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Objective evaluation of lean meat yield and EUROP scores for Icelandic lamb carcasses by video image analysis

Estimation of prediction accuracy and genetic parameters with special interest in the correlation between video image analysis and *in vivo* measurements

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Estimation of prediction accuracy and genetic parameters with special interest in the correlation between video image analysis and *in vivo* measurements

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Clarification of contribution

I hereby declare that the writing of the following thesis and the two manuscripts is my work under the supervision and assistance of my advisor Emma Eyþórsdóttir and the co-advisors Chris R. Smith and Jón V. Jónmundsson.

The VIAscan® project was set out by the KS abattoir. The equipment was located at KS and the trials were carried out on their premises during the years 2006 and 2007. The steering group for the project was formed by persons from KS abattoir, SASTEK (producer of VIAscan®, later; Ceder Creek Company Pty Ltd, Australia), The Farmers Association of Iceland, The Agricultural University of Iceland and The Icelandic Food and Veterinary Authority.

The trials included the deboning trial supervised by Chris R. Smith from SASTEK. In 2007 I took a direct part in the project, where my main role was to work with the EUROP trial where three expert classifiers, plant classifiers and VIAscan® were compared.

The deboning dataset (862 carcasses) was obtained from Chris R. Smith but the EUROP trial dataset (696 carcasses) was built up by myself. With guidance from Emma Eyþórsdóttir and Chris R. Smith I built up the prediction models for lean meat yield for VIAscan® and the current grading system and tested the equations.

The records for estimation of genetic parameters (38.576 lamb/carcasses) were obtained from the National Sheep Recording database at the Farmers Association except for the VIAscan® assessment data that came directly from KS. I was responsible for building up the dataset, preparing and analysing the data for the estimation of genetic parameters. Besides supervision from Emma Eyþórsdóttir, Þorvaldur Kristjánsson assisted me in building up the pedigree file and Elsa Albertsdóttir guided me in the use of the DMU software, which was used for analysing variance components.

Eyþór Einarsson

Abstract

Objective lamb carcass grading by use of video image analysis (VIA) was recently introduced in Iceland for the first time. The current grading system in Iceland is the EUROP classification system including visual conformation assessment and fat assessment which is based on manual fat measurement. This research project was carried out at KS abattoir in north Iceland where a VIAscan® unit from the Australian company Ceder Creek Company Pty Ltd was installed. The main objectives of the study were to evaluate the ability of VIAscan® to predict lean meat yield (LMY) and classify into EUROP classes (5 conformation classes and 6 fat classes). Another objective was to estimate genetic parameters, especially the correlations between the EUROP score of VIAscan® (viaEUROP) and the current system (pEUROP) and between traits measured by VIAscan® and traits evaluated *in vivo*. The current grading system was evaluated in the same way as the assessment of VIAscan® in order to set a benchmark. The prediction accuracy of VIAscan® and the current grading system in assessing LMY% of the whole carcass or separately of legs (Leg%), loin (Loin%) and shoulder (Shldr%) was evaluated by the dissection of 862 carcasses. The data obtained was divided into two data sets; for calibration (603 carcasses) to build up prediction equations and validation (259 carcasses) to test the equations. To test the agreement between the viaEUROP and pEUROP scores, 696 carcasses were graded by both methods, they were assessed by 3 expert classifiers and the results compared both to individual classifiers and to a panel of expert classifiers. Genetic parameters were estimated for 9 VIAscan® traits (LMY%, Leg%, Loin%, Shldr%, Leg (kg), Loin (kg), Shldr (kg), conformation score (viaEUROPc) and fat score (viaEUROPf)), 4 traits from the current grading system (conformation score (pEUROPc), fat score (pEUROPf), fat thickness (GR), hot carcass weight (HCW)) and 7 traits evaluated *in vivo* (ultrasound muscle depth (UMD), ultrasound fat depth (UFD), ultrasound muscle shape (UMS), score for conformation of shoulder and breast (shldr score) and for conformation of the hind legs (leg score), length of the left cannon bone (ML) and live weight (LW)). Performance records were available for 38,576 lambs in total, where 1,446 lambs had records for all traits. The results showed that VIAscan® explained 62%, 32%, 47% and 60% of the variation in Leg%, Loin%, Shldr% and LMY% respectively while the current system explained 58%, 31%, 38% and 56% respectively. The current EUROP system did predict LMY% and fat (FAT%) with more accuracy than EUROP scores of

VIAscan®. The best single predictor of LMY% (R^2: 30%) and FAT% (R^2: 74%) was the GR-measure.

The agreement in classification between VIAscan® and a panel of expert classifiers showed that 82% of carcasses were classified identically for conformation and 73% for fat which is within the minimum limit set by the Icelandic authorities. The heritability for VIAscan® yield prediction as proportions was generally high, ranging from 0.39 to 0.63, lowest for Shldr% and highest for Loin%. Heritability of viaEUROPc was 0.32 and 0.29 of viaEUROPf while heritability was 0.35 for pEUROPc and 0.31 for pEUROPf. For weight related traits (Leg (kg), Loin (kg), Shldr (kg), HCW and LW) the direct heritability ranged from 0.17 to 0.21, maternal heritability from 0.09 to 0.11 and maternal environmental effects (c^2) from 0,21 to 0,23. For traits evaluated *in vivo* the heritability ranged from 0.27 to 0.52, lowest for UMS and highest for ML. The genetic correlation between viaEUROPc and pEUROPc was 0.94 and 0.82 between viaEUROPf and pEUROPf. It was concluded that this correlation was sufficiently high to define EUROP scores assessed by these two methods as identical traits. The correlations between LMY% and *in vivo* traits were favorable and not unexpected except for the positive correlations between Loin% and traits measuring fat. This was explained by unsuitable methods used for deboning loin and flanks. Genetic and phenotypic correlations between EUROP scores and *in vivo* traits were similar for both grading methods ranging from -0.53 to 0.70 for viaEUROP and -0.56 to 0.77 for pEUROP. The results indicate that VIAscan® is capable of predicting LMY% and classifying in EUROP classes with sufficient accuracy for the Icelandic sheep industry. Results for genetic parameters also indicate that the technology can replace the current grading system. Objective carcass grading by the VIAscan® technology is thus an option for the Icelandic sheep industry. However, the costs of implementing the method need to be evaluated before it can be put into practical use.

Ágrip

Ný aðferð við dilkakjötsmat hefur verið prófuð á Íslandi. Hún byggir á rafrænni tækni sem kallast video image analysis (VIA) og er það viðfangsefni ritgerðarinnar að fjalla um prófanir á þessari tækni. Núverandi kjötmatskerfi byggir hins vegar á svonefndu EUROP kerfi þar sem kjötmatsmaður flokkar huglægt í vöðvaflokka og í fituflokka með hjálp handvirks fitumælis. Prófanir á tækninni fóru fram á sláturhúsi kjötafurðarstöðvar KS á Sauðárkróki þar sem tæki af gerðinni VIAscan®, frá fyrirtækinu Ceder Creek Company Pty Ltd í Ástralíu, var sett upp. Markmið rannsóknarinnar var annars vegar að meta hæfni VIAscan® til að spá fyrir um vöðvahlutfall skrokka og að flokka samkvæmt EUROP kerfinu (5 vöðvaflokkar og 6 fituflokkar). Hins vegar að meta erfðastuðla bæði fyrir kjötmatsþætti og stigun líflamba með áherslu á að kanna hversu vel líflambamatið tengist rafræna matinu og hvort rafrænt EUROP mat (viaEUROP) og núgildandi EUROP mat (pEUROP) mældi sömu eiginleika. Í úttekt á rafrænu kjötmati var núgildandi kjötmat sett til viðmiðunar. Rannsóknin byggir á þremur megin gagnasöfnum. 1) Öryggi VIAscan® og núverandi kjötmats við mat á vöðvahlutfalli skrokksins í heild (LMY%) og í þremur skrokkhlutum, lærum (Leg%), hrygg (Loin%) og framparti (Shldr%), var metið út frá gögnum um 862 úrbeinaða skrokka. Hluti gagnasafnsins (603 skrokkar) var notaður til þess að byggja upp spálíkön með því að velja bestu mælingar rafræna matsins og annar hluti (259 skrokkar) var notaður til þess að prófa líkönin og staðfesta notagildi þeirra. 2) Hæfni VIAscan® til þess að flokka samkvæmt EUROP kerfinu var rannsakað út frá 696 skrokkum sem voru metnir bæði rafrænt og af þremur yfirkjötmatsmönnum. 3) Gögn sem notuð voru við útreikninga á erfðastuðlum innihéldu upplýsingar um 38.576 lömb, þar af voru 1.446 lömb með mælingar á öllum 20 eiginleikunum. Erfðastuðlar voru reiknaðir fyrir 9 eiginleika rafræna kjötmatsins (LMY%, Leg%, Loin%, Shldr%, Leg (kg), Loin (kg), Shldr (kg), vöðvaflokk (viaEUROPc) og fituflokk (viaEUROPf)), 4 eiginleika núgildandi kjötmats (vöðvaflokk (pEUROPc), fituflokk (pEUROPf), fallþunga (HCW) og fitu þykkt á síðu (GR)) og 7 eiginleika úr líflambamati (ómmæling á þykkt bakvöðva (UMD), ómmæling á þykkt fitu (UFD), lögun bakvöðva (UMS), stig fyrir frampart (Shldr score), stig fyrir læri (Leg score), lengd fótleggjar (ML) og lífþungi (LW). Niðurstöður fyrir mat á vöðvahlutfalli sýndu að rafræna kjötmatið útskýrði 62% breytileika í lærum (Leg%), 32% í hrygg (Loin%), 47% í frampörtum (Shldr%) og 60% í heilum skrokkum

(LMY%) með beinum mælingum en núgildandi EUROP mat útskýrði 58%, 31%, 38% og 56% breytileikans í þessum eiginleikum í sömu röð. Þegar borin var saman hæfni EUROP kerfisins samkvæmt rafrænu mati og núgildandi mati kom í ljós að núgildandi kerfi gaf heldur nákvæmara mat á vöðva- (LMY%) og fituhlutfalli (FAT%). Besta einstaka mælingin til að meta LMY% (R^2: 30%) og FAT% (R^2: 74%) var fitumæling á síðu (GR). Samanburður á EUROP flokkun milli VIAscan® og þriggja yfirkjötmatsmanna leiddi í ljós að samræmi var í vöðvaflokkun í 82% tilfella og fituflokkun í 73% tilfella, sem er yfir þeim mörkum sem Matvælastofnun hefur sett sem lágmarkskröfur fyrir rafrænt kjötmat. Í heildina reyndist arfgengi (h^2) á öllum eiginleikum meðalhátt eða hátt. Arfgengi á mati VIAscan® á vöðvahlutfalli var á bilinu 0,39 til 0,63, lægst fyrir Shldr% og hæst fyrir Loin%. Arfgengi fyrir viaEUROPc var 0,32 og fyrir viaEUROPf 0,29 en 0,35 fyrir pEUROPc og 0,31 fyrir pEUROPf. Fyrir eiginleika tengda þunga (Leg (kg), Loin (kg), Shldr (kg), HCW og LW) var beint arfgengi (h_d^2) á bilinu 0,17 til 0,21, arfgengi mæðraáhrifa (h_m^2) voru 0,09 til 0,11 og umhverfisþáttur mæðraáhrifa (c^2) var á bilinu 0,21 til 0,23. Arfgengi á eiginleikum líflambamatsins var á bilinu 0,27 til 0,52, lægst fyrir lögun bakvöðva (UMS) og hæst fyrir fótlegg (ML). Erfðafylgni (r_g) milli vöðvamatsins viaEUROPc og pEUROPc var 0,94 en milli fitumatsins viaEUROPf og pEUROPf var það 0,82. Það telst nægilega há fylgni til þess að hægt sé að skilgreina EUROP mat samkvæmt báðum aðferðum sem sama eiginleika. Eiginleikar líflambamatsins voru með nokkuð sterka fylgni við rafrænt mat á vöðvahlutfalli og kom þar fátt á óvart nema niðurstöður fyrir vöðva í hrygg (Loin%), sem hafði jákvæða fylgni við eiginleika tengda fitumati. Skýringin var talin óheppileg aðferð við úrbeiningu á hrygg og síðum. Erfða- og svipfarsfylgni milli EUROP flokkunar og líflambamats var svipuð fyrir báðar kjötmatsaðferðir eða á bilinu -0,53 til 0,70 fyrir viaEUROP og -0,56 til 0,77 fyrir pEUROP. Í heildina sýna þessar niðurstöður að rafrænt kjötmat getur spáð fyrir um vöðvahlutfall og metið í EUROP flokka með nægilegri nákvæmni fyrir íslenskan lambakjötsiðnað. Niðurstöður mats á erfðastuðlum sýna jafnframt að rafrænt EUROP mat getur komið í stað núgildandi matsaðferðar. Rafrænt kjötmat með notkun VIAscan® er því valmöguleiki fyrir íslenska sauðfjárrækt. Meta þarf kostnað við innleiðingu rafræna matsins áður en hægt er að taka það til notkunar hér á landi.

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Table of content

Original papers included in the thesis

The following thesis is based on two original paper manuscript, which are referred to by roman numerals.

I. Einarsson, E., Eythórsdóttir, E., Smith, C.R. & Jónmundsson, J.V. The ability of video image analysis (VIA) to predict lean meat yield and EUROP score of Icelandic lamb carcasses. Unpublished manuscript.

II. Einarsson, E., Eythórsdóttir, E., Smith, C.R. & Jónmundsson, J.V. Genetic parameters for lamb carcass traits assessed by video image analysis, EUROP classification and *in vivo* measurements. Unpublished manuscript.

List of tables

1. Introduction

The stability of carcass grading is an important issue for the Icelandic sheep industry as it has many objectives. It should ensure fair payment to farmers for their production and give them feedback from the market, give the abattoir information about the product they are buying, create a way of communication with other markets and provide a tool to sort carcasses for further processing. Further the carcass grading creates fundamental data for the breeding work. The consistency of the grading system is therefore of major importance. The current grading system of lamb carcasses in Iceland is based on visual conformation assessment and a fat assessment that is primarily based on manual measurement of fat thickness. This system is commonly recognized as the EUROP system. Fully automated EUROP classification systems for lamb carcasses are not in commercial use anywhere to our best knowledge.

In 2006 experiments on objective carcass grading were started in Iceland for the first time using video image analysis (VIA) technology. The project was carried out at the KS abattoir in north Iceland where the VIAscan® unit from the Australian company Ceder Creek Company Pty Ltd was installed. This system had been used already to predict lean meat yield (LMY%) of carcasses in Australia, New-Zealand and France. The aim of the project was to derive VIAscan® prediction equations for the prediction of LMY% and evaluate their applicability on the Icelandic lamb carcasses as well as to develop equations for VIAscan® to classify carcasses according to the current grading system.

In the present study the aim is to evaluate VIAscan® as a grading tool for the Icelandic sheep industry. This includes evaluation of the ability of VIAscan® to predict LMY% and classify into EUROP classes. The current EUROP classification system is evaluated in same manner for benchmarking. Genetic parameters of traits assessed by VIAscan®, the current grading system and by live lamb measurements are estimated. These are of major interest to obtain the correlation with the EUROP score obtained from the two grading methods and to examine genetic and phenotypic correlations between live lamb assessment and the carcass assessment by the new objective technology. The state of current knowledge and findings of related research is reviewed.

2. Literature review

2.1 Definitions

2.1.1 Carcass composition

Carcass composition commonly refers to the proportions of bone, muscle and fat. Thorgeirsson (1981) studied the developmental pattern of Icelandic sheep and found that mean carcass composition of ram lambs at slaughter age was divided into 11.9% bone, 59.9% muscle and 28.1% fat. The male lambs have generally less fat and higher proportion of muscles and bones than the female lambs.

It has been the subject of many studies to develop a form of measurement that can predict carcass composition, either based on live animal assessment or carcass assessment. The accuracy of the methods is often presented as the amount of the variation explained (R^2) of the actual carcass composition based on dissection. It is variable whether the scientists are interested in predicting weight of tissues or proportion of the carcass. Generally LMY kg is predicted with a considerably higher accuracy than LMY%.

2.1.2 Carcass quality

Carcass quality refers to objective and subjective measurements of carcass conformation and fatness, joint proportion and carcass composition. This covers traits like dressing percentage, carcass weight, conformation score, fatness score and various carcass conformation measurements (Cañeque et al., 2004; Lambe et al., 2008).

2.1.3 Meat quality

Meat quality can have different definitions between countries and sectors (Smith & Carpenter, 1970; Nardone & Valfré, 1999). In the literature, meat quality both refers to meat eating quality traits or palatability which can be tested by sensory evaluation and traits which are measured instrumentally. Lambe et al. (2008) declares meat quality traits other than meat eating quality traits as chemical composition, mechanical properties and bacteriological stability.

2.1.4 Carcass conformation and muscularity

Carcass conformation was defined by De Boer, Dumont, Pomeroy and Weniger (1974) as thickness of flesh and subcutaneous fat relative to dimensions of skeleton. Other authors have defined conformation as the carcass shape in terms of convex or concave profiles (Johansen, Aastveit, Egelandsdal, Kvaal & Røe, 2006).

Muscularity cannot be assessed at the carcass level because muscles are not visible on the external surface but conformation can both be assessed on carcasses and live animals (Nsoso, Young & Beatson, 2000). Objective measurements of muscularity can be achieved by using the ratio of a muscle thickness to a bone length or muscle weight to a bone length (Hopkins, Fogarty & Menzies, 1997; Jones, Lewis, Young, Wolf & Warkup 2002a).

2.1.5 Linear measurements

In the search for good measurements to predict carcass composition many linear measurements have been identified and tested. These are both cross-sectional measurements and external measurements. Cross-sectional measures require either the carcass to be cut or the use of special technology like CT scanning or ultrasound.

Many studies of lamb carcass composition have focused on assessing the *musculus longissimus* of the *erector spinae*. This muscle is known as *longissimus thoracis et lumborum* also recognized as *L. dorsi*. Sometimes these muscles are divided in to two parts according to the region it belongs to. When referring to the part of the muscle on the thoracic vertebrae and ribs region it is named *longissimus thoracis,* sometimes called "eye muscle" and when referring to the lumbar region it is named *longissimus lumborum* (Kauffman, Smulders, Hartman, Habel & Bergstrom, 1990).

Dr. Halldór Pálsson was one of the first scientists to describe many of the measurements which are still in use (Stanford, Jones & Price, 1998a). Key measurements described by Pálsson (1939) are the cross-sectional measurements taken at the last rib. Following are descriptions of some of the most commonly used measurements:

A = length of eye muscle (also known as the width of the eye muscle) – the maximum distance across the cross-section surface of the *longissimus dorsi* from the end next the spinal process outwards along the rib.

B =depth of eye muscle – the greatest distance at right angles to A on the same surface.

C =thickness of back-fat over the deepest part of the eye muscle.

J =thickest layer of fat over the rib.

Pálsson also identified several external measurements on live sheep. One of them is the length of the fore cannon bone (metacarpal), abbreviate as M (Pálsson, 1939). Later also recognized as ML (Thorsteinsson, 1983).

In the year 1957 an extensive progeny testing program of rams was started in Iceland at the experimental farm Hestur, where most of the measurements identified by Pálsson were included as well as ratios between some of these measurements. After 20 years of progeny testing, some of these measurements were dropped since they did not add much information beyond the other measurements. The carcass measurements that were kept in as important parameters for research on carcass quality were measurements A, B, C and J and the length of tibia (T), leg length/depth of the crutch (F), minimum width of the thorax (V) and maximum depth of the thorax (Th). Also kept were conformation scores for legs and shoulders (Thorsteinsson, 2002).

Thorgeirsson and Thorsteinsson (1986) investigated the ability of several carcass measurements in predicting carcass composition and concluded that the J measurement is most valuable in carcass grading or classification and the best single predictor of fatness. They also found that the best predictors for muscle weights, beside carcass weight and J, were the product of the eye muscle measurements (A x B) and difference between hind leg measurements (F-T) which together explained 97.6% of the variation.

Closely related to the J-measurement is the GR-measurement which was introduced in New-Zealand in the 1973/74. GR measures the total tissue depth, measured perpendicular to the surface on the region of the 12th rib, 11 cm from the mid-line. It can be measured by a metal ruler or special optical probes (Kirton, Woods & Duganzich, 1984). Kirton (1989) argued that no single carcass measurement would predict carcass composition as accurately as the GR measure. Recently Hopkins, Ponnampalam and Warner (2008) also confirmed the usefulness of the GR as an accurate and practical predictor of lean content proportion (R^2= 48.1%, RSD = 1.89%). Similar results have been found by Hopkins, Anderson, Morgan and Hall (1995), Stanford, Woloschuk, McClelland, Jones and Price (1997) and Hopkins, Safari, Thompson and Smith (2004). Table 1 summarizes results of several studies concerning predictability of carcass measurements.

Measurements B and C are used in many countries to assess carcass composition of lambs measured by ultrasound technology (Stanford et al., 1998a). The length of the cannon bone (M) relative to live weight has been recognized as a useful measure for improving the conformation of the carcass and increasing proportion of muscle relative to bones (Thorgeirsson, 1981; Thorsteinsson, S. 2002).

Table 1. Prediction accuracy of lamb carcass composition by various carcass assessments. Coefficients of determination (R^2) and root mean square error (RMSE).

Method	**Prediction**	**Predictors**	**R^2 (RMSE)**	**Reference**
BIA	Fat free lean(%)	HCW + BIA	0.30 (3.80%)	Allen & McGeehin (2001)
Carcass weight	Fat free lean(%)	HCW	0.01 (3.80%)	Allen & McGeehin (2001)
EUROP system	LMY %	EUROP classes + GR	0.38 (2.29%)	Einarsdóttir (1998)
EUROP system	LMY%	Conformation class	0.03 (2.85%)	Einarsdóttir (1998)
EUROP system	LMY%	Fat classes	0.23 (2.54%)	Einarsdóttir (1998)
EUROP system	LMY%	EUROP classes + CCW	0.41	Johansen et al (2006)
GR probe	LMY%	GR	0.27 (2.48%)	Einarsdóttir (1998)
GR knife	LMY%	GR + HCW	0.41 (2.39%)	Hopkins et al. (2004)
GR knife	LMY %	GR	0.48 (1.89%)	Hopkins et al. (2008)
GR and subjective assessment	LMY%	GR + conformation class	0.52 (1.84%)	Stanford et al. (1998b)
Linear measurements	LMY%	GR + G + L/HCW	0.61 (1.3%)	Stanford et al. (1997)
TOBEC	LMY%	EM scanning	0.72 (2.56%)	Berg et al. (1997)
USDA yield grade	LMY%	USDA yield grade	0.60 (0.02%)	Cunha et al. (2004)
VIA system	LMY%	VIA + CCW	0.71 (1.43%)	Stanford et al. (1998b)
VIA system	LMY%	LVS + HCW	0.60 (0.03%)	Brady et al. (2003)
VIA system	LMY%	LVS + HCW	0.68 (0.02%)	Cunha et al. (2004)
VIA system	LMY%	LVS + HCW + PF	0.72 (0.02%)	Cunha et al. (2004)
VIA system	LMY%	VIA + HCW	0.52 (2.17%)	Hopkins et al. (2004)

BIA = Bioelectrical impedance, CCW = cold carcass weight, G = Leg circumference, GR = total tissue depth over the 12th rib, 110 mm from the midline, HCW = Hot carcass weight, L = Carcass length, LMY% = Proportion of lean meat yield and salable meat yield, PF = overall percent fat in the 12th /13th –rib interface obtained from VIA, LVS = Lamb vision system, TOBC = Total body electrical conductivity, EM = electromagnetic, VIA = video image analysis.

2.2 Grading systems

2.2.1 Objectives and requirements of grading systems

For some decades the general goal in lamb meat production has been to produce a carcass with a high proportion of muscle, an acceptable amount of fat and a minimum of bone. The amount of fat desired or accepted differs between markets (Berg & Butterfield, 1976). Berg and Butterfield (1976) argued that the most common purpose of a grading system is to evaluate the carcass composition. Knowledge of the composition makes it possible to assign value to the carcass and allows sorting for further processing (Stanford et al., 1998). Harrington and Kempster (1989) pointed out that carcass grading should include two equally important categories in order to increase consumer demand. On one hand, meat quality traits such as tenderness, cut size, fat cover, marbling, meat and fat colour, on the other hand traits such as saleable meat yield or proportion of fat, lean and bone. Another important purpose of carcass grading is to provide a language of communication between producers and meat purchasers and give producers feedback of consumer requirements (Kirton, 1989). Carcass grading also creates important information for sheep breeders that can be used in breeding programs. Some carcass grading systems include both assessment of carcass quality and meat eating quality assessment (Polkinghorne & Thompson, 2010).

Important properties of carcass grading systems are that the method is precise, accurate over time and distance and will function across different breeds, sexes and ages. It has to be relatively simple to carry out and non-destructive. Crucial properties are the cost and speed of the method. Greater cost and effort may be accepted where greater use is made of the assessment such as for breeding purpose (Berg & Butterfield, 1976; Hedrick, 1983; Stanford et al., 1998a). Berg and Butterfield (1976) argued that the maximum acceptable cost of the classification system has to be determined with respect to the returns which it brings to all the sections of industry. Speed is important as lamb production in many countries is based on seasonal slaughter (Kongsro, Røe, Kvaal, Aastveit & Egelandsdal, 2009).

The grading schemes in the meat industry differ all over the world but most of them have a common feature of carcass weight and some form of assessment of fat and muscle development that can be either objective or subjective (Strydom & Smith, 2005). The most common grading systems are visual classification, either by use of the EUROP (Europe) or the USDA classification system (North America) (Kongsro et al., 2009). In the large lamb production countries, New-Zealand and Australia, carcass assessment is based on carcass weight and fat assessment by the GR-measure.

2.2.2 EUROP classification system

The classification system for ruminant carcasses used in the European Union (and several other countries) is commonly named the EUROP classification system (Johansen et al., 2006). This system can also be used for pig carcasses (Kvapilík, Přibyl, Růžička & Řehák, 2009). Carcasses are classified according to fat assessment and conformation score. The fat classes describe the amount of visible subcutaneous fat on the carcass and the conformation describes the shape and is intended to indicate the amount of flesh (fat and lean) in relation to bone (Johansen et al., 2006). Generally the conformation is only based on subjective assessment but the fat assessment may be based on fat measurement as well.

The EUROP system consists of 5 main conformation classes and 5 main fat classes. The main conformation classes are E, U, R, O and P where E describes excellent conformation and P the poorest conformation. Main fat classes are from 1 to 5 where 1 describes the leanest carcasses and 5 the fattest (Russo, Preziuso & Veritá, 2003). An extra “superior” S-class is used in some countries for carcasses with extremely good conformation, such as double-muscled individuals. This class has been used for beef (Allen, 2005; Oliver, Mendizabal, Ripoll, Albertí & Purroy, 2010), pigs (Kvapilík et al., 2009) and heavy lambs (Rubino, Morand-Fehr, Renieri, Peraza & Sarti, 1999).

Each main class can be divided into 3 subclasses. Some countries use only subclasses for the most common classes for example in Ireland (Allen & Finnerty, 2000). Other countries, like Norway, use all the subclasses or the 15-point scales (Johansen et al., 2006). The EUROP classification system for light lambs (< 13 kg) is slightly different where conformation assessment is excluded and meat color is evaluated instead (Díaz et al., 2004).

The overall aim of the EUROP system is to sort carcasses for further processing and to ensure fair payment to farmers (Johansen et al., 2006). The main emphasis is on yield estimation but not on meat quality evaluation. This system has enabled the meat industry to describe carcass characteristics of commercial relevance in trading (Polkinghorne & Thompson, 2010).

The accuracy of the EUROP system as an estimator of lean meat yield has been evaluated in several studies. Einarsdóttir (1998) found that the EUROP system along with an objective fat measurement would explain 37.8% of the variation in lean meat yield in Icelandic lambs. Similarly Johansen et al. (2006) found that EUROP classification along with carcass weight would explain 41% of the variation in meat yield in lambs in Norway. Both these studies showed that the fat assessment is the most important predictor for yield when estimated as proportion.

Conformation has been criticized by many authors for having little practical value as a predictor of carcass composition since it has a poor relationship with lean meat yield, low heritability and the value of it is unclear (Berg & Butterfield, 1976; Kempster, Cuthbertson & Harrington, 1982; Hedrick, 1983; Nsoso et al., 2000). Stanford et al. (1997) suggested that different results between studies on the importance of conformation can be explained by the population of lambs evaluated. In studies including variable types of lambs the importance of the conformation score as a predictor of salable meat yield will be increased. Wolf, Jones and Owen (2001) argued that variation in lean yield at constant live weight within the Texel breed was likely associated with difference in conformation type. According to the literature it may be concluded that the importance of conformation needs to be analyzed within each breed or breeding program.

The association between conformation and fat makes it difficult to a get good relationship between conformation and LMY%. Thorgeirsson (1981) showed that compact conformation was strongly correlated to high proportion of muscle and fat relative to bone. Harrington and Kempster (1989) concluded that well conformed carcasses were fatter than poorly conformed carcasses with little difference in muscle thickness or proportion of higher priced cuts. Similarly Johansen et al. (2006) found EUROP conformation score to be a bad predictor for lean meat yield. When the importance of conformation is determined, carcasses should be compared at similar weight and subcutaneous fat percentage (Kempster et al., 1982).

Carcass conformation can have further objectives than estimating yield. The shape of the cuts can be important for consumers. A few authors have argued that good conformation provides cuts with more aesthetic appeals that are more desirable to traders and consumers than cuts of poorly conformed carcasses (Kempster et al., 1982; Horgan, Murphy & Simm, 1995; Hopkins, 1996).

It has been argued that improved assessment of conformation and muscularity can be obtained by development of objective methods to evaluate these traits (Stanford et al., 1998a; Nsoso et al., 2000). Hopkins (1996) suggested that conformation assessment could be improved by adopting methods like video image analysis (VIA) for this purpose.

2.2.3 Vision systems

The video image analysis (VIA) is a technology that provides objective and automatic carcass assessment based on various measurements of carcass dimensions, areas and colour characteristics. The equipment operates at normal slaughter chain speed and uses one or more views of the carcass (Lambe et al., 2009). The VIA systems are generally composed of one or more cameras, which capture image of the carcass and a computer to collect data. Computer software is used to extract data from the images, such as lengths, areas, volumes, angles and colours. Further computer software is then used to process the data and produce the desired results (Allen & Finnerty, 2000). The main sectors focusing on this technique have been the beef and pork industry (Stanford et al., 1998b). In recent years VIA systems have been established in lamb abattoirs in several countries (Lambe et al., 2009). The VIA technology provides various results and carcasses can be classified to several standards (Stanford et al., 1998b). Most common are predictions of salable yield in carcasses or in special cuts.

The Department of Agriculture in the USA started a development project for VIA for the beef industry in 1978 (Cross, Gilliland, Durland & Seideman, 1983). Since then a few companies in different countries have developed versions of this technology. In 2004 Ireland became the first country to have a VIA system authorized by EU for beef carcasses classified by the EUROP system (Allen, 2005). The European Commission has also approved image analysis as an official method of pig carcass classification (Oliver et al., 2010). A yield based payment system for lamb carcasses has been used in New-Zealand for several years (Jopson, McEwan, Logan & Muir, 2009) and in some abattoirs in

Australia. Ongoing trials have been carried out in different countries like UK (Rius-Vilarrasa, Bünger, Maltin, Matthews & Roehe, 2009a), France (Chris Smith, pers. comm., 4. September 2011), Norway (Morten Røe, Animalia, Norway, e-mail, 7. December 2009) and Canada (Stanford et al., 1998b).

There are several VIA systems in use for lamb carcasses:

VIAscan®

The VIAscan® system is a video image analysis system developed by Meat and Livestock Australia for lamb and beef carcass grading since 1989 (Stanford et al., 1998b). The VIAscan® system uses digital images of the dorsal view of each carcass. The images are stored on a computer, where special software extracts various measurements from the images including areas, length, widths and the colour at selected points. The system uses a one colour camera which is in a fixed position perpendicular to the carcass. Artificial lighting is used to illuminate the carcass from a dark background (Hopkins, 1996).

A comparison made between yield estimation of lamb carcass by VIAscan® and a concurrent grading system based on GR fat measure and conformation score showed that of the 93 variables produced by VIAscan® and tested in prediction equations, four were used in the final equation. The results showed that VIAscan® was able to predict LMY% (R^2=0.71 RSD= 14.3 g/kg) with more accuracy than the current grading system (R^2=0.52 RSD= 18.4 g/kg). It was concluded that further testing would be needed for evaluation of extremely lean or well muscled carcasses before VIA could be recommended to classify lamb carcasses (Stanford et al., 1998b).

Hopkins et al. (2004) reported that yield could be predicted with higher accuracy by using 8 VIAscan® measurements and hot carcass weight (HCW) than using HCW and GR tissue depth. The VIAscan® system predicted LMY% with an R^2 of 52 % and an RMSE of 2.17 %, while the concurrent system achieved R^2 of 41% and RMSE of 2.39 %. The VIAscan® parameters consisted of 8 measurements, 5 of carcass width and single colour measures from the loin, chump and shoulder.

VSS2000

The VSS2000 system is developed by E+V GmbH in Germany. This system is based on two images of each carcass, one from the dorsal view and one from the side (Rius-Vilarrasa et al., 2009a). The ability of VSS2000 to predict salable meat yield (SMY) was tested on UK lamb carcasses. The VIA system explained 66% (R^2) of the variation of the SMY while the MLC EUROP classification system explained 55% (R^2). The capability of VSS2000 to predict EUROP classes was also examined where the VIA technology was compared with a panel of expert classifiers using 5/7 point scale. The VIA classified 68% to 74% of carcasses in same conformation class as the panel of expert classifiers and 48% to 55% in the same fat class, depending on the suspension method of the carcasses. In this trial VIA showed higher repeatability than expert classifiers in classifying conformation but lower in fat classifying (Meat and Livestock Commission, 2007). Rius-Vilarrasa et al. (2009a) reported that the VSS2000 together with cold carcass weight (CCW) could predict weight of total primal carcass joints with a R^2 of 0.99 and RMSE of 0.254 kg. A prediction equation based on EUROP conformation and fat classes together with CCW explained the same amount of the variance but with slightly lower accuracy (RMSE = 0.292 kg).

Normaclass

In France the Normaclass system was developed for the industry organization, INTERBEV. This system uses 6 cameras which are located at different heights and viewing angles and has a capability of rotating the carcass. The 3D information is gained from different viewing angles (Allen, 2005).

The Lamb Vision System (LVS)

The Lamb Vision System (LVS) was developed in the USA and is based on the same technology as other VIA systems with a camera, a light source and a computer. The LVS showed more accuracy in predicting yield than the US grading system where it accounted for 60% of the observed variation in percent salable meat yield (SMY%) (Brady et al., 2003). This was confirmed by Cunha et al. (2004) who reported that improved equations based on LVS measurements would account for 68% of the variation (R^2) of SMY. Variables in the regression model were hot carcass weight (HCW) and the VIA measurements; carcass length, ratio of the maximum rack width and maximum shoulder width, ratio of the minimum and maximum body width (shoulder, rack, loin), groin to right leg length, leg width measurement closest to the groin and blue color score for the shoulder (adjusted for intensity). The explained variation of the SMY could be increased to 72% when measurements of the longissimus muscle area were included, based on an image of the exposed surface of the interface of the $12^{th}/13^{th}$ ribs.

Three VIA systems, the BCC-2 (Danish beef carcass system developed for EUROP classification (Borggaard, Madsen & Thodberg, 1996)), VBS-2000 (from the E+V in Germany) and the VIAscan® system were compared in Ireland in 1999 where the aim was to classify beef carcasses into EUROP classes and predict salable meat yield. All systems showed similar accuracy in predicting yield and all systems showed more accurate estimates of conformation class than fat class (Allen & Finnerty, 2000). Pabiou et al. (2011) investigated the ability of VIA to predict weight of special cuts in beef carcasses in Ireland. They found that EUROP assessment and carcass weight predicted LMY% with more accuracy than carcass weight and VIA variables while the latter measures were more accurate in predicting weight of special cuts. They concluded that VIA provided a powerful tool for the beef breeding program.

Lambe et al. (2009) investigated the relationship of various carcass measurements with carcass composition and meat quality traits of lambs. They concluded that automated carcass grading like VIA could be developed further by including information about eye muscle dimensions, subcutaneous fat depth and accounting for the sex of the lamb. This would improve the yield prediction and give an opportunity to evaluate meat quality traits like intra-muscular fat.

2.3 Other methods

2.3.1 Optical/electronic probes

Optical probes are instruments capable of measuring fat and muscle thicknesses automatically from differential light reflectance of tissues (Kempster, Chadwick and Jones, 1985). Optical probes have been used in different ways to evaluate carcass composition in pigs (Kempster et al., 1985), beef (Philips, Herrod & Schafer, 1987) and lambs (Kongsro et al., 2009). Optical probes can for instance be used for GR measurement on lamb carcasses (Stanford et al., 1998a). Kongsro et al. (2009) compared four lamb carcass grading methods in Norway (basic EUROP system, advanced EUROP system, CT scanning and Hennessy Grading Probe) where they concluded that the optical probe was the best grading system with respect to speed, cost and accuracy of prediction of carcass composition. Einarsdóttir (1998) compared two electronic probes on Icelandic carcasses, the FTC Lamb Probe from Sweden and ICEMEAT GR Probe from Iceland where the FTC probe gave better results when predicting fat and lean meat percentage.

2.3.2 Ultrasonic measurements

Ultrasound is used commercially for pig carcass grading. This technology has the capacity of over 1.000 carcasses per hour according to the producer (Carometec A/S, 2009). No studies were found about ultrasonic measurements as a grading tool for lamb carcasses.

2.3.3 Total body electrical conductivity (THOBEC)

The electromagnetic (EM) scanner measures total body electrical conductivity (TOBEC). The EM scanner called MQ-25 consists of a large coil of copper wire wound around a large plexiglass tube (EM scanning chamber). The carcass or box of meat is carried through the chamber/tunnel. The object absorbs energy from the field in proportion to its conductivity. Lean tissue is a good conductor because of its great water and electrolyte concentration while fat and bone are not as good conductors. The energy absorption is measured by detectors while the object passes through the field. (Berg, Forrest, Thomas, Nusbaum & Kauffman, 1994; Allen & McGeehin, 2001). It has been reported that EM scanning is effective for predicting the composition of lamb carcasses where this method could count for 77.5% of the variation in LMY% (Berg et al., 1994).

2.3.4. Bioelectrical impedance (BIA)

BIA technology measures the impedance of resistance, reactance and length between detector electrodes. The hypothesis behind the technology is that lean carcasses transmit electricity better than fat carcasses where muscles are highly conductive substances (Berg, Neary, Forrest, Thomas & Kauffman, 1997).

The difference between THOBEC and BIA techniques is that in BIA the current is passed through the carcass and the resistance to the current flow is recorded but TOBEC measures the absorption of electrical energy by a carcass from an electromagnetic field. The equipment for BIA is much cheaper than TOBEC but TOBEC is fully automated while

BIA needs an operator. The BIA technology was first investigated for use on live animals but more recently for use on carcasses (Allen & McGeehin, 2001). It has been shown that BIA can be an option for predicting lean yield of lamb carcasses (Berg et al., 1997; Allen & McGeehin, 2001). Recent tests of predicting yield in beef carcasses showed that BIA can estimate proportion of yield accurately (Zollinger, Farrow, Lawrence & Latman, 2010).

In a comparison between real-time ultrasound, optical reflectance probe, bioelectrical impedance analysis (BIA) and EM scanning, the THOBEC technology was the most accurate method to predict carcass lean weight and percentage of lamb carcasses (Berg et al., 1997). In agreement with these studies, Allen and McGeehin (2001) reported that the THOBEC technology would be more accurate in predicting carcass composition than the BIA technology, where the THOBEC together with some carcass dimensions explained 43% of the variation in proportion of fat free lean. These methods did predict lean mass with similar accuracy where BIA with HCW explained 72% of the variation but TOBEC and HCW explained 75% of the variation. They concluded that TOBEC would have a potential as an objective lamb carcass grading system since the whole carcass can be put through the equipment and the accuracy of the prediction is reasonable.

2.4 Body composition *in vivo*

To increase the rate of genetic improvement for consumer-preferred product it is important to be able to estimate the body composition *in vivo* to identify the best individuals for further breeding (Berg, Neary, Forrest, Thomas & Kauffman, 1996; Stanford et al., 1998a). The main objective of live appraisal techniques should be to assess the dressing percentage and the carcass composition, in particular the proportion of muscle mass of the live weight (Berg & Butterfiled, 1976). Table 2 summarized results from studies on different live lamb measurements for predicting lean meat yield either as proportion or weight. Depending on the parameter, between 14% and 95% of the variation in yield (R^2) was explained.

Table 2. Prediction of lamb carcass composition by various *in vivo* assessments. Prediction accuracy estimated by coefficient of determination (R^2) and root mean square error (RMSE).

Method	Prediction	Predictors	R^2 (RMSE)	Reference
BIA	TDL%	LW + BIA measurements	0.55 (3.27%)	Berg et al. (1996)
Conformation	LMY%	LSC +LW+ flock + sex	0.40 (26.0%)	Wolf et al. (2006)
CT scanning	Lean in leg kg	CT measures	0.95	Kvame & Vangen (2006)
CT scanning	Lean in mid-region kg	CT measures	0.91	Kvame & Vangen (2006)
CT scanning	Lean in shoulder kg	CT measures	0.85	Kvame & Vangen (2006)
Linear measurement	TDL%	LW+ linear measurments[1]	0.14 (4.52%)	Berg et al. (1996)
Mixed methods	TDL%	LW + BIA + UMD + linear measurments[1]	0.70 (2.91%)	Berg et al. (1996)
Ultrasound	LMY%	UFD	0.17 (1.70%)	Edwards et al. (1989)
Ultrasound	TDL%	UFD + UMD + LW	0.26 (4.46%)	Berg et al. (1996)
Ultrasound	LMY%	UFD + UMD + LW	0.28	Puntila et al. (2002)
Ultrasound	LMY kg	UMD + LW	0.51	Puntila et al. (2002)
Ultrasound	LMY kg	UFD + UMD + LW	0.86	Thorsteinsson (2002).
Ultrasound	LMY%	UFD + UMD + LW+ flock + sex	0.53 (23.1%)	Wolf et al. (2006)
Ultrasound	LMY kg	UFD + UMD + LW+ flock + sex	0.83 (0.36 kg)	Wolf et al. (2006)
Ultrasound and conformation score	LMY%	UFD + LW + LCS + flock + sex	0.54 (22.8%)	Wolf et al. (2006)
Ultrasound and conformation score	LMY kg	UFD + LW + LCS + flock + sex	0.84 (0.35 kg)	Wolf et al. (2006)
Ultrasound	LMY%	LMV + LW	0.70 (3.85%)	Silva et al. (2007)
Ultrasound	LMY kg	LMV + LW	0.92 (0.53 kg)	Silva et al. (2007)
Ultrasound	LMY%	UFD + UMD	0.34 (2.16%)	Einarsson et al. (2009a)
Ultrasound and in vivo assessment	LMY%	UFD + UMD + *in vivo* assessment[2]	0.40 (2.09%)	Einarsson et al. (2009a)

[1]Linear measurement =Hindsaddle length, shoulder height and heart girth.
[2]*In vivo* assessment = Subjective score for neck and shoulder girdle, subjective leg score, live weight and length of cannon bone.
BIA= Bioelectrical impedance, CT = Computer tomography, LCS = Leg shape score, LMV = volume of *longissimus thoracis et lumborum* obtained by *in vivo* real-time ultrasonography, LMY kg = Weight of lean meat yield, LMY% = Proportion of lean meat yield, LW = Live weight, TDL% = Total dissected carcass lean weight/Warm carcass weight, UFD = Ultrasound fat depth, UMD = Ultrasound muscle depth,

2.4.1 Live weight

Live weight is commonly used by in vivo prediction techniques. Live weight includes components like gut fill, head, feet, hide and other parts that are separated from the dressed carcass at slaughter (Berg & Butterfield, 1976) which make it difficult to measure live weight accurately (Stanford et al., 1998a). However, studies have demonstrated that live weight is the most important predictor for carcass lean weight (Berg et al., 1996).

2.4.2 *In vivo* conformation score

Visual conformation scores on live animals are subject to the same criticism as carcass conformation as being a poor indicator for lean content (Berg & Butterfield, 1976). Studies in this field give variable results where some authors have concluded that visual conformation score can be useful in breeding meat animals. Wolf et al. (2001) and Wolf, Jones and Owen (2006) studied the importance of subjective leg shape score in Texel lambs for predicting carcass composition. They reported a positive association with leg muscularity but only a weak correlation with proportion of lean in the carcass. Leg shape score was largely independent of live weight and fatness at a fixed age. Puntila, Mäki and Rintala (2002) studied the importance of EUROP score on live lambs and concluded that a visual EUROP conformation score on live animals might be a useful indicator trait in the breeding program as it had moderate heritability.

Icelandic reports have shown that leg shape score has a weak positive correlation with LMY% and moderate to strong correlation with ultrasound muscle depth. Further, *in vivo* leg shape score is strongly correlated to leg shape score of carcasses which is in turn associated with EUROP conformation score (Thorsteinsson, 1983; Einarsson, Eyþórsdóttir & Jónmundsson, 2009a). Conroy, Drennan, Kenny and McGee (2009) reported a high correlation between pre-slaughter conformation score of beef cattle and carcass conformation score and concluded that muscular scoring would be a useful indicator for carcass lean meat proportion.

2.4.3 Linear measurement

The use of linear measurements (shoulder height, heart girth, body length, etc.) for live lamb assessment has decreased since technologies enabling *in vivo* prediction of carcass composition became available. The inability of linear measurements to distinguish between lean and fat limits the usefulness of these methods for predicting carcass composition (Berg et al., 1996; Stanford et al., 1998a).

Various linear measurements on live lambs were widely used in the past in Iceland. The only measurement that is still in use is the length of the left fore cannon bone. Selection for a short cannon bone relative to live weight is based on research by Pálsson (1939) and Thorgeirsson (1981) who demonstrated the importance of this measure as an aid in breeding sheep with more compact bodies.

2.4.4 Ultrasound scanning

The ultrasonic technique was first introduced early in the 1950's as a tool for estimating carcass composition of live animals (Fisher, 1997). Ultrasound scanning is the most widely used *in vivo* measurement to evaluate the carcass composition in sheep (Jones, Lewis, Young & Wolf, 2002b). This method is relatively inexpensive and is easy to use (Stanford et al., 1998a). The ultrasound technology is based on sound waves above the frequency audible to the human ear. The waves are sensitive to the density of the material they pass trough and changes in tissues density results in reflection of waves back to the instrument (Berg & Butterfield, 1976; Houghton & Turlington, 1992).

Generally, the ultrasound technology is used to obtain a cross-sectional measure of the depth of the *L. dorsi* muscle (UMD) and the fat depth (UFD) over the muscle (measurements B and C) (Stanford et al., 1998a). It has also been used to evaluate the volume of muscles (Silva et al, 2007). The site of measurements differs between studies and countries. An Icelandic study compared measurements taken at 12th rib and the 3^{rd} lumbar vertebrae. The results showed that LMY kg was predicted with more accuracy based on measurements from the lumbar region than from the 12^{th} rib (Thorsteinsson, 2002). This is in agreement with a study by Teixeira, Matos, Rodrigues, Delfa and Cadavez (2006). The advantage of scanning at the last rib rather than the lumbar region is that it is easier for the technician to recognize the scanning site at the last rib (Puntila et al., 2002) which should make it easier to standardize the measurement.

In numerous studies the UMD and UFD along with live weight and various in vivo measurements explained 51% to 86% of the variation in LMY kg and 0.17 to 0.54 of LMY% (Edwards et al., 1989 ; Berg et al., 1996 ; Thorsteinsson, 2002 ; Puntila et al., 2002 ;, Wolf et al., 2006; Einarsson et al., 2009a). In these studies UMD was generally more important in predicting LMY kg than UFD. When predicting LMY%, the UFD was always the main predictor. More accuracy in yield prediction has been obtained by using volume measurement by taking several measurements at different sites (Silva et al., 2007).

2.4.5 Other methods

CT scanning of live animals is being utilized to estimate carcass tissue weight and distribution in commercial sheep breeding programs in a few countries (Jones et al., 2002b; Lambe et al., 2008). The method is known to be accurate in estimating carcass composition and considered as a useful tool to improve lean tissue growth and carcass muscularity (Jones et al., 2002b). Kvame and Vangen (2006) reported that CT estimates could explain 89% to 98% of the variation in weight of lean meat yield. Kvame, McEwan, Amer and Jopson (2004) suggested that there might be a potential in using CT scanning in combination with new technologies such as the VIA technology.

BIA has the potential to predict carcass composition of live lambs (Berg & Marchello, 1994). Berg et al. (1996) found that the BIA measurements gave a more accurate assessment of lean meat yield as proportion than ultrasound measurements. When BIA measurements were used in combination with ultrasound and linear body measurements the best assessment of LMY% was found but it was not considered as a practical way of live lamb measurements.

Live animal video image analysis (LVIA) has been investigated as a method to predict carcass composition (Lambe et al., 2008). This method has been found useful for estimating carcass composition and conformation of pigs (Doeschl, Whittemore, Green, Fisher & Schofield, 2003). Lambe et al. (2008) suggested that LVIA could give helpful information for estimating carcass composition of lambs in combination with CT scanning. The main disadvantage of this method is that all lambs have to be shorn before they are assessed which causes extra cost and stress to the animals.

2.5 Genetic parameters for carcass traits

One of the objectives of carcass assessment is to obtain information that can be used for breeding programs. For this purpose, it is important that carcass assessments yield measurements of inheritable traits. It is also important to recognize the correlation between the carcass assessments traits and the traits measured on live animals that are used to select livestock for improved carcass quality, where higher correlation should make the breeding more effective. Knowledge of genetic parameters (genetic variance of each trait and covariances among traits) is essential for the development of effective genetic evaluation and improvement programs for important production traits (Safari, Fogarty & Gilmour, 2005).

Heritability (h^2) can be defined as the proportion of superiority of parents in a trait which, on average, is passed on to offspring. (Simm, 2000). The correlation between traits is either measured as phenotypic correlation (r_P) or genetic correlation (r_G) (Simm, 2000). Heritability can also be used to measure the accuracy of different methods or assessors. Veerkamp, Gerritsen, Koenen, Hamoen and De Jong (2002) showed how it is possible to use heritability to test whether classifiers rank animals consistently.

Table 3 shows an overview assembled from the literature of heritability estimates for various carcass traits of sheep evaluated either on carcasses or on live animals in different countries on lambs from 3 to 6 months old. All traits shown in Table 3 are used for breeding purposes in Iceland, except carcass evaluation based on VIA and CT scanning and live EUROP conformation score. Live weight and carcass weight have generally a low or moderately-high heritability. The linear measurements like GR, J, cannon bone length and the ultrasound measurements have shown high heritability in most studies. The heritability of visual assessments on both live animals and carcasses range from being very low to extremely high. The few published estimates of heritability for yield evaluated by VIA are generally moderate to high. Heritability estimates for EUROP score of lamb carcasses evaluated by VIA were not found in the literature.

Two types of maternal effects can be expected on carcass traits in sheep. These are maternal genetic effects (m^2) where the phenotypic value of the mother for a certain trait can influence the same trait of the offspring. The other is maternal environmental effects (c^2) that causes resemblance between offspring of the same mother but not between offspring and mother (Falconer & Mackay, 1996). Maternal effects in sheep are most common for weight related traits like live weight and carcass weight. Maternal effects have been identified for live weight of Icelandic lambs (Jónmundsson, 1976). The genetic correlation (r_{am}) between direct and maternal genetic effects is commonly found to be negative (Table 3). Jónmundsson (1981) published a large negative genetic correlation between direct and maternal genetic effects on autumn live weight of Icelandic lambs.

Table 3. Estimates of heritability (h^2), standard error (SE), maternal heritability (h_m^2), maternal environmental effect (c^2) and direct-maternal genetic correlation (r_{dm}) for carcass traits.

Trait	h^2 (SE)	h_m^2 (SE)	c^2 (SE)	r_{am} (SE)	Records	Breed	Reference
Cannon bone length (ex vivo)	0.82 (0.12)				1,826	Icelandic	Thorsteinsson & Björnsson (1982)
Cannon bone length (*in vivo*)	0.64 (0.14)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
Cannon bone length (*ex vivo*)	0.80 (0.15)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
Cannon bone length (*ex vivo*)	0.87 (0.09)				4,447	$Crossbred_1$	Bennett et al. (1991)
Cannon bone length (*in vivo*)	0.23 (0.06)				1,057	Texel	Wolf & Jones (2007)
CT scanning Lean weight	0.57 (0.16)				1,821	Norwegian white sheep	Kvame & Vangen (2007)
CW	0.13 (0.01)				42,888	Icelandic	Jónmundsson (1977)
CW	0.11 (0.07)				1,826	Icelandic	Thorsteinsson & Björnsson (1982)
CW	0.25 (0.10)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
CW	0.22 (0.04)				4,447	Crossbred	Bennett et al. (1991)
CW	0.18 (0.05)	0.24 (0.03)	0.27 (0.03)		3,311	Icelandic	Eythórsdóttir (1999)
CW	0.15	0.08	0.05	-0.11 (0.13)	5,062	White breeds	Näsholm (2004)
CW	0.15	0.08		0.06 (0.12)	7,893	Gotland breed	Näsholm (2004)
CW	0.21 (0.06)				1,148	Scottish Blackface	Karamichou et al. (2007)
CW	0.32				6,565	Terminal and dual purpose	Jopson et al. (2009)
CW	0.20				6,565	Terminal and dual purpose	Payne et al. (2009)
CW	0.19 (0.10)				630	Crossbreds	Rius-Vilarrasa et al. (2010)
EUROP conformation	0.09				1,580	Scottish Blackface	Conington et al. (1998)
EUROP conformation	0.40				114,398	Icelandic	Sævarsson (1999)
EUROP conformation	0.25				5,062	White breeds	Näsholm (2004)
EUROP conformation	0.20	0.11	0.09	-0.69 (0.14)	5,062	White breeds	Näsholm (2004)
EUROP conformation	0.29				7,893	Gotland breed	Näsholm (2004)
EUROP conformation	0.13	0.04	0.11	-0.06 (0.25)	7,893	Gotland breed	Näsholm (2004)
EUROP conformation	0.14 (0.05)				1,148	Scottish Blackface	Karamichou et al. (2007)
EUROP conformation	0.10 (0.07)				630	Crossbreds	Rius-Vilarrasa et al. (2010)
EUROP fat	0.27				114,398	Icelandic	Sævarsson (1999)
EUROP fat	0.27				5,062	White breeds	Näsholm (2004)
EUROP fat	0.21	0.07	0.09	-0.50 (0.17)	5,062	White breeds	Näsholm (2004)
EUROP fat	0.27				7,893	Gotland breed	Näsholm (2004)
EUROP fat	0.15	0.01	0.13	-0.30 (0.23)	7,893	Gotland breed	Näsholm (2004)
EUROP fat	0.19 (0.05)				1,148	Scottish Blackface	Karamichou et al. (2007)
EUROP fat	0.10 (0.07)				630	Crossbreds	Rius-Vilarrasa et al. (2010)
J	0.28 (0.08)				1,826	Icelandic	Thorsteinsson & Björnsson (1982)
J	0.39 (0.12)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
J	0.20 (0.04)				4,447	Crossbred	Bennett et al. (1991)
J	0.70 (0.08)				1,241	Icelandic	Thorsteinsson & Eythórsdóttir (1998)
J	0.52 (0.08)				2,104	Icelandic	Thorsteinsson (2002)
Leg score *in vivo*	0.47 (0.12)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
Leg score *in vivo*	0.62		0.11		1,237	Texel	Wolf & Jones (2007)
Leg score carcass	0.54 (0.10)				1,826	Icelandic	Thorsteinsson & Björnsson (1982)

Table 3 (continued). Estimates of heritability (h^2), standard error (SE), maternal heritability (h_m^2), maternal environmental effect (c^2) and direct-maternal genetic correlation (r_{dm}) for carcass traits.

Trait	h^2 (SE)	h_m^2 (SE)	c^2 (SE)	r_{am} (SE)	Records	Breed	Reference
Leg score carcass	0.52 (0.13)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
Leg score carcass	0.79 (0.08)				1,241	Icelandic	Thorsteinsson & Eythórsdóttir (1998)
LEUROP	0.27 (0.03)				5,993	Finnsheep and meat breeds	Puntila et al. (2002)
LW	0.19 (0.03)	0.27 (0.04)			6,326	Icelandic male	Jónmundsson (1976)
LW	0.29 (0.04)	0.27 (0.04)			6,645	Icelandic female	Jónmundsson (1976)
LW	0.20 (0.02)				50,996	Icelandic	Jónmundsson (1977)
LW	0.18 (0.07)				1,826	Icelandic	Thorsteinsson & Björnsson (1982)
LW	0.37 (0.12)				955	Icelandic	Thorsteinsson & Thorgeirsson (1986)
LW	0.29	0.16	0.05		1,932	Suffolk	Simm et al. (2002)
LW	0.44 (0.03)				5,993	Finnsheep and meat breeds	Puntila et al. (2002)
LW	0.17 (0.05)				1,025	Scottish Blackface	Roden et al. (2003)
LW	0.17	0.12	0.07	-0.37 (0.07)	30,625	White breeds	Näsholm (2004)
LW	0.18	0.14	0.12	-0.33 (0.05)	43,642	Gotland breed	Näsholm (2004)
LW	0.19 (0.06)	0.14 0.04			1,266	Scottish Blackface	Karamichou et al. (2007)
LW	0.19 (0.05)	0.09 (0.03)	0.20 (0.04)		2,029	Texel	Wolf & Jones (2007)
LW	0.09				6,565	Terminal and dual purpose	Payne et al. (2009)
LW	0.28 (0.15)				6,417	Crossbred	Rius_Vilarrasa et al. (2009b)
UFD	0.42 (0.06)				2,946	Icelandic	Thorsteinsson & Eythórsdóttir (1998)
UFD	0.56	0.08	0.11		1,932	Suffolk	Simm et al. (2002)
UFD	0.39 (0.03)				5,993	Finnsheep and meat breeds	Puntila et al. (2002)
UFD	0.44 (0.07)				977	Scottish Blackface	Roden et al. (2003)
UFD	0.30 (0.05)	0.06 0.03			2,018	Scottish Blackface	Karamichou et al. (2007)
UFD	0.54 (0.06)				1,821	Norwegian White sheep	Kvame & Vangen (2007)
UFD	0.39 (0.07)				1,335	Texel	Maxa et al. (2007)
UFD	0.12 (0.09)				1,146	Shropshire	Maxa et al. (2007)
UFD	0.35 (0.04)				6,417	Crossbred	Rius_Vilarrasa et al. (2009)
UMD	0.42 (0.05)				2,946	Icelandic	Thorsteinsson & Eythórsdóttir (1998)
UMD	0.41	0.16	0.07		1,932	Suffolk	Simm et al. (2002)
UMD	0.46 (0.03)				5,993	Finnsheep and meat breeds	Puntila et al. (2002)
UMD	0.26 (0.06)				977	Scottish Blackface	Roden et al. (2003)
UMD	0.41 (0.05)				2,018	Scottish Blackface	Karamichou et al. (2007)
UMD	0.40 (0.05)				1,821	Norwegian White sheep	Kvame & Vangen (2007)
UMD	0.29 (0.07)				1,335	Texel	Maxa et al. (2007)
UMD	0.28 (0.09)				1,146	Shropshire	Maxa et al. (2007)
UMD	0.20 (0.05)	0.04 (0.02)	0.19 (0.04)		2,029	Texel	Wolf & Jones (2007)
UMD	0.35 (0.03)				6,417	Crossbred	Rius_Vilarrasa et al. (2009b)
Muscle weight	0.70 (0.08)				1,310	Icelandic	Thorsteinsson & Eythórsdóttir (1998)
VIA Leg yield (kg)	0.20 (0.09)				630	Crossbreds	Rius-Vilarrasa et al. (2009b)
VIA Leg yield (kg)	0.40				6,565	Terminal and dual purpose	Jopson et al. (2009)
VIA Leg yield (kg)	0.25				6,565	Terminal and dual purpose	Payne et al. (2009)

Table 3. (continued) Estimates of heritability (h^2), standard error (SE), maternal heritability (h_m^2), maternal environmental effect (c^2) and direct-maternal genetic correlation (r_{dm}) for carcass traits

Trait	h^2 (SE)	h_m^2 (SE)	c^2 (SE)	r_{am} (SE)	Records	Breed	Reference
VIA Loin yield (kg)	0.37				6,565	Terminal and dual purpose	Jopson et al. (2009)
VIA Loin yield (kg)	0.26 (0.10)				630	Crossbreds	Rius-Vilarrasa et al. (2009b)
VIA Loin yield (kg)	0.18				6,565	Terminal and dual purpose	Payne et al. (2009)
VIA Shoulder yield (kg)	0.08 (0.06)				630	Crossbreds	Rius-Vilarrasa et al. (2009b)
VIA Shoulder yield (kg)	0.42				6,565	Terminal and dual purpose	Jopson et al. (2009)
VIA Shoulder (kg)	0.20				6,565	Terminal and dual purpose	Payne et al. (2009)

CT = Computer tomography, CW = carcass weight, J = thickest layer of fat over the rib, LEUROP = Live EUROP conformation class, LW = Live weight, UFD = Ultrasound fat depth, UMD = Ultrasound muscle depth, VIA = video image analysis.

2.6 The Icelandic sheep industry

Icelandic sheep breeding is based on one breed, the Iceland sheep (Dýrmundsson & Thorgeirsson, 1989). This breed belongs to the North European short-tailed breeds and is the most numerous of them, counting 500,000 breeding sheep (Dýrmundsson & Niznikowski, 2010). It was brought to the country by the Vikings over 1000 years ago (Dýrmundsson & Thorgeirsson, 1989). The majority of the sheep are horned (both ewes and rams) but some 30% of the population are polled (Dýrmundsson & Thorgeirsson, 1989). Crossbreeding with other breeds is not an option as importation of livestock into Iceland is not allowed.

Interest in improving carcass traits of the Iceland sheep probably started in the late 1870's in connection with the export of wethers to Great Britain. Around 1900 the first sheep breeding organizations amongst farmers were established and in 1902 the first sheep breeding consultant of the Farmers Association of Iceland was employed (Pálsson, 1983). There was a breakthrough in selection for improved carcass quality of the Iceland sheep by the work of Dr. Halldór Pálsson in 1930-1950 (Pálsson, 1939; Pálsson, 1940; Pálsson, 1955) and later followed by the work of Dr. Sigurgeir Þorgeirsson (Thorgeirsson, 1981) on growth in sheep in relation to carcass characteristics. Since then the emphasis has been to breed for high yielding carcasses with compact conformation and various carcass measurements have been used as selection criteria.

In 1990 ultrasonic technology was first introduced as a tool in sheep breeding in Iceland (Thorsteinsson, 2002). The ultrasound is used to measure the depth of the *L. dorsi* (UMD) taken at the 3rd lumbar vertebra and the fat depth (UFD) over the muscle. Then the shape of the muscle is subjectively assessed (visual score). Besides ultrasound and live weight, selection candidates are ranked on the basis of several conformation scores. Male lambs are assessed for 9 traits, five for muscularity (neck and shoulder, chest, loin, rump and hind legs) as well as a score for head, straightness of legs, wool and overall harmony. Females are scored for conformation of the front part (shoulder and chest) and hind legs. Length of the fore cannon bone has been one of the base measurements for selection of compact conformation, and this measure is still a standard measure in the assessment of rams.

Carcasses are evaluated at slaughter by the EUROP system which was adopted for the Icelandic sheep industry in 1998 (Jónsson & Hilmarsson, 2007). Carcasses are classified subjectively into 5 conformation classes but the fat score is based on the GR-measurement, measured with an electronic probe. Fat is classified on a 6 point scale with 5 main classes and the subclass 3+ (Reglugerð um gæðamat, flokkun og merkingu sláturafurða nr. 882/2010; Jónsson & Hilmarsson, 2007).

The EUROP classification system is used directly by the Icelandic breeding program and records from all abattoirs are delivered to the database of the Farmers Association and used to calculate BLUP (Best Linear Unbiased Prediction) breeding values for carcass conformation and fat scores. Therefore it is important for sheep breeding scheme that the data are reliable, besides the general purpose of the system which is to ensure fair payment for the product. It is also important for the breeding community that the correlation between live assessment and carcass grading is strong and reliable.

3. The aim of the study

The overall objective of this study was to estimate the ability of VIAscan® as a carcass grading tool for the Icelandic sheep industry in comparison with the current system. The overall objective has been divided into three sub-objectives:

1. To estimate genetic parameters for VIAScan® traits, EUROP classification and live lamb measurements and the genetic correlation between live lamb measurements and VIAScan® traits.
2. To investigate whether EUROP scores by VIAScan® are genetically the same trait as EUROP scores based on subjective grading.
3. To estimate how accurately VIAscan® predicts yield and EUROP score in comparison with the current EUROP classification system

4. Materials and methods

4.1 VIAscan®

The VIAscan® technology consists of a video camera and computer software. The video camera is located at the end of the slaughter chain in a cabin. While the carcasses pass through the cabin at slaughter line speed, the video camera capture images of the dorsal view of the carcass. The computer software uses one standard image of each carcass to make various measurements. Based on these measurements about 110 variables are available including areas, lengths, widths and colour. The colour measurements are made over the entire dorsal view to assess fat distribution on 6 selected spots, 2 over the lumbar region, 2 over the thoracic region and 2 over the shoulders. Equations based on these variables are then used to predict proportion and weight of lean in the legs, loin and shoulder and total LMY% (sum of these three parts). The VIAscan® predicts the EUROP score according to the current EUROP system in Iceland. Previously the function of VIAscan® for lamb carcass grading has been described by Hopkins (1996) and Hopkins et al. (2004).

4.2 Data and statistical analysis

Three main data sets were used. Analysis of yield predictions was based on a deboning dataset including 862 carcasses. The dataset was split into calibration data (70%) and validation data (30%) where the calibration dataset was used for model building and validation dataset to test the accuracy of the prediction equations for lean meat yield in legs, loins and shoulders. The deboning dataset was also used to analyse the ability of the EUROP classes to predict LMY% and fat percentage (FAT%).

A dataset of 696 carcasses was used to evaluate the agreement in EUROP classifying between expert classifiers and VIAscan®. This was both evaluated as proportional agreement and the statistical analysis of the mean scores between grading methods. A more detailed description is found in manuscript I.

The third dataset contained information on 38,576 individual lambs that had records for some or all of the 20 traits that where included in calculation for genetic parameters. The traits included nine VIAscan® traits (Lean meat weight and lean proportion of whole carcass, legs, loin and shoulder, conformation score and fat score), four abattoir assessment traits (conformation score, fat score, GR and HCW) and seven *in vivo* traits (ultrasound muscle depth, ultrasound fat depth, ultrasound muscle shape, visual score for conformation of legs and shoulders, length of the left fore cannon bone and live weight).

Preliminary analysis of fixed effects was carried out by using the GLM procedure in the SAS package (SAS Institute Inc, 2004). (Co)variance components were estimated by using three different animal models. Heritability was estimated by single-trait analysis and phenotypic and genetic correlations were estimated in bivariate analysis. The variance components were estimated using the DMU-package (Madsen & Jensen, 2008). A more detailed description is found in manuscript II.

5. Results

5.1 Manuscript I

The regression models of VIAscan® did predict LMY% with more accuracy than models based on the current grading system according to results of the cross-validation. The regression model derived from the calibration data for predicting lean in legs included 8 VIAscan® parameters and explained 55% of the variation in Leg%. The model for loin consisted of 8 parameters and explained 35% of the variation in Loin% and the model for lean yield in shoulders had 11 parameters and explained 50% of the variation in Shldr%. The RMSE of the models were 1.02%, 0.75% and 1.11% for Leg%, Loin% and Shldr% respectively. The prediction equations were consistant when they were tested on the validation data. The equations predicted lean meat yield in Leg%, Loin% and Shldr% with 62%, 32% and 47% accuracy respectively and total LMY% was predicted by 60% accuracy with RMSE of 2.05%. The equations based on EUROP scores, GR measure and HCW also showed a good consistency in the cross-validation predicting total LMY% by 56% accuracy. This model predicted lean meat yield in Leg%, Loin% and Shldr% with the accuracy of 58%, 31% and 38% respectively. A model based only on GR measure and HCW predicted LMY% with a 39% accuracy and the lean in each part from 5% to 41%. All methods predicted Loin% poorest.

Comparison of the current EUROP system and EUROP system of VIAscan®, based on the full deboning dataset, showed that conformation class of VIAscan® explained 2% of the variation in LMY% while the conformation class of the current system explained 7%. When fat score was included in the model it raised the R^2 value significantly while including HCW had little effects. The equation including EUROP classes and HCW based on VIAscan® assessment explained 36% of the variation in LMY% and when based on the current grading system it explained 49% of the variation. By including GR measure in the model based on the current grading system it raised the R^2 value to 54%.

Least square means (LS means) of LMY% for conformation classes within fat classes, adjusted for HWC, were significantly different between all classes except conformation classes O and P. This was found both for the VIAscan® classification and the current EUROP conformation classes.

The current EUROP classification system did explain more of the variation in FAT% than the EUROP score of VIAscan®. The fat classification of the current system explained 70% of the variation in FAT% while fat class of VIAscan® explained 58%. The GR measure was the best single predictor for FAT% explaining 74% of the variation in FAT%. The current system model including fat class, conformation class, GR measure and HCW explained 78% of the FAT%. The LS means of FAT% were significantly different between all fat classes within conformation classes adjusted for HCW. This was both recognized for EUROP scores of the current grading system and the EUROP scores of VIAscan®.

Tests comparing the agreement between VIAscan® and expert/plant classifiers showed that VIAscan® classified 77% to 84% of the carcasses in agreement with each individual classifier for conformation. The agreement between VIAscan® and a panel of expert classifiers was 82% in conformation classification. The EUROP fat score was less consistent ranging from 69% to 73%. The agreement between VIAscan® and the panel of expert classifiers for fat assessment was 73%.

5.2 Manuscript II

Predicted lean meat yield as estimated proportion was highly heritable. The estimates of heritability (h^2) were 0.46 for LMY% and Leg%, 0.63 for Loin% and 0.39 for Shldr%. The estimates for EUROP conformation score was 0.32 and 0.35 and for fat score 0.29 and 0.31, respectively for VIAscan® and the current system. The GR measure was highly heritable (h^2: 0.58). Heritability for *in vivo* measurements (UMD, UFD, UMS, leg score, shoulder score, ML) ranged from 0.27 to 0.52, lowest for ultrasound muscle shape and highest for the cannon bone length.

Maternal effects were found for the weight related traits (HCW, Leg(kg), Loin(kg), Shldr(kg) and LW). The direct heritability (h_d^2) for these traits ranged from 0.17 to 0.22, maternal heritability (h_m^2) from 0.09 to 0.11 and maternal environmental effect (c^2) from 0.21 to 0.23. The direct-maternal genetic correlation (r_{dm}) was negative for all traits, ranging from -0.25 to -0.35.

The genetic correlation (r_g) between EUROP conformation scores of VIAscan® and plant classifiers was 0.94 and 0.82 between the fat scores. Fat score given by plant classifiers and the GR measure were genetically the same trait (r_g: 0.99). The genetic correlation between LMY traits as proportions and *in vivo* measurements was ranging from -0.65 to 0.53. The strongest negative correlation was between ML and Loin% and highest positive correlation was between *in vivo* conformation score of shoulders and Loin%. Unexpectedly the Loin% was positively correlated to ultrasound fat depth (r_g: 0.19). The EUROP scores of the VIAscan® had similar correlations with the *in vivo* measurements as the EUROP score of the plant classifiers, although in most cases the current system was more strongly correlated to the *in vivo* traits. The strongest genetic correlation between EUROP conformation score (both of the current grading system and VIAscan®) and *in vivo* traits was with the leg score. The EUROP fat score had strongest genetic correlation to UFD. Genetic correlation between LMY%, Leg% and Shldr% where high, ranging from 0.77 to 0.92 but the Loin% had unfavourable correlations to these traits ranging from -0.30 to 0.18.

6. Discussion

6.1 Prediction of LMY

The results demonstrate that VIAscan® is capable of predicting LMY% with more accuracy than the current grading system (Manuscript I). These results fall in between findings of Stanford et al. (1998b), Brady et al. (2003), Cunha et al. (2004) and Hopkins et al. (2004) but they presented R^2 values ranging from 0.52 to 0.71 for VIA systems predicting LMY% in lamb carcasses. The results for the current EUROP system are better than were found earlier by Einarsdóttir (1998) for the Icelandic EUROP system (R^2: 0.38) and Johansen et al. (2006) for the Norwegian EUROP system (R^2: 0.41).

The poor prediction ability of the lean in the loin across all methods tested in this study can be explained by how the loin was processed in the boning trial. In the analysis reported in manuscript I the flanks were excluded from the loin after the results from the genetic analysis (Manuscript II) had shown that loin with flanks was positively correlated with fatness. However results of Stanford et al. (1998b) and Brady et al. (2003) also showed lower prediction accuracy for lean in loin than in legs and shoulders. The prediction ability of Loin% is limited by the small amount of variability in this trait.

The VIAscan® predictions of LMY% were found to be highly heritable for all three carcass parts (h^2: 0.39-0.63) which indicates that the assessment of these traits is consistent and they can be improved by breeding (Manuscript II). No heritability estimates of lean meat yield as percentages assessed by VIA for lamb carcasses were found in the literature. Payne et al. (2009) did report lower heritability (h^2: 0.18 to 0.25) for weight of lean in legs, loin and shoulder that was assessed by VIAscan® and adjusted for carcass weight. The weight of lean is highly correlated to carcass weight and therefore the direct heritability of lean weight in the three parts (h_d^2: 0.17-0.21) has a similar heritability as carcass weight.

Maternal effects on carcass weight are well known from earlier studies, both for Icelandic lambs (Jónmundsson, 1976; Eythórsdóttir, 1999) and in other breeds (Safari et al., 2005) as well as the negative correlation between direct and maternal genetic effects (Jónmundsson, 1976; Safari et al., 2005). The heritability of lean yield weight was similar to findings of

Rius-Viarrasa et al. (2009b) for legs and loin but they found lower estimates for lean weight in shoulders obtained by the VIA technology. Jopson et al. (2009) reported somewhat higher estimates for LMY in all parts (h^2: 0.37-0.42) assessed on lamb carcasses in New-Zealand by VIAscan®.

The unfavourable genetic correlation between Loin(%) and LMY in other parts of the carcass and the high positive correlation with GR measure, indicated that the Loin(%) prediction equation was partially assessing fat. This is explained by how the deboning data for lean in the loin was built up, as the boneless flanks were not rendered into fat and lean, and were included with the loin as a whole. Where total lean is calculated by sum of the lean in the three parts, the erroneous prediction of lean in loin will make the prediction of total LMY poorer. The deboning trial followed the procedure described in the VIAscan® Lean Meat Yield Trial Manual (Meat and Livestock Australia, 2000), however the measurement of the chemical lean of the flanks (chemical lean is method to estimate fat content in representative samples of the meat) *via* the microwave method could not be undertaken as there were no facilities for this on site. It has been common practice with other VIAscan® trials (Australia, New Zealand and France) that the flanks are tested for chemical lean and are then adjusted to 85% chemical lean (15% fat desired in the lean content) as described in the VIAscan® Trial Manual (Chris Smith, pers. comm., 4. September 2011). In a study of Johansen et al. (2006) the chemical methods were used to assess the lean in low-value cuts and Hopkins et al., (2004) used Computer-Aided Tomography (CAT) to scan the flanks and measure fat and lean. For future development of prediction equations for LMY these equations must be improved by adjusting for the fat content of the flanks.

6.2 EUROP classification

The EUROP score of the current grading system explains LMY% and FAT% in the carcass with more accuracy than EUROP scores of VIAscan®. On the other hand it was shown (Manuscript I) that when VIAscan® predicted the LMY% directly it does so with more accuracy than the current system and when predicting FAT% (results not shown) by the VIAscan®, it delivers a similar accuracy as the direct measurements.

This brings up the question of the purpose of the EUROP system if the LMY can be assessed more accurately with direct measures? Johansen et al. (2006) explained that the purpose of the EUROP system would be to sort carcasses for further processing and to ensure fair payment to farmers. Solely assessing LMY will not give the description of the shape of the carcasses, which is also an important issue for some markets and it will not describe the thickness of the fat. It can also be expected that the EUROP system is important for communications between the European markets. But it can be proposed that the LMY should be presented as additional information along with the EUROP system where VIAscan® could easily offer a system that delivers both the assessment of the EUROP scores and an accurate LMY estimation *via* direct prediction.

The comparison in conformation classification between VIAscan® and expert classifiers (82%) demonstrates that VIAscan® can function just like one of the expert classifiers according to conformation classification, but Einarsson, Vilhjálmsson and Eyþórsdóttir (2009b) showed that agreement between individual expert classifiers was between 82% and 86%. This is probably the best achievement to date that has been reached for objective assessment with the VIA technique of EUROP conformation score. The agreement was not as good for the fat assessment (73%), but the consistency between individual expert classifiers was also lower for the fat assessment ranging from 79% to 82% (Einarsson et al., 2009b). These results indicate that VIAscan® can be authorised in Iceland where The Icelandic Food and Veterinary Authority have decided that minimum agreement between the machine and the panel of expert classifiers has to be 80% in conformation classification and 70% in fat classifications. These limits are presently 80% for both conformation and fat classification for Icelandic plant classifiers (Stefán Vilhjálmsson, Icelandic Food and Veterinary Authority, 9. July 2011). These results are more promising than results found in a similar trial in UK where the VIA technology was compared to expert classifiers (Meat and Livestock Commission, 2007).

A greater discrepancy in fat scoring than in conformation scoring was confirmed by the estimates of genetic correlations between EUROP scores of VIAscan® and the current grading system. The genetic correlation was high between conformation scores of VIAscan® and the current grading system (r_g: 0.94), showing that both methods are evaluating the same trait but the genetic correlation between fat assessment of these two grading systems was only 0.82. It is not clear from the literature how correlated two measurements must be, to be accepted as measurements of the same trait with respect to breeding programs. According to guidelines of Interbull (Interbull, 2001) the limit is set at

0.70, when using data for the same traits from different countries. Using the same guidelines the EUROP fat assessment of these two methods could be defined as sufficiently related traits to be used as one trait in the breeding work in Iceland.

The difficulty in getting full agreement in fat assessment between VIAscan® and the current grading system can probably be explained by the differences in how these two methods assess the fat. VIAscan® describes the fat from the colour measurements from the dorsal view of the carcass while the fat score of the current system is based on a single measurement over the ribs (GR). Some previous studies have shown that fat on the rib (J) and on the loin (C) can hardly be defined as the same trait while other studies have found correlations similar to the present study. Thorsteinsson and Björnsson (1982) found a genetic correlation of 0.62 between C and J but Bennet et al. (1991) found a correlation of 0.83 which closely agrees to this study. This indicates that it is not realistic to reach perfect agreement in the fat assessment between VIAscan® and the current system when one method assesses the dorsal view and the other the GR site although the agreement between them can be acceptable. It is clear that current system is totally based on the GR measure where the genetic correlation between GR and pEUROPf is 0.99.

The advantage of the fat assessment of VIAscan® is that it assesses the distribution of the fat better than the current system as it is based on colour measurements from more than one spot on the carcass. To improve the agreement between the EUROP fat score of VIAscan® and the current system, VIAscan® could possibly predict the GR measurements directly, which then could be translated to a fat score. Alternatively the current system could take greater account of the distribution of fat cover on the back. Such a subjective appraisal will raise the issues of consistency between classifiers, so it is questionable whether any additional information would be added to the current system. Although EUROP fat score of VIAscan® and of current system are not perfectly related, it is demonstrated in this study that VIAscan® can explain as much of the variation in FAT% as the fat assessment of the current system (Manuscript II).

The EUROP assessment of VIAscan® is highly heritable, with only slightly lower h^2 estimates than EUROP scores of the current system. These estimates are rather high compared to other estimates from the literature (Conington et al., 1998; Karamichou et al., 2007; Rius-Vilarrasa et al., 2010) but similar estimates have been found by Sævarsson

(1999) and Näsholm (2004). No heritability estimates were found for EUROP score assessed by objective methods.

6.3 *In vivo* measurements

The genetic and phenotypic correlation between LMY traits and *in vivo* measurements showed that most of the current live lamb measurements can be useful for improving LMY. Inference about the correlation between Loin(%) and *in vivo* measurements will not be made since the fat proportion of the flanks was not measured during the deboning trial, but still was included as the lean portion of the loin. The genetic correlations between the *in vivo* measurements and the EUROP score of VIAscan® were in full concordance with the correlations between *in vivo* measurements and the current EUROP system, although the latter was slightly stronger for most traits. It can be concluded that the *in vivo* measurements should function well with the VIAscan® system, both with regard to the LMY prediction and the EUROP classification.

The Leg score is the best indicator trait for conformation and Leg(%) and has only very weak correlation with traits measuring fat, such as UFD, GR and EUROP fat classes. The shoulder score did not function as well, with almost no correlation with Shldr(%) and was more correlated with conformation and fatness. The results indicate that UMD and UFD are good indicators for carcass traits, both LMY and EUROP scores. High negative correlations between the length of the cannon bone and conformation and fat classes confirm that shorter legs are related to increased compactness and fatness, as shown by previous studies (Pálsson, 1939, 1940; Thorgeirsson, 1981; Thorsteinsson & Björnsson, 1982; Thorsteinsson, 2002).

High or moderate heritability estimates were found for all *in vivo* traits (ranging from 0.27 to 0.52). For the muscle depth and fat depth measured by ultrasound, the estimates were equal (0.42) to these found by Thorsteinsson and Eythórsdóttir (1998) and similar estimates (0.40 – 0.56) were reported by Puntila et al. (2002), Simm et al. (2002), Roden et al. (2003) and Kvame and Vangen (2007). The UMS had the lowest heritability estimate (0.27) of all traits in this analysis. This is a visually assessed trait on a rather coarse scale (1-5) while UMD and UFD are objective measurements on a continuous linear scale. Conformation score of legs had high heritability which falls in between findings of

Thorsteinsson and Björnsson (1982), Thorsteinsson and Thorgeirsson (1986), Janssens and Vandepitte (2004). However Wolf and Jones (2007) found heritability values ranging from 0.31 to 0.62. The ML had the highest heritability value (0.56) of the *in vivo* traits, although higher estimates have been reported in older Icelandic studies (0.64-0.82) by Thorsteinsson and Björnsson (1982) and Thorsteinsson and Thorgeirsson (1986). The lower heritability of ML in this study could be attributed to the less variation in this trait as the aim of the breeding work last decades has been to reduce the cannon bone length or because of less accuracy in measuring.

6.4 Future use of VIAscan®

The concept LMY is one of the main subjects of this study. It must be one of the most important targets in meat production to assess the proportion of lean in the carcasses where it is known that the main preference is for lean lamb (Þorkelsson & Reykdal, 2002). Today we work with indirect measures of LMY, like EUROP classes and GR measurements. It would be more efficient to use the measure of LMY directly, given that it can be estimated with sufficient accuracy. If the proportion of LMY can be assessed it is straight forward to calculate the weight of lean, which must be interesting for the meat industry. It should also be useful information for the meat industry to have estimates of the lean in the major cuts. Information of LMY may not be sufficient alone since two carcasses with equal LMY% can be very different, one with poor muscularity and little fat while the other is muscular and fat. One idea of an improved system is to assess LMY within conformation classes. This could be assessed by VIAscan® with more accuracy than by the current grading system.

The VIAscan® technology offers several advantages. The most obvious advantage is the consistency in carcass grading over time and between abattoirs. It would make the system more reliable both for the buyers and sellers of the products and for the breeding work it would be valuable to measure changes in carcass grading from year to year based on objective methods. In this study we did not estimate the agreement of classifiers between plants but it seems likely that more disagreement is found between plant classifiers than between expert classifiers, as plant classifiers do not switch between abattoirs. It is likely that VIAscan® could provide a better assessment of fat distribution than that provided by one single fat measurement. However the GR measure is as good indicator for LMY% and FAT%. It would be interesting to analyse whether the selection for less fat based on the

GR site has led to increased fat on some other spots of the carcass. It can also be argued that VIAscan® provides a realistic option for adopting the 15 point EUROP score system instead of the 5/6 point system. The VIAscan® is more likely than the current system to keep consistency between sites with a more detailed classification. Further it can be pointed out that in later years the abattoirs in Iceland have become fewer and larger, with increased automation and increased speed on the slaughter line. Automatic carcass grading like VIAscan® is more likely to be able to keep up with greater speed of the slaughter line as it has operated commercially at abattoirs processing in excess of 360 carcasses per hour (Chris Smith, pers. comm., 4. September 2011).

To have the VIAscan® technology operating commercially in Iceland there are areas that need to be considered and addressed by the Icelandic lamb industry:
The flanks must be corrected for fat content or they have to be excluded from the loin. If the flanks should be included in the lean component of the loin, however it must be corrected for fatness. There are two possibilities to estimate the fat proportion of the flanks. One could conduct a trial to determine the relationship between total carcass fat% and flanks chemical lean percentage (Flanks CL) either using CT or manual deboning trials. Once the flanks have been corrected for fat content then the loin yield equation needs to be recalculated and the accuracy of prediction and genetic correlations re-estimated.
The establishment of business rules for operating the VIAscan® is very important, so that every carcass receives a prediction. In the event where the VIAscan® is unable to assess a carcass (ie: rotated or damaged carcasses) there have to be processes to manage these exceptions, either in real time within the VIAscan® or at a database level post slaughter.
A crucial issue is the cost of the method. The assessment of the cost and benefits of implementing the VIAscan® must be considered. Is the cost of implementing the technology commercially going to be offset by the benefits of higher level of LMY% prediction to underpin a farmer yield payment model, implementation of objective EUROP classification, and the possibility of more rapid genetic gains in LMY across the industry? This is an important question which has not been considered in this study.

7. Conclusion

VIAscan® provides an objective technology that is capable of predicting LMY of lamb carcasses and classify them into EUROP classes. The traits evaluated by VIAscan® can be improved by breeding since they are highly heritable and the current selection traits (*in vivo* traits) can be useful to improve them. VIAscan® predicts LMY% with more accuracy than can be provided by the current system and classifies successfully in EUROP conformation classes. It can predict FAT% with same accuracy as the GR measure although the GR measure was found as the best single predictor of FAT% and LMY% in this study.

The main weakness of VIAscan® carcass grading is the EUROP fat assessment and the prediction of lean in loin. It would be desirable to improve the agreement between the EUROP fat assessment of VIAscan® and the current system before adopting the technique. However the genetic correlation between the fat assessments of these two methods can be defined as sufficiently strong and VIAscan® did pass the test against a panel of expert classifiers. Improvement of the fat assessment should improve the ability of the EUROP scores of VIAscan® to evaluate LMY%. The prediction equations of lean in loin must be improved as Loin% was predicted with considerably lower accuracy than Leg% and Shldr%.

The VIAscan® system offer new opportunities to the Icelandic sheep industry and the use of it can be recommended according to the results of this thesis. It is also suggested that it could be useful for the sheep industry to focus more on direct evaluation of LMY% since this is fundamental trait in meat production

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Manuscript I

The ability of video image analysis (VIA) to predict lean meat yield and EUROP score of Icelandic lamb carcasses

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Abstract - The ability of Video Image Analysis (VIA) to predict proportion of lean meat yield (LMY%) and classify in to EUROP conformation and fat classes was investigated in three trials. The studies were carried out in Iceland where the VIA system VIAscan® was used to assess Icelandic lamb carcasses. In trial 1 a total of 862 carcasses that were evaluated both by VIAscan® and the current EUROP classification system were deboned and the actual yield measured. Models for predicting lean meat yield (LMY%) in legs (Leg%), loin (Loin%) and shoulder (Shldr%) were built up where best VIAscan® variables were selected by stepwise regression out of calibration data (603 carcasses). The equations were tested on validation data (259 carcasses). The results showed that VIAscan® predicted LMY% in Leg%, Loin% and Shldr% with an accuracy of 0.62, 0.32 and 0.47 respectively while the current EUROP system predicted LMY% with accuracy of 0.58, 0.31 and 0.38 for these three carcass parts. In trial 2 the EUROP classification from VIAscan® and the current system were compared with respect to the variation in LMY% and fat (FAT%) explained by each system. The EUROP scores from VIAscan®) explained 36% of the variation in LMY% and 60% of the variation in FAT% while EUROP score from the current system explained 49% and 72% of LMY% and FAT% respectively. The best single predictor for FAT% was the GR measure (thickness of tissue over the 12th rib 110 mm from the midline) explaining 74% of the variation. Significant differences in LMY% were found between all conformation classes except P and O for both grading methods. The differences in FAT% were highly significant between all fat classes from both methods.. In trial 3 the accuracy of VIAscan® to classify in EUROP classes was investigated by testing VIAscan® against a panel of three expert classifiers where 696 carcasses were classified. The VIAscan® classification agreed with the panel of expert classifiers in 82% of cases for conformation classes and 73% for fat classes. It was concluded that VIAscan® offers a technology that can directly predict LMY% of lamb carcasses with more accuracy than the current EUROP classification system. VIAscan® is also capable of classifying in to EUROP classes with an accuracy that fulfils minimum demands for the Icelandic sheep industry. The prediction equation for Loin% must however be improved before VIAscan® can be taken into commercial use.

Keywords: Video image analysis, lean meat yield, lamb, carcass, EUROP classification, conformation, fat.

1. Introduction

Objective carcass grading has been the subject of many studies in recent years (Berg, Forrest, Thomas, Nusbaum & Kauffman, 1994; Hopkins, 1996; Allen & McGeehin, 2001). In the lamb meat industry the focus has been on the video image analysis (VIA) technology as a fully automatic carcass grading system. VIA systems for lamb carcass grading have been developed in a few countries, like Canada (Brady et al, 2003), Germany (Rius-Viarrasa, Bünger, Maltin, Matthews & Roehe, 2009) and Australia (Hopkins, 1996). In Iceland the carcass grading is based on the EUROP system where carcasses are classified according to a visual conformation score and a fat score, based on the GR measure. Interest in the objective grading of carcasses led to the installation of the Australian VIA technology, VIAscan®, in the KS abattoir in North Iceland in the autumn 2006. Trials were undertaken with the objective of calibrating the VIAscan® system to predict lean meat yield (LMY%) and EUROP score of Icelandic lamb carcasses. Classification of lamb carcasses according to the EUROP system had not been tested before by VIAscan® and fully automatic, objective carcass grading had not been attempted before in Icelandic abattoirs.

Automatic carcass grading is of interest for the Icelandic sheep meat industry since it forms the basis for lamb meat prices (Einarsson, Eythórsdóttir, Smith & Jónmundsson, unpublished). The aim of this study was to estimate the accuracy of carcass grading by the VIA and compare it to the current grading system in Iceland. The further objectives were:

1. To develop and evaluate regression equations for predicting percentage of lean meat yield in lamb carcasses and compare the prediction ability of the VIAscan® with the current Icelandic grading system (trial 1).
2. To compare parameters of the EUROP classification systems obtained by VIAscan® and the current system in explaining the variation in LMY% and FAT% (trial 2).
3. To compare the accuracy of the VIAscan® with that of Icelandic expert classifiers and plant assessors in classifying lamb carcasses according to the EUROP systm (trial 3).

2. Material and methods

2.1. Animals

All lambs were slaughtered under commercial conditions at the KS abattoir in Sauðárkrókur. The trials were carried out during the normal slaughter season in September and October 2006 and 2007. Most lambs were born in April or May and were therefore generally 5 to 6 months old at slaughter. Lambs of both sexes were used in these trials.

2.2. VIAscan®

The VIAscan® unit was installed prior to the classifiers station at the end of the slaughter line. The unit consists of a large cabin which the carcasses pass at slaughter line speed. A digital camera takes pictures of the dorsal view of the carcass and the digital image is analysed further by special computer software. The software takes about 110 measurements of the carcass, which are lengths, widths, curves, angles as well as ratios between some measures. The fat is measured as Lab colour of six rectangles, 2 over the lumbar region, 2 over the thoracic region and 2 over the shoulder. Further description of the VIAscan® system can be found in Hopkins, Safari, Thompson and Smith, (2004).

2.3. EUROP system

The current Icelandic grading system is based on the EUROP classification system and carcass weight where carcasses are classified in five conformation classes (E,U,R,O,P) and six fat classes (1, 2, 3, 3+, 4, 5) (Reglugerð um gæðamat, flokkun og merkingu sláturafurða nr. 882/2010). Fat score is based on a measure of the soft tissue (GR) at 12th rib , 11 cm from midline. The fat is measured manually by a fat thickness probe for sheep carcasses called ICEMEAT GR Probe (Einarsdóttir, 1998). Numerical scores for EUROP classes are: **Conformation classes**: E=14, U=11, R=8, O=5, P=2, **Fat classes**: 1=2, 2=5, 3=8, 3+=9, 4=11, 5=14.

The EUROP score of VIAscan® used in this study was obtained from regression based on VIAscan® measurements, derived from 1828 carcasses classified by one expert grader (Stefán Vilhjálmsson) (Chris Smith, pers. comm., 4. September 2011). These EUROP scores were obtained from the database of VIAscan® at KS abattoir.

2.4. DATA

2.4.1. Trial 1: Precision and stability of models predicting LMY% and Trial 2: Accuracy of the EUROP system in assessing LMY% and FAT%

The deboning data included 862 carcasses. The boning trial was carried out over two years: 2006 (284 carcasses) and 2007 (578 carcasses), by two boning teams. The carcass was broken down into three primal cuts; hind leg, loin and forequarter. The hind legs were separated from the loin at the mid-length of the 6th lumbar vertebrae and the loin and forequarter separated between the 4th and 5th ribs. Each primal cut was separated into lean meat, bone and fat. Lean meat yield was defined as the weight of lean meat, obtained according to the specifications for deboning, presented as a proportion of cold standard carcass weight. The carcass breakdown was carried out as described by Hopkins et al. (2004), except for the flanks since here the boneless flanks with fat were included with the lean of the loin. The results of Einarsson et al. (unpublished) showed that the weight of the loin (including flanks) had stronger correlation to fat than lean in the carcass, and it was therefore decided to exclude the flanks from the loin in this analysis. The cold carcass weight was thus divided into lean, fat, bone and boneless flanks.

The lean meat proportions of legs (Leg%) and shoulders (Shldr%) were adjusted for differences between boning teams where significant differences were found. Table 1 presents the means, standard deviations and range of yield, fat and carcass assessments of all carcasses included in the deboning dataset.

Table 1.

The EUROP score and GR measure of all carcasses in the deboning dataset were derived by one expert classifier. The distribution of the deboned carcasses across the EUROP classes is shown in Appendix Table A1.

2.4.2 Trial 3: *Agreement in EUROP classification between VIAscan® and visual assessment.*

The trial was carried out in the autumn 2007 at the KS abattoir. Three expert classifiers worked independently. Undamaged carcasses were selected at random at the end of the slaughter line, after they had been assessed by the VIAscan® and plant classifiers. Each expert classifier measured the tissue depth at the GR site on hot carcasses with a grading probe (ICEMEAT GR Probe) and classified according to the EUROP system. Subsequently, the carcasses were mixed up, renumbered and graded again. The GR was only measured on the hot carcasses and therefore the single GR as initially measured by each classifier, followed the carcass throughout the trial. In the end the three expert classifiers jointly made a final EUROP score for all carcasses. The trial was repeated six times, on 4 days in September and 2 days in October, with 120 carcasses assessed each time, 720 carcasses in total. Due to poor carcass presentation VIAscan® was not able to assess all carcasses (e.g.; rotated and twisted carcasses) resulting in a final dataset of 696 carcasses. The average HCW was 15.7 kg, average conformation score and fat score according to the joint assessment of three expert classifiers was 8.16 and 6.76 respectively (Appendix Table A2).

2.5. Statistical analysis

2.5.1. Trial 1: Precision and stability of models predicting LMY%

The deboning data (862 carcasses) was divided randomly in to a calibration dataset (603 carcasses) and validation dataset (259 carcasses). Stepwise regression was used to select the best VIAscan® parameters for yield prediction out of the calibration dataset according to the root mean square error (RMSE) and coefficient of determination (R^2). Prediction equations for the current EUROP system were also derived from the calibration data. All measurements, including the EUROP scores (2-14) were treated as continuous variables (Johansen, Aastveit, Egelandsdal, Kvaal & Røe, 2006) The equations derived from the calibration data were subsequently used to predict LMY% in the validation data. Finally a regression analysis was used to compare the predicted LMY% and the actual boning yield of leg, loin, shoulders and total lean meat yield of the carcass using a general linear model (PROC GLM). All statistical analysis was performed in SAS (SAS Institute Inc, 2004).

2.5.2. Trial 2: Accuracy of the EUROP system in estimating LMY% and FAT%

The deboning dataset (862 carcasses) was used to evaluate the variation in LMY% and FAT% as explained by the parameters of the EUROP system obtained by VIAscan® and the current system respectively. The models included fat score and conformation score as class variables and HCW as a covariate. The EUROP scores were used as class variables since the differences in the dependent variables between classes did not follow a linear scale. The data was analysed by the general linear models (PROC GLM) . The following model was used:

$$Y_{ijk} = \mu + F\_class_i + C\_class_j + b_1(HCW_{ijk}) + e_{ijk}$$

where Y_{ijk} represents LMY% or FAT% according to boning results, μ is the overall mean, F_class and C_class fat and conformation classes and b_1 is the regression coefficient of HCW which is as covariate in the models.

Least squares means of LMY% between conformation classes within fat classes were compared after being adjusted according to the Tukey-Kramer method to ensure the overall significance level of P = 0.05.

2.5.3. Trial 3: *Agreement in EUROP classification between VIAscan® and visual assessment.*

The EUROP score of VIAscan® was compared to the 5/6 point EUROP score of three expert classifiers and plant assessors. The proportional agreement was assessed, either to each classifier, final agreement of the three classifiers and to the assessment of the plant assessors. For comparison of means, one-way ANOVA (PROC ANOVA) was used and the Tukey´s test, where P<0.05 were determined to be the level of significance.

3. Results

3.1. Trial 1: Precision and stability of models predicting LMY%

The model developed for predicting lean percentage in the legs (Leg%) included 8 VIAscan® measures which explained 55% of the variation. The model for Shldr% explained 50% of the variation using 11 variables. The poorest model was for Loin% only explaining 35% of the variation using 8 variables. Table 2 shows the order in which the variables were selected into the models based on stepwise regression. The coefficient of determination (R^2) indicates the accuracy of the models and the root mean square error (RMSE) indicates the precision.

Table 2.

Table 3 shows the applicability of three prediction models that were used to estimate lean yield in the calibration data set. The first is based on the VIAscan® measures (full model for each trait as shown in Table 2) The second utilises the current grading system (conformation class and fat class as continuous variables) together with the GR measure and HCW and the third model only includes the GR measurement along with HCW. The models based on VIAscan® variables predicted lean meat yield with more accuracy than the other methods. All methods did predict Leg% with the highest level of accuracy and Loin% with the poorest level of accuracy.

Table 3.

3.2. Trial 2: Accuracy of the EUROP system in assessing LMY% and FAT%

The current EUROP classification (conformation score and fat score as class variables) explained more of the variation in LMY% than the EUROP classification obtained by VIAscan® (Table 4). Conformation classes from both systems had very low predictability of the LMY% and explained only 2 - 7% of the variation. When EUROPf was included the R^2 increased markedly (0.36 - 0.49). The HCW had almost no effect, neither as a predictor of LMY% nor FAT%. Conformation classes (viaEUROPc and pEUROPc) were still significant ($P<0.0001$) in both models that included fat class and HCW. The EUROP classification of the current system explained more of the variation in LMY% than the EUROP scores of VIAscan®.

Table 4.

The best single predictor of Fat% is the GR measure. The model including EUROP classes, GR and HCW was slightly more accurate than the model only containing GR and HCW. The EUROP fat score explained more of the FAT% than the fat score of VIAscan®. The conformation scores of both systems were useful variables in predicting fat and they were equally accurate. Significant differences ($P<0.05$) in LMY% were found between all conformation classes except between classes O and P for both VIAscan® and plant classifiers conformation classification (Table 5).

Table 5.

Highly significant ($p<0.001$) differences in FAT% were found between all fat classes, from both the VIAscan® and plant classifiers (Table 6).

Table 6.

3.3. Trial 3: Agreement in EUROP classification between VIAscan® and visual assessment.

The agreement between VIAscan® and the three expert classifiers (working individually), the plant classifiers and the final assessment of the three expert classifiers is shown in Table 7. The agreement between VIAscan® and the classifiers was in all cases higher for conformation than for fat classes. The agreement for conformation between VIAscan® and the classifiers ranged from 77% to 84% and the agreement to the final assessment was 82%. There was an overall tendency of the VIAscan® to over predict as the bias ranged from +2% to +15% (average +6.75%). The agreement in fat classification ranged from 69% to 73% and the agreement to the final assessment was 73%. The bias was small in most cases or ranging from -5% to +3%. The disagreement in classifying between VIAscan® and the final assessment was in all cases within one class, except for one carcass.

Table 7.

The average conformation score of VIAscan® was not significantly different from the average score of the final assessment. The only significant difference found was between VIAscan® and classifier Y1, but he also had a significantly lower average score than the final assessment. There were no differences found at 5% significant level between fat scores.

4. Discussion

4.1. Accuracy of VIAscan® in predicting lean yield

VIAscan® provides a more accurate prediction of LMY% than the current grading system in Iceland. The differences between VIAscan® and the current system ranged from almost no differences (1% for Loin%) to considerable differences (9% for Shldr%). The results also indicated that the EUROP classes along with GR measure and HCW are more accurate in predicting LMY% than the GR measure along with HCW.

In the studies by Stanford et al. (1998) and Hopkins et al. (2004) VIAscan® also performed better than the current systems used in each trial to set a benchmark for prediction of LMY%. Studies with other VIA systems for lamb carcasses have shown similar results (Horgan, Murphy & Simm, 1995; Brady et al., 2003; Cunha et al., 2004; Rius-Vilarrasa et al., 2009).

The prediction equations based on VIAscan® parameters showed accuracy within the range of previous findings. Hopkins et al. (2004) presented an R^2 value of 0.52 when predicting LMY%, based on a model of 8 VIAscan® parameters and Stanford et al. (1998) presented R^2 value of 0.71 using 7 VIAscan® parameters and carcass weight. Brady et al. (2003) studied the ability of the Lamb Vision System (LVS) where 6 parameters along with HCW explained 60% of the variation in saleable meat yield (%) and Cunha et al. (2004) presented R^2 value of 0.68 for LVS. A much higher proportion of the variation is explained when predicting weight of lean rather than percentage since the carcass weight is highly correlated with the weight of lean meat yield. Rius-Vilarrasa et al. (2009) showed that the VIA technology along with carcass weight explained 99% of the variation in LMY weight.

Detailed descriptions of the VIAscan® variables are not available for publishing and can thus not be discussed in detail. The prediction of the percentage lean is highly dependent on the a* colour measurement from the Loin and also the b* colour measurement from the Shoulder. The partitioning of the colours across the dorsal view into tissue types (ie: thin or thick fat cover) were regularly used for predicting lean percentages, as these parameters assess fat distribution and thickness. Areas and widths were also used in the regression models, providing the assessment of carcass conformation and muscularity.

In this study and the studies of Stanford et al. (1998), Brady et al. (2003) and Rius-Vilarrasa et al. (2009) the VIA technology predicted lean meat yield in the leg with the highest accuracy and lean in the loin with the poorest accuracy of the three primal cuts; legs, loin and shoulder. Stanford et al. (1998) did not find any significant VIAscan® variables to use for predicting lean in the loin. They concluded that this was due to little variation in this trait. The poor performance in predicting lean in loin in this study could be influenced by the decision to exclude the flanks from the loin, as this reduced the Loin% variability. However similar trials conducted in Australia have also shown inferior ability of the VIAscan® to predict the Loin% to that of Leg% and Shldr% (Chris Smith, pers. comm., 4. September 2011).

Variation in the prediction accuracy between studies can be partly attributed to the differences in the deboning process. The deboning description can vary between trials according to different aims of the production and manual dissection is subject to the same inaccuracy as other subjective methods. Kongsro, Røe, Aastveit, Kvaal and Egelandsdal, (2008) have pointed out that it is more accurate to use CT scanning to calibrate methods of evaluating carcass composition than manual dissection.

4.2. The ability of the EUROP system to evaluate LMY% and FAT%

The EUROP classification by the expert classifiers explained the variation in LMY% and Fat% with more accuracy than the EUROP scores of VIAscan®. The VIAscan® EUROP classification is also useful in evaluating carcasses in terms of LMY%. As far as we know this is the first time that the precision of EUROP scores obtained by a VIA system in predicting lamb carcass composition is evaluated. Obviously if the aim is to assess LMY%, the best way is to evaluate it directly by VIAscan® which is more accurate than either EUROP system.

The EUROP classification scores, based on one expert classifer, along with GR measure and HCW explained 49% of the variation in LMY% which is higher than Einarsdóttir (1989) found earlier for the Icelandic EUROP system (38%) using conformation class, fat class and GR measure and Johansen et al. (2006) found for the EUROP system in Norway (41%).

Conformation score

Several authors have pointed out that conformation score is not a strong predictor for LMY% (Berg & Butterfield, 1976; Kempster, Cuthbertson & Harrington, 1982; Hedrick, 1983; Kirton, 1989; Horgan et al., 1995; Einarsdóttir, 1998; Nsoso et al., 2000) which is in agreement to the results of this study. The significant differences in LMY% between most conformation classes does however indicate that better conformed carcasses can be expected to give better yield within the same fat class and at similar weights.

Although conformation score is a poor predictor for of LMY% it has another important purpose which is to describe the shape of the carcass cuts. Hopkins (1996) demonstrated that muscularity can be used to identify carcasses with greater cross-sectional areas. He argued that if consumer demands were affected by the cross-sectional area of cuts per se then muscularity is important. Similarly Purchas and Wilkin (1995) showed that better conformed carcasses would have greater muscle depth relative to bone length and would yield somewhat higher in leg and saddle (loin) cuts. Thorgeirsson and Thorsteinsson (1986) argued that conformation was of more importance for the Icelandic breed than some other European sheep breeds because of the large variation in shape within the Icelandic breed. They also argued that better conformation would result in better products.

Fat score and GR

Other studies that have investigated the ability of the EUROP system to explain the variation in FAT% fully agree with the results for the current grading system shown in this study. Johansen et al. (2006) presented that the EUROP classes and HCW explained 74% of the fat proportion in the carcass and Einarsdóttir (1998) found that EUROP fat class and GR measurement explained 71% of the variation.

These results show that no single parameter can predict LMY% or FAT% with higher accuracy than the GR measurement. Einarsdóttir (1998) obtained slightly higher R^2 values, ranging from 0.76 to 0.86 for GR measured by different probes. Similarly, several authors have concluded that the J-measurement would be one of the best single predictors of FAT% (Pálsson, 1939; Thorgeirsson & Thorsteinsson, 1986). The J-measurement is a cross-sectional measure closely related to the GR measure. It is however clear from the results that including the EUROP classes in the model along with GR and HCW improves the prediction model for LMY%.

The EUROP fat score of VIAscan® is not as good indicator for FAT% as the fat score of the current system. This is probably because the current system relies heavily on the GR measure and it is difficult for VIAscan® to predict depth at a single site. On the other hand VIAscan® is capable of explaining as much of the variation in FAT% as the GR, by using 8 direct VIAscan® measures (results not shown). This is not unexpected since VIAscan® can predict LMY% with more accuracy than the current grading system. If VIAscan® is to be used to classify into EUROP classes alongside with manual grading the fat assessment must be improved towards better agreement with the current system and similar accuracy in predicting FAT%

4.3. Agreement in EUROP classification between VIAscan® and the visual assessment of expert classifiers and plant assessors.

The agreement between VIAscan® and the final assessment of the expert classifiers was higher for conformation than fat classification. This is in agreement with Einarsson et al. (unpublished) where higher genetic and phenotypic correlations were found between conformation assessment of VIAscan® and plant classifiers than between the fat assessment of these two grading methods. This is probably caused by the fact that VIAscan® is measuring the fat on the dorsal view of the carcass while the plant classifiers' assessment depends on the tissue depth at the GR site. Einarsson et al. (2009) analysed the differences between the three expert classifiers where the agreement was ranging from 82% to 86% for conformation classes and from 79% to 82% for fat classes. The agreement between VIAscan® and the final assessment in this study falls in between those ranges for conformation but not for fat assessment. However, these results indicate that VIAscan® has reached the minimum limits of agreement to be authorized in Iceland. These limits have been stipulated by the Icelandic Food and Veterinary Authority, and state that the VIAscan® must achieve 80% agreement in conformation classification with a panel of expert classifiers and 70% agreement in fat classification (Stefán Vilhjálmsson, Icelandic Food and Veterinary Authority, e-mail, 9. July 2011). The results of this study show better agreement between the VIA technology in EUROP classification than was found in the report of MLC in the UK where the agreement found between VIA and expert classifiers was ranging from 68% to 74% in conformation classification and 48% to 55% for fat (Meat and Livestock Commission, 2007).

5. Conclusion

The VIAscan® system predicts LMY% with more accuracy than the current grading system and it provides an excellent opportunity for the Icelandic sheep industry to focus more on direct measurements of LMY. The EUROP scores of VIAscan® are not as accurate as the EUROP scores of the current system in explaining the variation in LMY% and FAT%, although both methods are capable of estimating these traits. VIAscan® did reach the minimum demands of accuracy in classifying in EUROP classes to be authorized in Iceland (80% agreement in conformation score and 70% agreement in fat score with panel of expert classifiers). The fully automatic technology that VIAscan® provides is thus a realistic option for the Icelandic sheep industry. For VIAscan® to be used further it is important that the prediction of lean in loin and the agreement to the current system in EUROP fat classification be improved.

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Table 1. Description, number (N), mean, standard deviation (SD) and range of the variables in deboning data set.

Trait	Description	N	Mean	SD	Min.	Max.
LMY%	Proportion of lean meat yield in the carcass (%)	862	55.0	3.20	43.3	63.4
Shldr%	Proportion of lean in shoulders (%)	862	21.7	1.57	15.4	26.8
Loin%	Proportion of lean in loin (%)	862	9.40	0.91	6.75	12.3
Leg%	Proportion of lean in legs (%)	862	23.8	1.54	18.8	28.2
Fat%	Proportion of fat in the carcass (%)	862	14.1	3.53	3.96	27.0
HCW	Hot carcass weight (kg)	862	16.5	3.23	7.20	26.8
GR	Fat depth at GR side (mm)	854	9.26	3.31	2	21
pEUROPc	Visual EUROP conformation score (2-14)	862	8.73	2.88	2	14
pEUROPf	Visual EUROP fat score (2-14)	862	7.01	2.48	2	14
viaEUROPc	VIAscan® EUROP conformation score (2-14)	862	8.65	2.86	2	14
viaEUROPf	VIAscan® EUROP fat score (2-14)	862	7.05	2.42	2	14

Table 2. Best-fit multiple regression equations developed from the calibration data (n=603) to predict percentage of lean meat yield in the legs (Leg%), loin (Loin%) and shoulders (Shldr%) using VIAscan® variables.

Variables	**R^2**	**RMSE (%)**
Leg%		
Loin Colour a*	0.19	1.36
X_1+Groin Angle 2	0.30	1.27
X_1+X_2+ Area of thick Fat Cover	0.37	1.20
$X_1+X_2+X_3$+ Trunk width 20	0.40	1.17
$X_1+X_2+X_3+X_4$+Loin Area	0.50	1.07
$X_1+X_2+X_3+X_4+X_5$+Trunk width 18	0.54	1.03
$X_1+X_2+X_3+X_4+X_5+X_6$+Chump Colour a*	0.55	1.03
$X_1+X_2+X_3+X_4+X_5+X_6+X_7$+ Leg Momnet Area	0.55	1.02
Loin%		
Groin Angle 3	0.19	0.83
Y1+Shoulder Colour b*	0.24	0.81
Y1+Y2+Leg Ratio of Widths	0.26	0.80
Y1+Y2+Y3+Lean Area 2	0.29	0.78
$Y_1+Y_2+Y_3+Y_4$+Groin Angle 5	0.29	0.78
$Y_1+Y_2+Y_3+Y_4+Y_5$+Area of Thin Fat Cover	0.32	0.77
$Y_1+Y_2+Y_3+Y_4+Y_5+Y_6$+Loin Colour Profile	0.32	0.76
$Y_1+Y_2+Y_3+Y_4+Y_5+Y_6+Y_7$+Lean Area 4	0.35	0.75
Shldr%		
Loin Colour a*	0.22	1.38
Z1+Trunk Width 4	0.25	1.35
Z1+Z2+Minimum Shoulder Width	0.38	1.23
Z1+Z2+Z3+Shoulder Colour b*	0.42	1.19
$Z_1+Z_2+Z_3+Z_4$+Loin Moment Area	0.44	1.17
$Z_1+Z_2+Z_3+Z_4+Z_5$+Shoulder Moment Area	0.46	1.15
$Z_1+Z_2+Z_3+Z_4+Z_5+Z_6$+Area of thick Fat Cover	0.47	1.14
$Z_1+Z_2+Z_3+Z_4+Z_5+Z_6+Z_7$+ Trunk Width 10	0.48	1.13
$Z_1+Z_2+Z_3+Z_4+Z_5+Z_6+Z_7+Z_8$+Trunk Width 5	0.49	1.12
$Z_1+Z_2+Z_3+Z_4+Z_5+Z_6+Z_7+Z_8+Z_9$+Trunk Width 12	0.50	1.11
$Z_1+Z_2+Z_3+Z_4+Z_5+Z_6+Z_7+Z_8+Z_9+Z_{10}$+Shoulder Width Ratio	0.50	1.11

R^2 = Coefficient of determination

RMSE = Root mean square error

Table 3. Prediction accuracy of three models based on 1) VIAscan® variables, 2) current grading system (EUROP scores as linear variables), GR and HCW and 3) GR and HCW, in predicting proportion of lean meat yield in leg (Leg%), loin (Loin%), shoulder (Shldr%) and for total lean in the carcass (LMY%). Equations developed from calibration data set and applied to the validation data set (n=259).

	Leg%		**Loin%**		**Shldr%**		**LMY%**	
Model	R^2	RMSE	R^2	RMSE	R^2	RMSE	R^2	RMSE
1) VIAscan®	0.62	1.01	0.32	0.72	0.47	1.16	0.60	2.05
2) Current grading system	0.58	1.07	0.31	0.72	0.38	1.26	0.56	2.22
3) GR + HCW	0.41	1.24	0.05	0.85	0.36	1.28	0.39	2.53

VIAscan® = Full model for each trait according to Table 2.
Current grading system = EUROP conformation score (pEUROPc), EUROP fat score (pEUROPf), hot carcass weight (HCW) and tissue depth over the 12. rib, 11 cm from midline (GR).

Table 4. Coefficients of determination (R^2) and root mean square error (RMSE) values for the prediction of lean meat yield (LMY%) and fat in the carcass (FAT%) using different models with parameters from the EUROP system (EUROP scores as class variables), based on the deboning data set (n=862).

	LMY%		FAT%	
Independent variables	**R^2**	**RMSE**	**R^2**	**RMSE**
viaEUROPc	0.02	3.18	0.24	3.09
viaEUROPf	0.22	2.82	0.58	2.29
viaEUROPc+viaEUROPf	0.36	2.57	0.60	2.25
viaEUROPc+viaEUROPf+HCW	0.36	2.57	0.60	2.25
pEUROPc	0.07	3.10	0.24	3.08
pEUROPf	0.33	2.62	0.70	1.93
pEUROPc+pEUROPf	0.49	2.30	0.72	1.89
pEUROPc+pEUROPf+HCW	0.49	2.30	0.72	1.88
GR	0.30	2.68	0.74	1.81
GR+HCW	0.39	2.50	0.76	1.74
pEUROPc + pEUROPf+GR+HCW	0.54	2.19	0.78	1.66

viaEUROPc = EUROP conformation class of VIAscan®, viaEUROPf = EUROP fat class of VIAscan®, pEUROPc = conformation class of the current grading system, pEUROPf = fat class of current grading system, GR = tissue depth over 12. rib, 11 cm from midline, HCW = hot carcass weight.

Table 5. Least square means for lean meat yield (LMY%) of the conformation classes (E, U, R, O and P) within fat classes, classified by VIAscan® and one expert classifier.

	Conformation classes				
	E	**U**	**R**	**O**	**P**
VIAscan®	56.6	54.4	52.6	50.9	51.1
Expert classifier	56.3	53.9	52.6	51.2	50.5

All mean values within classification methods were significantly different with $p<0.0001$, except between R and P ($p<0.01$) and between O and P ($p> 0.05$).

Table 6. Least square means for fat proportion (FAT%) of the fat classes (1, 2, 3, 3+, 4 and 5) within conformation classes, classified by VIAscan® and one expert classifier.

	Fat classes					
	1	**2**	**3**	**3+**	**4**	**5**
VIAscan®	8.6	11.1	14.4	16.5	19.5	23.9
Expert classifier	8.2	11.1	14.3	17.0	19.8	24.7

All mean values within classification methods were significantly different with $p<0.0001$, except between fat classes 4 and 5 from VIAscan® ($p<0.001$)

Table 7. Agreement and bias[1)] of VIAscan® compared to three expert classifiers (X,Y and Z) first (1) and second (2) assessment, plant assessors (plant) and final assessment of the expert classifiers (Final XYZ) for EUROP conformation and fat score of 696 carcasses (trial 3). Percentages are rounded to the nearest whole number.

	Conformation				Fat			
Classifier	**VIAscan® Agree %**	**VIAscan® Lower %**	**VIAscan® Higher %**	**Bias %**	**VIAscan® Agree %**	**VIAscan® Lower %**	**VIAscan® Higher %**	**Bias %**
X1	79	8	12	+4	71	15	14	-1
X2	81	7	12	+5	73	14	14	0
Y1	77	4	19	+15	70	16	15	-1
Y2	80	7	14	+7	70	17	14	-3
Z1	81	5	14	+9	69	17	14	-3
Z2	81	9	11	+2	69	18	13	-5
plant	84	5	11	+6	71	14	15	+1
Final XYZ	82	6	12	+6	73	12	15	+3

[1)]Bias = proportion of carcasses underestimated or overestimated by VIAscan®.

Appendix 1

Table A1. Distribution of carcasses in deboning data set .(trials 1 and 2) into EUROPclasses according to the assessment of the expert classifier. Number of carcasses and percentage (in brackets).

	1	2	3	3+	4	5	Total
E		7 (0.8)	39 (4.5)	17 (2.0)	6 (0.7)	1 (0.1)	70 (8.1)
U	2 (0.2)	41 (4.8)	114 (13.2)	85 (9.9)	39 (4.5)	4 (0.5)	285 (33.1)
R	7 (0.8)	111 (12.9)	115 (13.3	76 (8.8)	17 (2.0)		326 (37.8)
O	46 (5.3)	88 (10.2)	13 (1.5)	1 (0.1)			148 (17.2)
P	27 (3.1)	6 (0.7)					33 (3.8)
Total	82 (9.5)	253 (29.4)	281 (32.6)	179 (20.8)	62 (7.2)	5 (0.6)	862 (100)

Fat classs 1 to 5 (columns) and conformation classes E, U, R, O, P (rows).

Table A2. Distribution of carcasses in trial 3 into EUROP classes according to final assessment of three expert classifiers. Number of carcasses and percentage (in brackets).

	1	2	3	3+	4	5	Total
E			3 (0.4)	1 (0.1)			4 (0.6)
U		18 (2.6)	73 (10.5)	54 (7.8)	5 (0.7)	1 (0.1)	151 (21.7)
R		174 (25.0)	204 (29.3)	48 (6.9)	3 (0.4)		429 (61.6)
O	25 (3.6)	72 (10.3)	6 (0.9)				103 (14.8)
P	8 (1.1)	1 (0.1)					9 (1.3)
Total	33 (4.7)	265 (38.1)	286 (41.1)	103 (14.8)	8 (1.1)	1 (0.1)	696 (100)

Fat classs 1 to 5 (columns) and conformation classes E, U, R, O, P (rows).

Manuscript II

Genetic parameters for lamb carcass traits assessed by video image analysis, EUROP classification and *in vivo* measurements.

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Abstract - The VIA system, VIAscan® from Australia, was used to predict lean meat yield (LMY) in shoulder, loin and legs of lamb carcasses and to classify carcasses according to the EUROP classification system currently used in Iceland, which is a visual classification based on conformation and fatness. The objective of this study was to estimate heritability of traits obtained from VIAscan® carcass assessments (EUROP classes and yield predictions) and the genetic and phenotypic correlation between VIAscan® traits and *in vivo* lamb traits (ultrasound measurements, conformation score and length of the left fore cannon bone). To estimate the ability of VIAscan® to classify lamb carcasses, genetic parameters for EUROP traits obtained from VIAscan® were compared to those obtained from the current grading system. The genetic correlation between EUROP scores from VIAscan® and scores from plant classifiers was 0.94 for conformation and 0.82 for fat score. It was concluded that these correlations are sufficiently high to define the EUROP scores of these two methods as identical traits. Heritability of conformation was 0.32 and 0.35 and for fat score 0.29 and 0.31 based on VIAscan® assessment and plant classifiers assessment respectively. Yield predictions as proportions of carcass weight, from VIAscan® were highly heritable, ranging from 0.39 to 0.63. LMY estimated as weight in major cuts had direct heritability ranging from 0.17 to 0.21, maternal heritability ranging from 0.09 to 0.11 and maternal environment (c^2) effect of 0.22-0.23. Genetic correlations between predicted LMY of VIAscan® and live lamb measurements were ranging from -0.65 to 0.53 Lean meat yield as proportion (LMY%) in all parts had the highest correlation to *in vivo* leg score (r_g: 0.44). Favourable correlation was found between LMY(%) in all parts and *in vivo* measurements except the lean meat yield in loin which was positively correlated to ultrasound fat depth (UFD) and negatively correlated to lean meat yield in shoulder and legs. This was explained as a consequence of unsuitable methods of deboning loin and flanks. The EUROP scores obtained by both procedures had similar genetic and phenotypic correlations to *in vivo* assessments, ranging from -0.53 to 0.70 for VIAscan® and -0.56 to 0.77 for plant classifiers. It was concluded that VIAscan® can be used as a grading tool for the Icelandic sheep industry and measurements of carcass traits obtained from the system would be useful in the national sheep breeding program.

Keywords: Genetic parameters, Video image analysis, lamb, carcasses, EUROP classification, lean meat yield, ultrasound measurements.

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1. Introduction

Lamb carcass grading systems have various purposes. Generally the objectives are to evaluate the carcass composition, ensure fair payment to farmers, classify the product for further processing and provide information to breeders. The method has to be accurate and precise over time and between abattoirs and crucial properties are the cost and speed of the method (Berg & Butterfield, 1976; Stanford, Jones & Price, 1998; Johansen, Aastveit, Egelandsdal, Kvaal & Røe, 2006).

The current lamb carcass assessment in Iceland is based on the EUROP classification system (Johansen et al., 2006) where carcasses are classified according to the conformation and external fatness by trained assessors (Reglugerð um gæðamat, flokkun og merkingu sláturafurða nr. 882/2010). Carcass assessment from abattoirs is available to farmers for every animal and provides fundamental information for the sheep breeding in Iceland. Lamb meat is the main product of the Icelandic sheep industry, based on one native breed, which is mainly selected for improved carcass traits. Ultrasound measurements and conformation scores on live lambs are widely used among farmers to evaluate the selection traits, here called *in vivo* traits. Experiments with objective carcass grading started in the year 2006 in Iceland using video image analysis (VIA) to predict lean yield and EUROP scores. The VIA equipment which was installed in one Icelandic abattoir was the Australian system called VIAscan® (Hopkins, Safari, Thompson & Smith, 2004).

When a new grading method is introduced it is important to obtain the genetic parameters of the measurements. For breeding purposes it is fundamental that the selected carcass traits are heritable. The heritability expresses the reliability of the phenotypic value as a guide to the breeding value (Falconer & Mackay, 1996). Therefore heritability can be used to compare the accuracy of different methods. Veerkamp, Gerritsen, Koenen, Hamoen and De Jong (2002) showed how genetic parameters can be used to test different classifiers to ensure that they rank animals consistently and in agreement with each other. It is also important to have knowledge about the genetic correlations to realize how improvement of one character may cause simultaneous changes in other characters (Falconer & Mackay, 1996).

Genetic parameters of lamb carcass composition obtained by VIA technology have been published in a few studies, where moderate to high heritabilities have been found (Jopson, McEwan, Logan & Muir, 2009; Payne et al., 2009; Rius-Viarrasa et al., 2009). There are no published values of genetic parameters for EUROP scores of lamb carcasses based on the VIA technology, to our best knowledge. Similarly correlations with *in vivo* traits have not been estimated elsewhere.

The objective of this study was to estimate the heritability of carcass traits based on the VIAscan® assessment, current lamb carcass grading system and *in vivo* measurements of carcass traits as well as the genetic correlations between all these traits. The main objective is to evaluate the ability of VIAscan® as a grading tool for Icelandic lamb carcasses in an attempt to provide answers to the following questions:

I. Are the EUROP traits based on VIAscan® assessment genetically the same traits as EUROP traits based on the current grading system?
II. Is the heritability of VIAscan® EUROP traits assessment comparable to heritability of EUROP traits based on the current grading system?
III. Do EUROP traits evaluated by VIAscan® have comparable genetic correlation with the *in vivo* traits as EUROP traits evaluated by the current grading system?
IV. How heritable are the VIAscan® estimates of lean meat yield and how are they genetically correlated with the *in vivo* traits?

2. Material and methods

2.1. Animals

The data set contained records for carcass traits based on VIAscan® predictions, abattoir assessments and *in vivo* ultrasonic and conformation assessment. Data was collected from 48 commercial sheep breeding farms, mainly from north (Skagafjordur) and west Iceland in the years 2007 and 2008. All farms participated in a progeny testing program, involving live assessment of lambs and recording of carcass traits. All flocks were registered in the national sheep data base. Most of the lambs from all farms were slaughtered at the KS abattoir where the VIAscan® unit is located.

2.2. Carcass traits

EUROP scores and yield predictions based on the Video image analysis by the VIAscan® equiqment are designated as VIAscan® traits. More detailed description of the VIAscan® unit is given by Einarsson, Eythórsdóttir, Smith and Jónmundsson (unpublished). The VIAscan® equipment predicts total lean meat yield in the carcass, specifically for leg, loin and shoulders both presented as percentage and weight of lean yield.

All carcasses were graded at slaughter according to national Icelandic regulations (Reglugerð um gæðamat, flokkun og merkingu sláturafurða nr. 882/2010), based on the EUROP classification system, into five conformation classes; E, U, R, O, P (numerical scores: E=14, U=11, R=8, O=5, P=2) and six fat classes; 1, 2, 3, 3+, 4, 5 (numerical score: 1=2, 2=5, 3=8, 3+=9, 4=11, 5=14). The fat class is based on fat depth measured at second last rib, 11 cm from midline. This measurement is recognized as GR measurement in the literature (Stanford et al., 1998). Carcass grading at KS abattoir was carried out by the same two experienced plant classifiers in both years. Carcass weight is presented as cold carcass weight (CCW).

2.3. In vivo traits

The *in vivo* traits included ultrasound measurements and conformation assessment carried out by trained assessors. Muscle depth (UMD) was measured at the third lumbar vertebrae where the eye-muscle (m. *longissimus lumborum*) is deepest. Fat depth (UFD) was measured directly above the UMD. The muscle shape (UMS) is a visual score from 1 to 5, where 5 describe excellent shape. All lambs were scored for conformation of legs (Leg score, 15-20) and shoulders (Shldr score, 5-10). The length of the left fore cannon bone (ML) was measured with a ruler on male lambs only. Table 1 shows descriptive statistics for the 20 traits that were included in the analysis.

Table 1.

2.4. Data structure

Performance records were available for 38,576 lambs in total, of which 1,446 lambs had records for all 20 traits. The structure of the data set is shown in Table 2 according to trait groups. VIAscan® records were not available for all carcasses due to recording errors, such carcasses were excluded based on error codes to ensure the best possible data integrity. Of the 26,795 lambs with information on abattoir traits, 5,862 lambs were slaughtered elsewhere than at the KS abattoir.

The lambs were sired by 885 rams with the average progeny group of 42 lambs, ranging from 1 to 287 offspring. Common sires of lambs with all records were 758; with VIAscan® records and *in vivo* records 758; with VIAscan® and abattoir trait records 814; with *in vivo* records and abattoir records 785. Dams of lambs with records were 18,577 and dams with records on two lambs or more were 12.705. The age of dams ranged from one to fourteen years, where 11% were one year old, 19% were two years old, 42% were three to five years old and 28% were six to fourteen years old. Average age of lambs at slaughter was 135 days. Most lambs were born as twins (75%) and reared as twins. Lambs reared as quadruplets or more were excluded. The pedigree file included 85,847 animals, the oldest born in the year 1900.

Table 2.

2.5. Statistical analysis

The importance of fixed effects was determined for all traits through preliminary analyses by using the GLM procedure in the SAS package (SAS Institute Inc, 2004). The fixed effects included in the models were combination of flock and year (71 flock-years), sex (male or female), age class of dam (4 classes: 1, 2, 3-5, 6-14), rearing status (single, twin, triplet). The linear covariates included were cold carcass weight (CCW) for EUROP scores and GR; live weight (LW) for *in vivo* traits and birth day deviation (days counted from 1. April) for weight related traits. Other fixed effects and covariates tested were of less importance and were excluded from the final models (number of lambs born, age of lambs at slaughter, slaughterhouse, date of slaughter, CCW in second power, type of ultrasound unit and interactions).

Three different animal models were used to estimate the (co)variance components. Maternal genetic effects were included in the model III for weight related traits (LW, CCW, Leg(kg), Loin(kg), Shldr(kg)) but not for other traits that were adjusted for LW or CCW. Table 3 explains which model was used to estimate the (co)variance components for each trait. The models were as follows:

Model I: $Y_{ijkm} = f_i + s_j + d_k + b_1(CW_{ijkm}) + a_m + e_{ijkm}$
Model II: $Y_{ijkm} = f_i + s_j + d_k + b_2(LW_{ijkm}) + a_m + e_{ijkm}$
Model III: $Y_{ijklmno} = f_i + s_j + d_k + n_l + b_3(dev_{ijklmno}) + a_m + m_n + c_o + e_{ijklmno}$

Y indicates the records for animal m,
f_i is the effect of i^{th} combination of year and farm.
s_j is the effect of j^{th} sex of animal,
d_k is the effect of k^{th} dam age,
n_l is the effect of l^{th} number of lambs with dam,
CW is the carcass weight as a covariate with b_1 as the linear regression coefficient of Y on carcass weight,
LW is the live weight as a covariate with b_2 as the linear regression coefficient of Y on live weight,
bdev is the deviation of birth day from 1 April as a covariate with b_3 as the linear regression coefficient of Y on deviation of birth day,
a_m is the direct additive genetic effect of the m^{th} animal with mean = 0 and variance σ^2_a.
m_n is the maternal additive genetic effect of the n^{th} dam with mean = 0 and variance = σ^2_m.
c_o is the common environmental effect due to the o^{th} dam with mean = 0 and variance = σ^2_c,
e indicates random residual effects pertaining to the corresponding Y with mean = 0 and variance = σ^2_e.

Table 3.

Variance components were estimated using the DMU-package (Madsen & Jensen, 2008). Heritability was estimated by single-trait analyses but genetic and phenotypic correlations were estimated in bivariate analyses. Heritability (h^2) based on models I and II was estimated as $h^2 = \sigma^2_a / \sigma^2_p$ where $\sigma^2_p = \sigma^2_a + \sigma^2_e$. In model III direct heritability was estimated as $h^2_d = \sigma^2_a / \sigma^2_p$, maternal heritability as $h^2_m = \sigma^2_m / \sigma^2_p$ and common environment due to the dam as $c^2_c = \sigma^2_c / \sigma^2_p$ where $\sigma^2_p = \sigma^2_a + \sigma^2_m + \sigma_{am} + \sigma^2_c + \sigma^2_e$.

3. Results

3.1. Heritability and variation

The estimates of heritability were moderate to high for all traits, ranging from 0.27 to 0.63 (Table 4). Heritability estimates for EUROP scores for conformation and fat by VIAscan® were similar to those for scores given by plant classifiers. Heritability of VIAscan® traits based on lean yield percentage was high, ranging from 0.39 to 0.63. Heritability of *in vivo* traits was lowest for the visual score of ultrasound eye muscle shape (0.27) and highest for the length of the cannon bone (0.52). The leg score had the highest heritability estimate (0.40) of all subjectively estimated traits.

Table 4.
Table 5.

Variance components and heritability of weight-related traits are presented in Table 5. Direct heritability ranged from 0.17 to 0.22, highest for LW. Maternal heritability ranged from 0.09 to 0.11. Common environmental variance as a fraction of the total phenotypic variance was similar for all the traits, ranging between 0.21 and 0.23. The direct-maternal genetic correlation was negative for all weight-related traits, ranging from -0.25 to -0.35.

Table 6.

The coefficient of additive genetic variation was highest for UFD but lowest for Leg score (Table 4). Coefficients of variation for EUROP score and GR ranged from 9.4% to 12.9%. VIAscan® yield traits showed lower variation, ranging from 1.9% to 2.7%, ultrasound traits showed rather large variation while for the *in vivo* conformation scores and ML the CV_A was ranging from 1.7% to 2.3%.

3.2 Correlations

The genetic correlation (Table 4) between viaEUROPc and pEUROPc was high (0.94), while the genetic correlation between EUROP fat scores was a bit lower (r_g: 0.82). The genetic correlations between the *in vivo* traits and EUROP scores were similar whether the EUROP scores were based on VIAscan® or plant classifiers. The Leg score was genetically strongly related to both EUROP conformation scores. The UMD had lower correlations with EUROP conformation scores than the Leg score, slightly higher with pEUROPc than viaEUROPc. The UFD was genetically highly correlated to both EUROP fat scores (r_g: 0.59). The LMY(%) had highest genetic correlations with Leg score (0.44) and UMF (-0.40) of the *in vivo* traits. The LMY(%) correlated better to EUROP scores based on VIAscan® than to the scores based on plant classifiers. The Leg(%) and Shldr(%) were highly positively correlated to each other but negatively correlated to Loin(%). Unlike Leg(%) and Shldr(%), the Loin(%) was positively correlated to EUROP fat score, GR and UFD and highly correlated to EUROP conformation score. The Shldr(%) had almost no genetic correlation to Shldr score and was the only trait with a positive correlation to length of the left fore cannon bone. The Leg(%) had a weak positive genetic correlation to Shldr score, but a negative correlation to ML and rather a strong positive correlation to Leg score.

All weight-related traits were heavily intercorrelated (Table 6), especially VIAscan® yield traits and CCW. In general the genetic correlations were higher than the phenotypic correlations.

4. Discussion

4.1 Heritability

Heritability estimates of EUROP scores evaluated either by VIAscan® or plant classifiers were alike, ranging from 0.29 to 0.35 indicating comparable accuracy of both methods. Similar breeding progress may thus be expected from selection based on both methods. Heritability estimates of EUROP conformation score in the current study were somewhat lower than found in a previous study (0.40) on Icelandic data (Sævarsson, 1999). A wide range of heritability estimates can be found in the literature. Conington, Bishop, Waterhouse & Simm (1998), Näsholm (2004), Karamichou, Merrell, Murray, Simm and Bishop (2007), Maxa, Norberg, Berg and Pedersen (2007) and Rius-Vilarrasa et al. (2010) reported heritability estimates from 0.09 to 0.45 for carcass conformation score. Karamichou et al. (2007) and Rius-Vilarrasa et al. (2010) explained low estimates as consequences of using a subjective assessment. Heritability estimate for fat score was slightly higher in this study than what Sævarsson (1999) reported (0.27). Näsholm (2004) estimated heritability of fat score ranging from 0.25 to 0.29, which agrees with the current study, but Conington et al. (1998), Karamichou et al. (2007), Maxa et al. (2007) and Rius-Vilarrasa et al. (2010) found lower estimates ranging from 0.10 to 0.19.

The heritability estimate of GR was much higher than for EUROP fat score. This difference may be caused by a scale effect, since GR is measured on a continuous linear scale which is more precise than the EUROP score. Thorsteinsson (2002) found heritability of 0.52 in agreement with current study but other heritability estimates of fat depth on the rib cover a wide range (0.28 – 0.70) (Thorsteinsson & Björnsson, 1982; Thorsteinsson & Eythórsdottir, 1998; Thorsteinsson, 2002).

Estimates of heritability of carcass yield as a percentage are generally high in the literature. Stanford et al. (1998) reviewed methods of predicting lamb carcass composition where they concluded that heritability for this trait would commonly be ranging from 0.40 to 0.45. Payne et al. (2009) analysed genetic parameters for VIAscan® traits where lean weight, adjusted for carcass weight showed lower heritability estimates than in the current study, ranging from 0.18 to 0.25. Heritabilities of yield in beef carcasses, both based on trimmed retail cuts and predicted yield have been estimated from 0.45 to 0.58 (Shackelford et al., 1994; Gilbert, Bailey & Shannon, 1993; Mukai, Oyama & Kohno, 1995; Splan, Cundiff, Dikeman & Van Vleck, 2002) which is within the same range as the results from the current study.

The heritability estimates for UMD and UFD reported here, are exactly the same as Thorsteinsson & Eythórsdóttir (1998) found in an earlier study of Icelandic lambs (0.42). Compared to the literature these estimates are rather high, although within the range of previous findings. Puntila, Mäki & Rintala (2002), Simm, Lewis, Grundy & Dingwall (2002), Roden, Merrell, Murray & Haresign (2003) and Kvame & Vangen (2007) all reported h^2 estimates between 0.40 and 0.56. UMS had a lower heritability than both UMD and UFD, which is probably because the UMS is visually evaluated with lower accuracy and is difficult to standardize. These are to our best knowledge the first published heritability estimates for the shape of the eye-muscle. Leg score (h^2*:* 0.40) had higher heritability than other subjective conformation scores in this study, even though this trait has a narrow genetic distribution (CV_A*:* 1.7%). High heritability estimates of *in vivo* conformation score of the hind limbs have been reported, ranging from 0.31 to 0.62 (Thorsteinsson & Björnsson, 1982; Thorsteinsson & Thorgeirsson, 1986; Janssens &

Vandepitte, 2004; Wolf & Jones, 2007). The cannon bone length was found to be highly heritable (h^2: 0.52) in accordance to other studies that have reported extremely high heritability estimates for this trait, ranging from 0.64 to 0.82 (Thorsteinsson & Björnsson, 1982; Thorsteinsson & Thorgeirsson, 1986; Bennett, Johnson, Kirton & Carter, 1991). In a recent study by Wolf and Jones (2007) based on Texel lambs, a lower estimate was found (h^2: 0.23).

4.2 Direct and maternal heritability of weight related traits

Direct heritabilities (0.17 – 0.22) of weight related traits (LW, CCW, Leg(kg), Loin(kg), Shldr(kg)) were in good agreement with findings of other authors although estimates can be found on a wide range. Safari, Fogarty and Gilmour (2005) reported a weighted mean of 0.20 of four heritability estimates of carcass weight and Simm (2000) suggested that a typical heritability for weaning weight would be 0.15 to 0.25. Heritability estimates for Icelandic lambs for carcass weight are ranging from 0.11 to 0.25 and for weaning weight from 0.18 to 0.37 (Jónmundsson, 1977; Thorsteinsson & Björnsson, 1982; Thorsteinsson & Thorgeirsson, 1986; Eythórsdóttir, 1999). The heritability estimates for prediction of lean weight in current study was similar as Rius-Viarrasa et al. (2009) found for leg (0.20) and loin weight (0.26) but they reported lower values for shoulder weight (0.08) based on VIA predictions of lamb carcasses in the UK. Jopson et al. (2009) found somewhat higher heritability estimates for these traits, ranging from 0.37 to 0.42 based on VIAscan® evaluation in New-Zealand.

The presence of maternal effects on weight related traits in sheep is well known and has been reported by many authors (Safari et al., 2005). Results for direct heritability, maternal heritability and environmental effects for LW are in full agreement with findings of Wolf & Jones (2007). The maternal heritability also falls in between findings of Näsholm (2004) but common environmental effects were stronger in the current study. In agreement to this study, Eythórsdóttir (1999) estimated effects of common environment on carcass weight as 0.27 for Icelandic lambs. Jónmundsson (1976) found maternal heritability of autumn weight of 0.27 which is greater than in the current study but the effects of common environment were not estimated. It may be suggested that strong common environmental effects can be expected under the Icelandic production system, where the lambs grow up at their mother's side on mountain pastures in variable environments.

The negative correlations between direct and maternal genetic effects for weight related traits as reported here, have been widely reported and reviewed by some authors (Maria, Boldman & Van Vleck, 1993; Tosh & Kemp, 1994; Maniatis & Pollott, 2002; Näsholm & Danell, 1996; Safari et al., 2005). Jónmundsson (1981) found a direct-maternal correlation of -0.43 for weaning weight in Icelandic sheep. This correlation has been explained as genetic antagonism between the effects of a individual´s genes for growth and those of its dam for a maternal contribution. This might be due to natural selection for an intermediate optimum (Tosh & Kemp, 1994).

4.3 Correlations

The high genetic correlation (0.94) between viaEUROPc and pEUROPc indicates that VIAscan® and plant classifiers are evaluating the same trait. The genetic correlation was not as strong (0.82) between viaEUROPf and pEUROPf. The limit used by Interbull (2001) for a minimum correlation between breeding values for the same trait measured in different countries is 0.70. According to those guidelines the traits measured by VIAscan® are sufficiently related to the traits from current grading system to be considered interchangeable in the breeding program. Therefore it can be concluded that VIAscan® can be used beside the current grading system as a tool for the Icelandic sheep breeding work. The lower genetic correlation between the EUROP fat score of VIAscan® and plant classifiers than between objective and subjective conformation assessments might be explained by a difference in how these fat assessments are obtained. The fat score of VIAscan® is based on the fat cover on dorsal view of the carcass but the plant classifiers measure fat at a single site on the 12^{th} rib (GR) and use that as a major guideline for the fat score. Studies have shown that there is not a perfect correlation between fat measurements on various parts on the carcass. Bennett et al. (1991), found a high genetic correlation (0.83) between measurements of fat thickness on the back (C) and on the rib (J), similarly Thorsteinsson and Björnsson (1982) also report a high correlation (r_g: 0.62). Therefore it can be speculated that it will be difficult to get perfect correlation between fat assessments based on these different spots on the carcass.

A perfect genetic correlation (0.99) was found between GR and pEUROPf which indicates that the GR fat measurement totally controls the EUROP fat score given by plant classifiers. It may thus be argued that selection for low fat score, based on pEUROPf will mainly decrease fat on the side while selection based on fat score from VIAscan® could be expected to decrease fat on the dorsal area of the carcass.

It can also be expected that the VIAscan® fat score based on six patches along the dorsal view will help to control the carcass fat distribution more than fat assessment based on one spot, like current system does. For breeding work it can be suggested, with continued use of current grading system, to use the GR measurements directly as fat assessment instead of the EUROP fat classes as the GR is a more accurate measure with higher heritability than pEUROPf. High positive genetic correlation was found between EUROP conformation score and fat score indicating that selection for improved conformation will increase fatness. This unfavourable correlation was stronger between the assessments of plant classifiers than VIAscan®. Possibly this due to poorer ability of the VIAscan® to estimate fat score. Positive genetic correlations between conformation and fat are in agreement with other studies (Safari & Fogarty, 2003; Karamichou et al., 2007).

The yield proportion estimates had much stronger correlations to EUROP fat score than conformation score, which is in agreement with Johansen et al. (2006) who analysed the relationship between EUROP scores and carcass yield. Loin(%) was negatively correlated to Leg(%) and Shldr(%) while Leg(%) and Shldr(%) were highly positively correlated. This was unexpected and not in agreement with the findings of Payne et al. (2009). The Loin(%) on the other hand was more closely related to EUROP fat score, GR and UFD than LMY(%). A likely explanation for this may be found in the methodology used to obtain the boning data, from which the yield equations were derived. The flanks where not dissected into fat and lean and were included with the lean meat yield in loin (Einarsson et al., unpublished). This results in inaccurate lean meat yield predictions and makes it difficult to infer the relationship of Loin(%) and LMY(%) with other traits. For future development of loin yield equation the flanks must be treated differently. Possible methods are to exclude the flanks or correct them for fat content. That could be done by chemical methods like was described in Hopkins et al. (2004).

Most *in vivo* traits had favourable genetic correlations with Leg(%) and Shldr(%) and selection for these traits can be expected to improve VIAscan® yield estimates. The EUROP scores from VIAscan® had, in general, similar correlations with the *in vivo* traits as EUROP scores given by plant classifiers. The usefulness of UMD and UFD as predictors for carcass yield is well known from the literature (Stanford et al., 1998) and was confirmed here. The genetic correlation between UMD and both EUROP conformation scores was rather high compared to Karamichou et al., (2007) while others have found similar or higher genetic correlation between these traits (Maxa et al., 2007). On the other hand, the genetic correlation between UFD and EUROP fat score was much lower than Karamichou et al. (2007) found (r_g: 0.97) but Maxa et al. (2007) obtained a similar estimate (r_g: 0.66) for Shropshire in Denmark. The positive genetic correlation between UMD and UFD is in agreement with other studies (Safari et al., 2005; Puntila et al., 2002) although negative correlations can also be found between these traits in the literature (Conington, Bishop, Waterhouse & Simm, 1995; Maxa et al., 2007). Negative correlation has been found between these traits in Icelandic lambs (Thorsteinsson & Eythórsdóttir, 1998) based on data from an experimental flock that had been subject to strong selection for low fat and thick muscles. These first results of genetic parameters for UMS show that this trait is highly correlated to UMD but has similar or weaker relation to all abattoirs and VIAscan® traits than the muscle depth. Therefore it is suggested that the usefulness of UMS as a selection trait for improved lean meat yield and conformation should be further analysed. Leg score is the most important indicator trait for EUROP conformation score according to the genetic correlation. The leg score had positive genetic correlation with Leg(%) while there was almost no genetic correlation between shoulder score and Shldr(%). It seems likely that live lamb assessors tend to give fat lambs relatively high scores for shoulders that do not reflect the actual lean meat yield.

5. Conclusion

The current grading system based on visual carcass assessment can be replaced by the VIAscan® technique since genetic correlations between objective and subjective EUROP assessments are sufficiently strong and the heritability is comparable between methods. However it would be desirable to improve the agreement between these two methods of EUROP fat score to get a stronger genetic correlation, especially if information based on both methods is used for breeding purposes. The best way to improve the agreement over time and between abattoirs for carcass grading in Icelandic abattoirs would be to install VIAscan® units in all the main abattoirs.

Estimation of carcass composition by VIAscan® yield prediction is an option for Icelandic sheep industry. These estimates are highly heritable and can be improved by selection for current *in vivo* traits. For further usage of VIAscan® yield predictions, the equation for lean in loin needs to be corrected in future developments by either excluding the flanks from the loin yield or correcting it for fatness using total carcass fatness measured during the boning trials. The results show that objective carcass grading is an option for Icelandic sheep industry.

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Table 1. Trait descriptions, number of records (N), means, standard deviations (SD) and ranges for all traits included in the analysis.

Traits	Trait description	N	Mean	SD	Min.	Max.
VIAscan® traits						
viaEUROPc	VIA estimate of EUROP conformation score (2 -14)	18,745	8.46	2.02	2.00	14.0
viaEUROPf	VIA estimate of EUROP fat score (2 -14)	18,745	6.84	1.98	2.00	14.0
LMY (%)	VIA estimated percentage of lean meat yield (%)	18,745	61.4	1.79	48.6	73.6
Leg (%)	VIA estimated percentage of lean meat yield in legs (%)	18,745	23.7	1.03	18.8	37.5
Loin (%)	VIA estimated percentage of lean meat yield in loin (%)	18,745	15.8	0.64	13.0	18.1
Shldr (%)	VIA estimate of lean meat yield in shoulders (%)	18,745	21.8	1.04	13.4	26.1
Leg (kg)	VIA estimated weight of lean yield in legs (kg)	18,680	3.65	0.54	1.69	6.44
Loin (kg)	VIA estimated weight of lean meat yield in loin (kg)	18,680	2.45	0.45	0.99	4.82
Shldr (kg)	VIA estimated weight of lean meat yield in shoulders (kg)	18,680	3.37	0.56	1.47	5.90
Abattoir assessment data						
pEUROPc	Visual EUROP conformation score (2 -14)	33,414	8.74	1.83	2.00	14.0
pEUROPf	Visual EUROP fat score (2 - 14)	33,414	6.87	1.77	2.00	14.0
GR	Fat depth at second last rib, 11 cm from the midline of the carcass (mm)	26,975	8.64	2.11	2.00	18.4
CCW	Cold carcass weight (kg)	33,185	15.6	2.55	6.70	29.7
***In vivo* traits**						
UMD	Ultrasound muscle depth *in vivo* at 3rd lumbar (mm)	10,091	26.0	2.82	16.0	38.0
UFD	Ultrasound fat depth *in vivo* at 3rd lumbar (mm)	9,992	2.95	0.95	0.70	9.00
UMS	Score for the ultrasound muscle shape (1 -5)	9,992	3.60	0.53	1.50	5.00
Shldr score	Shoulder and breast conformation score (5 – 10)	9,978	8.18	0.39	7.00	9.50
Leg score	Conformation score of hind legs (10 – 20)	9,978	16.9	0.54	15.0	19.5
ML	Length of the left metacarpal (cannon bone) (mm)	4,364	109	4.20	95.0	125
LW	Live weight (kg)	10,043	40.8	5.10	22.0	67.0

Table 2. Data structure.

	VIAscan® traits	Abattoir traits	*In vivo* traits[a]
Lamb with records	18.680	26.795	9.930
Sires (n)	815	845	821
Dams (n)	12.073	15.125	7.189
Males:females	10,405:8,275	15,048:11,747	1,419:8,511
Farm-years	68	69	68
bdev[b]	45.9	45.3	43.3

[a]ML not included.

[b]Birthday deviation where days are counted from 1. April.

Table 3. Traits analysed by each of the three statistical models used to estimate (co)variance components.

Model I	**Model II**	**Model III**
viaEUROPc	UMD	Leg(kg)
viaEUROPf	UFD	Loin(kg)
LMY(%)	UMS	Shldr(kg)
Leg(%)	Shldr score	CCW
Loin(%)	Leg score	LW
Shldr(%)	ML	
pEUROPc		
pEUROPf		
GR		

Table 4. Coefficients of additive genetic variation (CV_A), heritability (diagonal), phenotypic (above diagonal) and genetic correlations (below diagonal) for weight adjusted traits estimated by models I and II.

	CV_A (%)	**via EUROPc**	**via EUROPf**	**LMY (%)**	**Leg (%)**	**Loin (%)**	**Shldr (%)**	**pEUROPc**	**pEUROPf**	**GR**	**UMD**	**UFD**	**UMS**	**Shldr score**	**Leg score**	**ML**
viaEUROPc	10.2	**0.32**	0.12	0.29	0.26	0.56	-0.04	0.53	0.15	0.20	0.26	0.08	0.22	0.25	0.35	-0.30
viaEUROPf	10.9	0.33	**0.29**	-0.49	-0.52	0.31	-0.56	0.07	0.43	0.50	0.00	0.34	0.02	0.18	0.09	-0.21
LMY (%)	1.9	0.46	-0.61	**0.46**	0.87	0.23	0.51	0.24	-0.27	-0.34	0.21	-0.30	0.13	0.08	0.23	-0.09
Leg (%)	2.6	0.33	-0.70	0.92	**0.46**	0.04	0.58	0.19	-0.32	-0.40	0.21	-0.27	0.13	0.05	0.21	-0.01
Loin (%)	2.7	0.87	0.53	0.18	-0.06	**0.63**	-0.19	0.50	0.29	0.37	0.10	0.14	0.09	0.27	0.28	-0.47
Shldr (%)	2.7	-0.05	-0.79	0.83	0.77	-0.30	**0.39**	-0.03	-0.34	-0.43	0.12	-0.36	0.04	-0.07	0.04	0.13
pEUROPc	9.4	0.94	0.34	0.42	0.27	0.83	-0.03	**0.35**	0.15	0.18	0.27	0.02	0.22	0.27	0.40	-0.07
pEUROPf	10.7	0.41	0.82	-0.44	-0.52	0.50	-0.63	0.40	**0.31**	0.77	-0.06	0.32	-0.01	0.15	0.03	-0.20
GR	12.9	0.42	0.81	-0.43	-0.52	0.50	-0.62	0.38	0.99	**0.58**	-0.06	0.42	-0.01	0.19	0.04	-0.23
UMD	5.6	0.47	0.05	0.37	0.32	0.22	0.25	0.53	-0.13	-0.14	**0.42**	0.00	0.47	0.32	0.46	-0.04
UFD	17.2	0.16	0.59	-0.40	-0.35	0.19	-0.53	0.13	0.59	0.57	0.11	**0.42**	-0.02	0.12	0.04	-0.09
UMS	7.1	0.41	0.05	0.26	0.24	0.23	0.12	0.50	-0.12	-0.08	0.76	0.02	**0.27**	0.29	0.38	-0.09
Shldr score	2.3	0.60	0.28	0.25	0.17	0.53	-0.03	0.59	0.26	0.29	0.45	0.21	0.50	**0.32**	0.48	-0.17
Leg score	1.7	0.70	0.12	0.44	0.38	0.52	0.13	0.77	0.02	0.01	0.62	0.12	0.65	0.69	**0.40**	-0.19
ML	2.1	-0.53	-0.21	-0.25	-0.13	-0.65	0.08	-0.56	-0.44	-0.40	-0.14	-0.07	-0.24	-0.25	-0.36	**0.52**

Table 5. Additive genetic variance (σ_a^2), maternal genetic variance (σ_m^2), direct-maternal genetic covariance (σ_{am}), common environmental variance (σ_c^2), residual environmental variance (σ_e^2), direct heritability (h_d^2), maternal heritability (h_m^2), maternal environmental effect (c^2) and direct-maternal genetic correlation (r_{dm}) for weight-related traits estimated by model III.

Variable	**σ_a^2 (SE)**	**σ_m^2 (SE)**	**σ_{am} (SE)**	**σ_c^2 (SE)**	**σ_e^2 (SE)**	**h_d^2**	**h_m^2**	**c^2**	**r_{dm} (SE)**
LW	2.90 (0.416)	1.22 (0.451)	-0.55 (0.421)	2.89 (0.327)	7.01 (0.307)	**0.22**	0.09	0.21	-0.29(0.18)
CCW	0.76 (0.074)	0.44 (0.075)	-0.17 (0.069)	0.97 (0.051)	2.30 (0.049)	**0.18**	0.10	0.23	-0.29 (0.10)
Leg (kg)	0.039 (0.004)	0.021(0.005)	-0.009 (0.004)	0.043 (0.003)	0.093 (0.003)	**0.21**	0.11	0.23	-0.31 (0.12)
Loin (kg)	0.023 (0.003)	0.014 (0.003)	-0.006 (0.003)	0.030 (0.002)	0.071 (0.002)	**0.17**	0.11	0.23	-0.35 (0.12)
Shldr (kg)	0.041 (0.005)	0.018 (0.005)	-0.007 (0.004)	0.044 (0.003)	0.106 (0.004)	**0.20**	0.09	0.22	-0.25 (0.13)

SE = Standard Error.

Table 6. Phenotypic (above diagonal) and genetic correlations (below diagonal) for weight-related traits estimated by bivariate analysis, model III.

	LW	CCW	Leg (kg)	Loin (kg)	Shldr (kg)
LW		0.86	0.78	0.85	0.78
CCW	0.84		0.99	1.02	0.98
Leg (kg)	0.82	0.92		0.97	0.99
Loin (kg)	0.87	0.94	0.85		0.94
Shldr (kg)	0.80	0.92	0.96	0.83	