaves and ear of the whole-crop barley silage. If fed *ad libitum* the results might have been different due to possibilities for feed selection.

The intakes of NDF, ADF and ADL of grass silages increased with advanced maturity stage. Jalali *et al.* (2012a) showed similar results with an increase in the daily intakes of NDF with advancing stage of maturity in grass silage, due to the increased concentrations of fibre and lignin in the grass as it matures. Nadeau *et al.* (2015) did not see any differences in NDF intake with an advanced maturity in lactating ewes. The rumen fill limited the DM intake in the lactating ewes when they were fed grass harvested at a later maturity. The maturity stage of whole-crop barley silage did not affect fibre intakes of the wethers, which could be because they only ate to cover their basic metabolic needs. Rustas *et al.* (2010) showed a higher NDF intake (kg/day) in dairy steers fed whole-crop barley silage harvested at heading stage compared to whole-crop barley

silage harvested at dough stage. The lack of difference in this present study could be explained by the fact that the NDF, ADF and ADL values of the two silages are similar.

Chewing

Chewing is the main activity to break down large fibrous forage particles making the digestible OM accessible for rumen microbial digestion. The NDF intake from forage is the major driver for chewing activity (Mertens, 1997). Time spent chewing (eating and ruminating combined) in this study ranged from 629-709 min/day during the period of restricted feeding (80% of *ad libitum*). This is slightly lower than what Hadjigeorgiou *et al.* (2003) found (890-901 min/day for yearling wethers fed rye grass hay) and Jalali *et al.* (2012a) found 800-861 min/day for pregnant ewes fed grass silage harvested at different maturities. The shorter chewing time in our study is probably because the sheep in the studies by Hadjigeorgiou *et al.* (2003) and Jalali *et al.* (2012a) were fed *ad libitum* whereas the sheep in this study had a restricted feed intake of 80% of *ad libitum*. If you take 80% of the values from Hadjigeorgious *et al.* (2003) and Jalali *et al.*, (2012a) the values are somewhere in between the values in this study. In a study done on the same wethers housed during the same conditions fed clover, grass and maize silages at 80% of *ad libitium* the total time spent chewing was 679-725 min/day (Gerðinum, 2014).

Total chewing time per kg NDF intake from forage was 796 minutes in this study. This is close to the chewing time in pregnant ewes fed grass silage *ad libitum* observed by Jalali *et al.* (2012a) and Helander *et al.* (2014). However, it is longer than the chewing time of 573 minutes per kg NDF intake from forage in lactating ewes observed by Helander *et al.* (2014).

Basic chewing rate (JM/s) was higher when feeding WCBH compared to the grass silages. The BCR expresses the rhythmic of chewing. Schulze *et al.* (2014) observed an increasing BCR value during rumination in heifers fed different grass silages harvested at different stages of maturity at increasing NDF content of grass silage. Schulze *et al.* (2015) observed no effect of stage of maturity or conservation method on BCR during total chewing, but observed higher BCR during ruminations in heifers fed late cut grass hay compared with early cut grass hay. One explanation could be related to the higher NDF intake relative to BW in wethers fed WCBH compared with wethers fed early grass silages.

There was a tendency for a higher total number of cycles per day for WCBH compared to the other treatments. The effective chewing time per cycle was higher for LG compared to WCBM, indicating a correlation between intake of forage NDF/BW and duration of ruminating cycles. Likewise, Schulze *et al.* (2015) observed increased duration of ruminating cycles due to delayed harvest and increased intake of forage NDF in heifers fed grass silage or grass hay

Ruminating

In this study, the general time spent ruminating each day ranged from 475 to 542 minutes for all forages, which corresponds to 32-38% of the day. Since approximately one third of a day for ruminants is spent ruminating according to Sjaastad *et al*. (2010) and forage is known to stimulate rumination, this seems to be in the normal range considering that the wethers were fed 80% of *ad libitum*. In a study by Jalali *et al*. (2012a) on pregnant ewes the time spent ruminating ranged from 283 to 345 minutes per day which is a slightly lower than the results from this study. However, the time spent eating in their study ranged from 348-405 minutes per day,

making the total chewing time on average between 800 and 861 minutes per day, which is much higher than for this study. This could be explained by the fact that pregnant ewes have a much higher energy requirement. Schulze *et al.* (2014) did a study on heifers where the time spent ruminating ranged from 270 to 462 minutes per day.

The number of rumination cycles per day of 559-637 cycles/day is in line with the numbers of other studies (639-663 cycles/day for Hadjigeorgiou *et al*., 2003 and 427-502 cycles/day for Jalali *et al.*, 2012a). The number of rumination periods per day was higher for EG (21.6) compared to WCBM (16.8). Jalali *et al.* (2012a) had no differences between different forages and the number of periods was 15-19 per day.

The NDF intake and DMI did not have a direct effect on the individual rumination parameters in this study. However, Schulze *et al*. (2014) observed a difference in heifers where total rumination time increased with a higher NDF concentration of the grass silage. According to Nørgaard *et al.* (2010) the rumination time per kg NDF intake from forage decrease with a higher NDF intake from forage. The results in this study could be because the diets did not differ enough from each other or that the wethers were non-producing making their energy requirement low.

Eating

Total eating time ranged from 141 to 175 min/day. The wethers spent more than twice as much time ruminating compared to eating. Likewise, Dutilleul *et al.* (2000) studied yearling female sheep fed a diet of grass hay and 250 g/day of concentrate and observed that sheep fed *ad libitum* spent almost twice as much time ruminating compared to eating.

The basic chewing rate for eating in this study is 1.87-1.97 JM/s. This is in range with other studies done on sheep (Jalali *et al.*, 2012a; Jalali *et al.*, 2012b). When comparing to studies done on cattle the basic chewing rate is somewhat lower. For example in a study by Schulze *et al.* (2015) basic chewing rate ranged from 1.24 to 1.32 JM/s. The basic chewing rate (JM/s) in this study was higher for the whole crop barley silages compared to EG. Results from Schulze *et al*. (2014) suggest that a slower BCR could be related with a lower NDF content or intake. Since the NDF intake was lower for EG that could be an explanation for the lower BCR in EG.

The total number of jaw movements, the effective eating time per cycle and the number of jaw movements per cycle were higher for LG compared to the other treatments. Wethers fed LG also had the highest NDF, ADF and ADL intakes, suggesting that the fibre levels could be an explanation to the higher number of jaw movements. The effective eating time per period was higher for LG compared to WCBH and EG. Jalali *et al.* (2012a) reported that the daily time spent eating appeared to depend primarily on the intake of forage NDF.

Particle size

Overall, faeces from wethers fed whole crop barley silage had a higher proportion of large particles compared with wethers fed grass silage, especially late harvested WCBM. Wethers fed WCBM had 1.3% of all faecal particles that were larger than 1 mm. In a study by Jalali *et al*. (2012a) comparing grass silages harvested at different maturity stages the early harvested grass silage had the highest proportion of faecal particles larger than 1 mm. In a study on steers by Rustas *et al*. (2010) the lowest proportion of large particles (> 1.0 mm) was found in the whole-

crop barley silage harvested at dough stage which is the opposite compared to the results in this study. This could be explained by the fact that steers are large ruminants whereas wethers are small ruminants giving them somewhat different chewing patterns. In a study on dairy heifers fed grass-clover silages, Schulze *et al*. (2014) found that the proportion of large particles (> 1.0 mm) in faeces increased with a higher NDF content of the silages (but only from 1.12% to 2.21% of PDM). Jalali *et al.* (2015) also found that a higher NDF content of the forage increased the proportion of large particles (> 1.0 mm) in the faeces. However, WCBM was not the forage with the highest content of NDF according to the analysis done in this study. Differences in particle size distribution between grass silages and whole-crop barley silages could be due to differences in fibre structure between the different plant species. It is the content and characteristics of NDF that primarily influence the digestibility of the silage (Allen 1996; Jalali *et al.*, 2012a). The stem of the whole crop barley has a higher proportion of NDF than the grass silages, but since that was not analysed in this study no conclusions can be drawn.

In general, the proportion of particles larger than 1 mm was lower than what was observed by Jalali *et al.* (2012a). This could be explained by differences in the passage rate of the feed through the rumen since the wethers in this study were fed restricted, while the pregnant ewes in the study by Jalali *et al.* (2012a) were fed *ad libitum*.

The geometric and arithmetic mean particle size did not differ between treatments in this study. This could be explained by the absence of differences in chewing time per kg of NDF intake. Jalali *et al.*, (2012a) reported an increase in overall particle size both for the geometric and arithmetic mean particle size for late harvested grass silage compared to early harvested grass silage in pregnant ewes. In their study the chewing time differed between early harvested and late harvested on a DM intake basis but not on NDF basis. Rustas *et al.*, (2010) observed a larger mean particle size in dairy steers fed whole crop barley silage harvested at dough stage compared to heading stage.

The smaller faecal particle size from wethers fed the rapeseed meal is in contrast to results reported by Jalali *et al.* (2015), who observed that increased dietary proportion of concentrate decreased the proportion of small particles in faeces.

Rustas *et al.* (2010) could observe a larger proportion of small particles in dairy steers fed whole crop barley silage harvested at heading stage compared to dough stage. In this study the same can be seen for particles smaller than 0.2 mm and particles smaller than 0.5 mm with the difference that the late harvested whole crop barley silage was harvested at milk stage instead of dough stage. Jalali *et al.* (2015) also found a decreased proportion of small faeces particles with advancing maturity stage. A decreased proportion of small particles might be related to increased resistance against physical degradation during rumination leading to larger particles due to increased lignification of forage NDF at advancing maturity stage. However, only few ruminating and chewing responses appear to differ between wethers fed grass silage and whole crop barley silage. Because of this, it is not possible to draw clear conclusions about possible differences in chewing behaviour due to forage type and harvest time from this study alone. More studies on the subject is required.

Conclusions

Maturity stage at harvest did not have an effect on DMI. The DM intake in percentage of LW was higher for the whole crop barley silages compared to the grass silages. Maturity stage had an effect on NDF, ADF and ADL intakes in the grass silages with an increased intake with delayed harvest. However, maturity stage did not affect NDF intake in the whole crop barley silages.

The chewing behaviour did not differ that much between the different forages, which is in contrary to what was hypothesised. Total daily chewing time ranged from 629 to 709 min/day and total chewing time per kg NDF intake from forage was 796 minutes. Daily rumination time ranged from 475 to 542 minutes. NDF intake and DMI did not have a direct effect on individual rumination parameters. Daily eating time ranged from 141 to 175 minutes. There were no differences between forages when looking at the eating time in relation to DMI or NDF intake.

Regarding particle size in faeces whole-crop barley silage harvested at milk stage had a higher proportion of large particles compared to the other forages. Delayed harvest decreased the proportion of small faeces particles less than 0.2 mm for both forage types, but did not affect the overall mean particle size.

However, the differences between the four treatments were only minor suggesting that whole-crop barley silages could be a suitable equivalent to grass silage in lamb production given that it is not harvested too late.

Implications and future research

This study suggests that whole-crop barley silage could be a suitable equivalent to grass silage in lamb production. Farmers could use whole crop barley as a nursing crop for ley and harvest for silage at heading or milk stage. However, the maturity stage of the crop has some impact on some of the parameters regarding chewing behaviour and faecal particle size. Because of this more research is needed to determine how to use whole-crop barley silage as optimal as possible to get a profitable lamb production.

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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
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