Productivity and Health of Indigenous Sheep Breeds and Crossbreds in the Central Ethiopian Highlands

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Abstract

This thesis is based on seven related studies on Ethiopian indigenous Horro and Menz sheep breeds and crossbreds of Menz with exotic breeds to test the general hypothesis that there exist genetic and environmental dependent variations among and within breeds that could be utilised to improve overall productivity and health of the Ethiopian sheep population. The specific studies deal with growth, survival, causes of mortality, risk factors for major causes of mortality, outbreak investigations, maedi-visna, and economics of anthelmintic treatment and supplementation.

Results of studies on lamb growth and survival revealed that Horro lambs were heavier than Menz lambs both at birth and weaning. Birth weight increased significantly from the first to third parity; was higher for lambs born as singles than multiples, and for male than female lambs. Lambs born in the wet season had higher birth weight, pre-weaning average daily weight gain and weaning weight than their contemporaries born in the dry season. Pre- and post-weaning mortalities were 33.1% and 54.5% for the Horro and 19.2% and 25.9% for the Menz sheep. Cumulative mortality up to yearling was more than twice as high for Horro than for Menz lambs (69.6 vs. 30.2%). Mortality was higher for lambs born in the dry season compared to those born in the wet season, for multiple-born lambs than singles, and for male lambs than females. There was a positive relationship within breed between birth weight and survival at all ages. Causes of mortality were similar in Horro and Menz, pneumonia accounting for more than half of all deaths, followed by digestive and gastrointestinal problems, endoparasitism, starvation-mismothering-exposure complex and septicaemia. Within breed, sires were a significant source of variation for lamb growth and survival.

A retrospective case-control study conducted on 6718 sheep of the Horro and Menz breeds on risk factors for mortality associated with respiratory diseases revealed that 54.4% of total mortality was due to respiratory diseases. Annual mortality associated with respiratory diseases ranged from 6.3 to 19.0%, and breed, sex and month of the year were significant sources of variation. Mortality associated with respiratory diseases was higher for the Horro than for the Menz breed (16.5% vs. 12.4%), and between October and March than between April and September. There was a significant relationship between monthly mortality associated with respiratory diseases and monthly average minimum air temperatures and with the average monthly daily deviation between maximum and minimum air temperatures.

Estimation of genetic and environmental parameters for growth traits showed that the maternal genetic component was important for birth weight, weaning weight and pre-weaning average daily gain. The contribution of the permanent environmental component in the models was also substantial but less important than the common (litter) environmental component. Total heritability estimates for Menz and Horro were generally low to moderate at 0.22 vs. 0.26 for birth weight, 0.15 vs. 0.12 for weaning weight, 0.21 vs. 0.04 for yearling weight, 0.14 vs. 0.11 for pre-weaning average daily gain, and 0.11 vs. 0.11 for post-weaning average daily gain.

Estimates of genetic parameters on lamb survival from the mixed Linear Model and Survival Analysis were compared. For the mixed Linear Model, survival defined as a binary trait measured at different pre-determined time, and for the Survival Analysis, survival defined as time to respective periods for lamb surviving (censored records) and time to death (uncensored records) was used. The maternal genetic effect was important for lamb survival at all survival periods. The heritabilities from Survival Analysis (0.3% to 18.5%) were higher than those obtained with the mixed Linear Model (0.5% to 5.6%). The

accuracies of predicted breeding values were also higher for the traits analysed with Survival Analysis. Some limitations of Survival Analysis are discussed.

An investigation into a respiratory diseases outbreak in Menz and Awassi × Menz crossbred sheep revealed that multi-factorial causes were involved. These include *peste des petits ruminants* (72.3%, serologically confirmed), lungworms, maedi-visna, bacterial bronchopneumonia, enzootic pneumonia and fungal infections. A follow-up serological study revealed that 74% were positive for maedi-visna antibodies in sheep of two ranches, but antibodies for maedi-visna were not detected in sheep and goats from elsewhere in Ethiopia. The maedi-visna was detected in the indigenous Menz and imported pure Awassi and crossbreds of Menz with Awassi, Hampshire, and Corriedale with a significant breed difference in prevalence. This result suggested that the maedi-visna might have been introduced into Ethiopia through sheep importations.

The profitability of anthelmintic treatment and supplementation was evaluated in a 2×2×3 factorial experiment under natural sub-clinical helminthosis challenge using partial budget analysis. Supplemented sheep had significantly higher marginal profit per sheep than non-supplemented sheep. Likewise, the anthelmintic treated sheep performed significantly better than their non-treated contemporaries. The indigenous Menz and 50% Awassi × Menz were significantly more profitable during the experimental period than the 75% Awassi × Menz crosses, but ranking of genotypes changed with age.

Timely health and management interventions on identified key factors and utilising genetic variation through selection would improve lamb survival and growth. Life-time assessment of economic returns helps to draw early decisions in sheep improvement programmes. Sheep breeding objectives are discussed in the context of reducing risks of genetic loss in low-input systems and improving productivity of indigenous breeds. Breeding programmes are proposed to be based on open-nucleus flocks utilizing government ranches at the top of a three tier system of flocks. Such schemes could be used for conservation and improvement of indigenous breeds as well as for crossbreeding.

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To

My parents
My brother **Elisha A. Tibbo**
My wife, **Genet Hundie**
My son, **Eyoab**
My daughters, **Fisson & Yedidiya**

Contents

Appendix

Papers I–VII

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Mukasa-Mugerwa, E., Lahlou-Kassi, A., Anindo, D., Rege, J.E.O., Tembely, S., Tibbo, M. & Baker, R.L. 2000. Between and within breed variation in lamb survival and the risk factors associated with major causes of mortality in indigenous Horro and Menz sheep in Ethiopia. *Small Ruminant Research* 37(1-2), 1–12.

II. Tibbo, M., Mukasa-Mugerwa, E., Woldemeskel, M. & Rege, J.E.O. 2003. Risk factors for mortality associated with respiratory disease among Menz and Horro sheep in Ethiopia. *The Veterinary Journal* 165(3), 276–287.

III. Tibbo, M., Ermias, E., Anindo, D., Tembely, S., Amare, H., Mukasa-Mugerwa, E., Baker, R.L., Philipsson, J., Malmfors, B., Näsholm, A., Ayalew, W. & Rege, J.E.O. 2006. Genetic and environmental parameter estimates of growth traits in indigenous Ethiopian Horro and Menz sheep breeds. (Submitted).

IV. Tibbo, M., Anindo, D., Tembely, S., Mukasa-Mugerwa1, E., Baker, R.L., Strandberg, E., Schneider, M. del P., Philipsson, J., Ayalew, W. & Rege, J.E.O. 2006. Genetic parameter estimates of lamb survival using Linear Models and Survival Analysis in indigenous Ethiopian Menz and Horro sheep breeds. (Submitted).

V. Tibbo, M., Woldemeskel, M. & Gopilo, A. 2001. An outbreak of respiratory disease complex in sheep in central Ethiopia. *Tropical Animal Health and Production* 33(5), 355–365.

VI. Woldemeskel, M., Tibbo, M. & Potgieter, L.N.D. 2002. Ovine progressive pneumonia (maedi-visna): an emerging respiratory disease of sheep in Ethiopia. *Deutsche Tierärztliche Wochenschrift* 109, 486–488.

VII. Tibbo, M., Aragaw, K., Philipsson, J., Malmfors, B., Näsholm, A., Ayalew, W. & Rege, J.E.O. 2006. Economics of sub-clinical helminthosis control through anthelmintics and nutrition in indigenous Menz and Awassi-Menz crossbred sheep in Ethiopia. (Submitted).

Abbreviations

ADG1	Pre-weaning average daily weight gain
ADG2	Post-weaning average daily weight gain
AGID	Agar gel immunodiffusion
AnGR	Animal genetic resources
BWT	Birth weight
CSA	Central Statistics Authority
DAGRIS	Domestic Animal Genetic Resources Information System
ELICO	Ethio Leather Industry Private Limited Company
EPA	Ethiopian Privatisation Agency
ETB	Ethiopian Birr
FAO	Food and Agricultural Organisation of the United Nations
GDP	Gross domestic product, the value of all goods & services produced
IAR	Institute of Agricultural Research of Ethiopia
ILCA	International Livestock Centre for Africa
ILRI	International Livestock Research Institute
kg	Kilogram
km	Kilometre
LC	Large colony
LM	Mixed Linear Model
m.a.s.l.	Meters above sea level
MARD	Mortality associated with respiratory diseases
mm	Millimetre
MP	Marginal profit
MV	Maedi-visna
n	Effective independent lamb contributions
OIE	World Organisation for Animal Health
ONBS	Open-nucleus breeding scheme
OR	Odds ratio
PCV	Packed cell volume
PPR	*Peste des petits ruminants*
RDC	Respiratory disease complex
SA	Survival Analysis
SM	Sire model analysed in Linear Model
SME	Starvation-mismothering-exposure
spp.	Species
SPS	Sanitary and phytosanitary standards
SPS-LMM	SPS and livestock and meat marketing
SURV1	Lamb survival from birth to weaning
SURV2	Lamb survival from weaning to 12 months of age
SURVRD	Birth to maximum possible time for survival from respiratory diseases
SURVT	Overall lamb survival from birth to 12 months of age
UNFPA	United Nations Population Fund
vs.	Versus
WWT	Weaning weight of lambs at 90 days of age
YWT	Yearling weight or weight of lambs at 12 months of age

Introduction

In Ethiopia, sheep are reared mainly by smallholder farmers and are grazed in small flocks on communal open natural pastures. Ethiopia's sheep population estimated at 23.6 million (CSA, 2004), is the third largest in Africa (FAO, 2004) with more than 18 breeds or populations (DAGRIS, 2004). This diverse sheep genetic resource is distributed from the cool alpine climate of the mountainous highlands to the arid pastoral areas of the lowlands.

The annual off-take rate for sheep is estimated at 33% (EPA, 2002) with an average carcass weight of about 10 kg, which is the second lowest amongst sub-Saharan African countries (FAO, 2004). Nevertheless, sheep contribute a substantial amount to the farm household as income, mutton and non-food products (manure, skins and coarse wool). They are a source of risk mitigation during crop failures, of property security and of monetary saving and investment in addition to many of other socio-economic and cultural functions. However, sheep productivity is constrained by scarcity of feed, diseases, inadequate utilisation of indigenous sheep breeds, lack of infrastructure and market information, and trained personnel.

In sheep industry, fast growing and early maturing sheep are more profitable compared to slow growing and late maturing ones since the ultimate product is mutton. A slow growth rate, resulting in a low market weight of indigenous sheep, as an important limiting factor on profitability of sheep, has been documented in the Ethiopian highlands (Mukasa-Mugerwa *et al.*, 1994). Early growth is influenced by several factors such as the genes of the individual for growth, the environment provided by the dam, sex of lamb, litter size and season of birth (Lewis & Beatson, 1999; van Wyk *et al.*, 2003; Abegaz *et al.*, 2005). Genetic improvement could be one way to improve growth in the indigenous sheep breeds.

Compared with sheep in temperate regions, the productivity of sheep in Ethiopia is presently low due to high lamb losses. Mortality rates of lambs ranging from 8 to 50% were reported in literature (e.g. Dalton *et al.*, 1980; Peterson & Danell, 1985; Yapi *et al.*, 1990). Lamb mortality may vary due to location, birth type, year and season of birth, between and within breeds (Dalton *et al.*, 1980; Traore & Wilson, 1988) and among sire progeny groups (Knight *et al.*, 1979). However, information is scarce on the variability in lamb survival among sire progeny groups, causes and risk factors of lamb mortality in Ethiopia.

To improve lamb survival, selective breeding and crossbreeding could be a possibility (Haughey, 1993; Freking & Leymaster, 2004). However, low heritability of survival traits (e.g. Safari *et al.*, 2005) constrained genetic progress through selection. Improving the estimation method may partly solve this problem. The most commonly used Linear Model (LM), where mortality is defined as a binary variable for survival to an arbitrary or predetermined time point, ignores the continuous nature of the trait (Yazdi *et al.*, 2002). This results in a loss of information due to failure to account for censoring and covariate interactions that varies with time (Allison, 1997; Mandonnet *et al.*, 2003). Survival Analysis (SA), which is based on failure-time (Ducrocq, 1987; Lee, 1992), would take into

account of censoring and covariate interactions that vary with time, and this eventually improves the accuracy of breeding values (Carlén *et al*., 2005). However, no study was known to-date that used Survival Analysis in lamb survival.

The breeds studied in this thesis are largely the indigenous Menz and Horro sheep breeds of Ethiopia. The experimental flocks were maintained by the International Livestock Research Institute (ILRI) to assess genetic resistance to endoparasites among and within the two breeds (e.g. Rege *et al*., 2002). The two breeds were chosen for their perceived phenotypic difference (e.g. coat colour, body size), large population size and representation within the country and similarity of their production system in the highlands of Ethiopia. This thesis reports growth, survival and causes of mortality of the indigenous Horro and Menz breeds (Papers I, II, III and IV). Other genotypes studied were 75% Awassi $\times$ 25% Menz and 50% Awassi $\times$ Menz crossbreds (Papers V, VI & VII), and Corriedale-Menz and Hampshire-Menz crossbreds (Papers VI). These crossbreds were largely maintained by two governmental ranches to improve growth and wool of indigenous breeds through crossbreeding and distributing 75% exotic rams to smallholder farmers.

The high number of animals in relation to grazing areas, unreliable rainfall, increasing human population, small landholding size, and decreasing land productivity are major threats to livestock production (Dibissa, 2000). Therefore, there is an urgent need to maximise production per unit of input. The overall purpose of this thesis was to investigate productivity and health constraints of indigenous Menz and Horro sheep breeds and crossbreds and indicate possible improvement alternatives.

Background

Overview of Ethiopian agriculture

Ethiopia's economy is based on agriculture, accounting for 55% of the national GDP in addition to the raw material it provides for domestic small-scale industries, 60-85% of exports and 80% of total employment (Aklilu, 2002; CIA-The World Fact Book, 2005). Agriculture will continue to provide food for the ever-increasing human population, estimated in June 2005 at 77.4 million with annual population growth rate of 2.4 (UNFPA, 2005). Unfortunately, the agricultural sector suffers low productivity per unit of input and high risk due to predominantly rain-fed agriculture, the rainfall of which has two seasons of erratic intensity and duration and great year to-year variability (Segele and Lamb, 2005). Smallholder farmers deal with these uncertainties by growing different crops and keeping multiple species of livestock depending on the available natural resource base in different agro-ecological zones. Major agricultural products are cereals, pulses, coffee, oilseed, sugarcane, potatoes, qat (*khat* or *chat*), hides and skins, cattle, sheep, and goats. Recently, floriculture has emerged as an important sector targeting the export trade.

Contribution of livestock to livelihoods

Ethiopia is known as the leading African country in livestock population and ranks 9th in the world (FAO, 2005). The livestock sub-sector accounts for about 40% of the agricultural GDP and 20% of the total GDP (Aklilu, 2002) without considering the contribution of livestock in terms of draught power, manure and transport services. The livestock population (in millions) is estimated at 44.3 cattle, 23.6 sheep, 23.3 goats, 2.3 camels, 6.1 equines (donkeys, horses and mules) and 42.9 chickens (CSA, 2004). Excluding exports of live animals and other products, leather and leather products alone contribute 18% of the total export earnings (EPA, 2002). Smallholder farmers raise livestock for milk, meat, blood, hides and skins, manure and draught power. In addition, they are a source of risk mitigation in case of crop failures, of property security and of monetary saving and investment. Among various social functions, livestock serve as a measure of the wealth status of the rural poor. Major constraints to livestock production include inadequate nutrition, disease, lack of support services (e.g. efficient extension services), insufficient data to plan for improved services, and inadequate information (livestock recording is lacking) to design appropriate animal breeding strategies, marketing, and processing.

Small ruminants production

As compared to large ruminants, sheep and goats require small investments, have shorter production cycles, faster growth rates and greater environmental adaptability, and hence have a unique niche in smallholder agriculture. They are important protein sources in the diets of the poor and help to provide extra income and support survival for many farmers in the tropics and sub-tropics. It is projected that by the year 2025 sheep and goats will account for half the red meat production in sub-Saharan Africa (Winrock International, 1992). The recently released poverty map by ILRI (Thornton *et al.*, 2002) indicate that livestock types are key indicators of where families sit on the poverty scale, sheep and goats being considered poor-man's species.

In Ethiopia, sheep and goats provide 25% of the domestic meat consumption with production surplus, which is exported mainly as live animals. The two species also provide almost 50% of the domestic wool requirements, about 40% of fresh skins and hides production and 92% of the value of semi-processed skins and hides export trade (ILCA, 1993; Kebede, 1995). The annual mutton and goat meat production of the country is estimated at 78 and 69 thousand metric tonnes, respectively (FAO, 2004). About three-quarters of the sheep inhabit the cool highland regions of Ethiopia (Mukasa-Mugerwa & Lahlou-Kassi, 1995) though a recent report (Aklilu *et al.*, 2005) claims that the distribution has recently changed to about an even distribution between highlands and lowlands. The highlands of Ethiopia constitute 36 percent of the total land area and support 88 percent of the human and 70 percent of the livestock population (MOA, 1995).

In the mixed crop-livestock system, sheep represents less than 10% of the farm capital invested in livestock, yet contributes as much as 22-63% to the net cash income and 19-23% to the food subsistence value derived from livestock production (Gryseels, 1988; Zelalem & Fletcher, 1993). In addition to mutton,

sheep provides skins, manure and coarse wool (Figure 1). Estimates by the Ethiopian Ministry of Agriculture for the year 2000 indicated that the skin removal rate is 33 percent, which translates into an output of 8.3 million sheepskins (Industry Canada, 2005). On average, Ethiopia has the capacity to supply 16 to 18 million pieces of hides and skins to local tanneries. For example, out of the 12 million annual total skins supplied to tanneries 7 million were sheepskins (LMA, 2001).

Figure 1. Wool carding, Ethiopian highlands
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Sheep production systems

In Ethiopia there are two main categories of sheep production systems. The first and the most common system is the traditional smallholder management system. The second, which is limited in scope and area coverage, is the private commercial and parastatal production system.

In the *traditional subsistence smallholder management system*, sheep are kept as an adjunct to other agricultural activities along with other livestock species. There is no specialised system with defined breeding objectives. The common trend, however, is that the majority of people in the highlands keep small flocks and practice mixed crop-livestock agriculture, whereas those in the sub-moist, cold, very high altitude areas and in arid lowlands keep large flocks in pastoral production system. When closely examined, three different production systems can be identified:

1) *Sheep-barley or sheep production system* prevails in high altitude areas (above 3000 m.a.s.l.) where sheep are the main source of cash income, meat, manure, skins and coarse wool for traditional cottage industry to produce blankets, rugs and mattresses by the local handcrafts (Figure 1). In extreme altitudes, precipitous terrain, recurrent droughts, cold

temperature and windy climate limit crop production to sheep-barley or just sheep production. Sheep breeds of this system (for example, the Menz breed) are perceived to be the hardiest sheep types evolved under stressful environments. The sheep breeds thrive well with slow growth rate but considerably high annual reproduction rate under gastro-intestinal parasite infestations, recurrent drought and grazing scarcity (Lemma, 2002).

2) *Mixed crop-livestock system*, which covers areas in altitudes between 1500 and 3000 m in which sheep are kept in small flocks as a source of cash income, meat, manure, skins and in some areas for coarse wool. The sheep flocks are kept along with other livestock species (cattle, goats and equines) in rather reduced communal grazing areas, unsuitable for cropping, or fallows, waterlogged land and steep slopes (Mengistu, 2000).

3) *Pastoral production system* is located in arid and semi arid lowland areas below 1500 m.a.s.l. in which livestock rearing is the mainstay of people. Livestock and livestock products provide subsistence, either directly as milk, milk products, meat and blood, or indirectly in the form of purchased cereals through sales of animals. Sheep are raised mainly for cash income (mainly through export) and meat, except in isolated areas where they also keep them for milk (for example, in Afar and parts of Tigray regions). Other important species in this system include cattle, goats and camels. Constant or partial herd mobility is a strategy to achieve feed and water. Pastoralists have no permanent home and, hence move with their herds within their traditional territory (Mengistu, 2000).

The other type of production system, the *parastatal and commercial production system* represent a very small proportion of sheep production systems in Ethiopia. Sheep in these systems are managed either intensively or semi-intensively. Privately owned ranches, farms or governmental sheep breeding and multiplication centres constitute this type of production system. Privately owned ranches not only breed sheep for market but also purchase grown rams from nearby farmers, and fatten and sell them during festive occasions. Some ranches, however, export sheep to the Middle East either as live animals or as mutton. Established by government (parastatal), two ranches (namely, Debre Berhan and Amed Guya) have been crossbreeding and distributing crossbred rams to farmers on cost-recovery basis until banned in 2001 when maedi-visna disease was confirmed in crossbreds and associated sheep flocks.

Constraints to sheep production

Sheep production in Ethiopia is based on indigenous breeds except for less than 1% exotic sheep group of mainly Awassi-Menz crossbreds. The indigenous sheep are year round breeders and mating is not controlled. However, the current off-take rate is very low. Increasing the current level of productivity is essential to provide meat to the ever-increasing human population, to increase export earnings and household income thereby improving the living standard of smallholders. There are, however, a number of constraints to sheep production and the major ones are summarised as follows.

Lamb mortality is the single most important constraint limiting productivity. Studies indicate that up to 50% of the lambs born can die mainly due to diseases and other causes such as adaptation failure, dystocia, cold stress, starvation and mismothering (Hinch *et al.*, 1986). Information is required on pattern and causes of mortality to improve survival.

Feed scarcity: Sheep in the tropics primarily graze natural pastures or utilise crop residues and their by-products, whose supply and quality fluctuate seasonally. In the highlands of Ethiopia, the communal grazing land is diminishing due to encroachment by cropping land because of increased food demand due to the human population growth (Dibissa, 2000). The land is degraded (Sundquist, 2003) due to high and increasing human and livestock population worsened by poor land use policy resulting in low productivity of the system. Overgrazing, nutrient depletion due to limited recycling of dung and crop residues in the soil, low use of chemical fertilisers, declining fallow periods, soil and organic matter burning, soil erosion and deforestation are all major concerns (Desta *et al.*, 2000). Inadequate access to feed influences the severity of several infections, particularly in young animals (MacRea, 1993; Van Houtert *et al.*, 1995). Isolated efforts to solve this problem may alleviate only part of the problem. Instead, integrated efforts should involve combined efforts of improving land tenure policies to promote natural resource management, livestock productivity through reducing stressors (e.g. diseases) by herd/flock health management, genetic means (e.g. within and between breed selection, crossbreeding), and improving productivity per unit of input than keeping large number of mediocre animals. Furthermore, efforts should be made in family planning to limit human population growth rate and exercise human mobility through re-settlement alternatives in less degraded and under-utilised but productive areas within the country.

Inadequate utilisation of indigenous sheep breeds: Despite the fact that huge sheep genetic diversity does exist in the country, no comprehensive analysis into the variation of growth potential of the indigenous breeds has been undertaken. For example, almost none of the sheep breeds from the Ethiopian highlands are exported due to darkening of the meat after slaughter which is less liked by importers (Aklilu *et al.*, 2005). But this 'defect' has not been investigated. The indigenous sheep breeds of Ethiopia, though often been considered low-producers without careful analysis of their output per unit of input, are highly adapted to low-input systems or are naturally selected for survival under sub-optimal and disease-ridden environments. They thrive and produce on marginal and often uncultivable lands. These breeds need to be well characterised, documented, improved and conserved through proper utilisation.

Transport and infrastructural problems include lack of road transport system. Sheep are often transported on-foot and trek long distance without water and feed. In some cases, they are transported in unsuitable vehicles or lying on top of public transport (bus) by immobilising them with a rope. Overloading frequently occurs as well as driving for long hours without rest, water and feed. This predisposes them to infections, injuries, and stresses, the latter seriously affecting meat quality. Market yards do not have required facilities and operate without water and feed, shades, partitions, scales, crushes, loading ramps and toilets (Aklilu *et al.*, 2005).

Most abattoirs have no holding grounds and hence animals cannot be rested and treated.

Paucity of market information at all levels is a limiting factor. For example, about the export market, information flow on grades and standards for all stakeholders in the marketing channel is needed. However, there is no up to date media coverage on livestock market information.

Lack of trained personnel and absence of recording: Despite the contribution of the livestock sector to the household and national economy, trained manpower is very limited. Specialisation in sheep is missing and trained personnel in one species may be on call to contribute in every species as necessary. Recording in general is hardly practiced in any livestock species. Incomplete records available for ruminants are mainly in research stations and government owned ranches. Farmers mix different livestock species as a strategy to meet the family food demand – cattle are kept mainly for traction and milk, sheep and goats for income and meat, equines for transport and chickens for income, egg and meat. This together with illiteracy at smallholders' level, lack of co-ordination and facilitation at the extension level, and inadequate knowledge and skill on genetic evaluations even in personnel of research stations, are all major impediments.

Growth and survival in sheep

Growth in animals can be measured by the increase in live weight. Early growth in lambs is influenced by breed, sex of lamb, litter size, season of birth as a reflection of seasonal fluctuation in feed availability and also milk yield of the dam (e.g. Rastogi *et al*., 1993). Due to seasonal fluctuation of forage availability in the tropics, animals lose weight during the dry season and gain weight during feed abundance in the wet season, deposit fat during the latter season and mobilise during unfavourable periods to meet energy demands as a coping mechanism (Negussie *et al*., 2000; Ermias *et al*., 2002). However, a slow growth rate has been limiting profitability of the indigenous sheep breeds (Mukasa-Mugerwa *et al*., 1994). There is paucity of information on genetic variability for growth in indigenous sheep breeds of Ethiopia.

Lamb survival is of major economic importance to sheep producers world-wide since most lambs are sold primarily for mutton. Literature reviews show that geographical variation in lamb mortality is considerable (e.g. Dalton *et al*., 1980; Peterson & Danell, 1985; Yapi *et al*., 1990). In South Africa, management inputs even with intensive care failed to reduce 'core' level of lamb losses below 15% (Brand *et al*., 1985). It is generally accepted that during the first few days of life the majority of weak lambs will die and the mortality declines as survivors grew older. Why are these 'weakly' lambs born to die is the question to address. Information is scarce on genetic factors as a source of variation for lamb survival.

Causes of sheep mortality

Identifying all causes of mortality in lambs is generally difficult. Studies show, however, that important causes of lamb mortality tend to be similar in most countries studied (e.g. Bekele *et al*., 1992a, b; Green & Morgan, 1993; Binns *et*

al., 2002). In general, during the perinatal period (less than 1 week after birth) lambs die from adaptation failure, hypothermia, dystocia, starvation-mismothering-exposure (SME) complex and septicaemia consequent upon inadequate colostrums intake (e.g. Woolliams *et al*., 1983; Gama *et al*., 1991; Hinch *et al*., 1986). Between 1 and 3 weeks of age, deaths can result from trauma, abscesses and meningitis secondary to ompholophlebitis (''navel ill'') (e.g. Green & Morgan, 1993). Older lambs commonly die of various infections causing pneumonia, gastro-intestinal diseases (e.g. enteritis or diarrhoea) and endoparasitism along with malnutrition and predation (Weiner *et al*., 1983; Yapi *et al*., 1990; Nash *et al*., 1997; Baker *et al*., 2003). In the Ethiopian highlands, pneumonia accounted for the majority of lamb deaths (Bekele *et al*., 1992a, b; Roger, 1996; Ayelet *et al*., 2001).

The causes of mortality due to respiratory diseases in the highlands of Ethiopia are multi-factorial. Hence, the term respiratory disease complex (RDC) is used for the condition conventionally known as bronchopneumonia. It is locally identified as '*Engib*', '*Wozuwuz/Wotwut*', and '*Gifaw*'. The causative agents could be bacterial, mycoplasmal, viral, and parasitic lung worms (Njau *et al*., 1988a; Bekele *et al*., 1992a, b; Ayelet *et al*., 2004). The control of respiratory diseases has continued to be difficult. The reasons behind are unawareness of smallholder farmers of the importance to bring sick animals to veterinary clinics at early stages of pneumonia; single dosing of animals with antibiotics due to negligence of the farmers to bring back the animals for subsequent injections resulting in development of drug resistance by the pneumonia causing micro-organisms. Furthermore, irregular and incomplete vaccination programmes for diseases such as pasteurellosis and PPR, and incompleteness of the available vaccine for pasteurellosis which does not include all species and serotypes for *Pasteurella haemolytica* (Ayelet *et al*., 2004) were important problems. Moreover, lack of practising strategic mass drenching against parasites and the emergence of non-treatable maedi-visna virus as an important agent in RDC were all major impediments.

It has been argued that reductions in lamb mortality can be achieved only by identifying and targeting the specific causes of mortality on a given farm (Kirk & Anderson, 1982). However, because specific causes of lamb deaths are similar under many different systems it might be more appealing to identify underlying factors associated with mortality from multiple causes and change general farm and lambing management practices accordingly (Rowland *et al*., 1992; Binns *et al*., 2002). For example, environmental and/or managemental factors can act as stressors and hamper the immune response (Kimberling, 1988) and these, combined with increased exposure to pathogens, may lead to respiratory infection (Rook *et al*., 1990). An alternative to costly treatments for pneumonia is prevention through adjusting the management routines to reduce the risk of disease development. Although losses due to pneumonia have been reported to be high in Ethiopian highland sheep (Njau *et al*., 1988a; Bekele *et al*., 1992 a, b; Ayelet *et al*., 2001), risk factors predisposing sheep to pneumonia have not been systematically studied.

Characterisation and improvement of sheep genetic resources

Over long periods, indigenous sheep breeds have become adapted to various stressors such as heat, cold, humidity, water scarcity, seasonal fluctuations in feed availability in terms of quality and quantity, and various diseases. They thrive on marginal and marshy lands unsuitable for cultivation, and on road-sides (Figure 2); also convert left-over and by-products into animal protein, manure, wool and skin. Unfortunately, a large number of these genetic resources have been lost and many more are threatened due to uncontrolled crossbreeding and replacement with exotic breeds. Despite large sheep genetic resources endowment, so far efforts have been limited to identify and characterise the genotypes existing in Ethiopia. Furthermore, programmes for genetic improvement are still lacking.

Results from fragmented studies indicate that there are 18 indigenous sheep populations in Ethiopia. The diverse groups of sheep populations in the central and western highlands (above 2000 m.a.s.l.) include the Menz, Legagora, Tucur (also called Lasta), Arsi-Bale, and Dangila (also called Washera, Agew). These are collectively referred by Epstein (1971) and Wilson (1991) as Abyssinian sheep or Ethiopian Highland sheep.

Figure 2. Indigenous Menz sheep grazing on road-side at Debre Berhan

Another categories are the thin-tailed Horro sheep in the western humid mid-highlands (1400–2000 m.a.s.l.), the fat-tailed Afar sheep (also called Danakil, Adal) found in the north-east lowlands of the arid Rift Valley and the fat-rumped Blackhead Somali sheep (also known as Blackhead Ogaden, Berbera Blackhead)

found in the eastern lowland plains up to 1100 m.a.s.l. (Galal, 1983). Many other localized types are not yet explored. Local names and general areas of distribution for few of the sheep types of Ethiopia have been mentioned by various authors (e.g. Epstein, 1971; Wilson; 1991) in their effort to categorize and describe African sheep types. Lemma (2002) made the first comprehensive phenotypic characterisation of sheep in the Amhara Regional State of Ethiopia and classified sheep groups of the state into four major groups, namely Central Highland sheep, North-western Highland sheep, North-western Lowland sheep, and Rift Valley sheep types. Some characterisation efforts include studies on Wello sheep (ILCA, 1989), Dangila (Washera or Agew) sheep (Chipman, 2003), Bonga sheep (Tibbo & Tefera, 2004), and Abergelle sheep (Desta, 2004). A country-wide doctoral study by Solomon Gizaw covering morphological and molecular characterisation of Ethiopian sheep breeds is hoped to shed light on the overall sheep genetic diversity status, including genetic distances between the breeds.

On-station characterisation of some sheep breeds was started in 1977 when Horro, Adal, and Blackhead Somali were characterised by the Institute of Agricultural Research (IAR) (now EIAR) of Ethiopia. The International Livestock Centre for Africa (ILCA) (now ILRI) evaluated the indigenous Menz and Horro at Debre Berhan for genetic resistance to gastro-intestinal nematode parasites. The Sheno Agricultural Research Centre (now Debre Berhan Agricultural Research Centre) characterised performance of indigenous Menz and its crosses with imported Awassi. An in-depth characterisation on the performance of Horro sheep has been done at Bako Research Centre. None of these stations, however, applied selection for economically important traits due to small flock size kept in different stations leading to small selection differentials (Abegaz & Duguma, 2004).

Crossbreeding: Sheep importations to Ethiopia for crossbreeding with the aim to improve growth and wool of indigenous sheep, was first launched in 1944 when the Merino breed was introduced from Italy. The Merino breed has been crossed with the indigenous Arsi sheep in the Agarfa ranch (in the former Bale province in Ethiopia), but the detection of maedi-visna in the flock prompted stamping-out in 1988-89 with a complete closure of that ranch (BOA, 2000). In late 1960s, sheep breeds imported were Bleu du Maine from France, Rambouillet from Spain, Romney and Corriedale from Kenya, and Hampshire from UK (Brännäng *et al*., 1987; Beyene, 1989) and were mainly crossbred with the indigenous Menz at Debre Berhan ranch, which is located 135 km north-east of Addis Ababa at an altitude of 2790 m.a.s.l. Farmers in the highlands of Ethiopia, however, declined to accept the crossbreds due to their phenotypic unlikeness to the indigenous sheep. Consequently, due to assumed phenotypic similarity to the local sheep the Awassi breed (Figure 3) was imported in 1980, 1984 and 1994 from Israel, and was crossed with the indigenous Menz (Rummel *et al*., 2005). These crosses of Awassi-Menz have been well accepted by farmers of Ethiopian highlands. Subsequently, producing of crosses has been boosted by establishing another ranch at Amed Guya 300 km north-east of Addis Ababa at an altitude of 2900 m.a.s.l.

Figure 3. Imported Awassi ewes (left) and rams (right) at the Debre Berhan ranch

A follow up milestone was the establishment of a research centre (the then Sheno Agricultural Research Centre) for improvement of the indigenous Menz sheep. The research centre also produced Awassi-Menz crosses and used them for on-station and on-farm research. According to records from the Debre Berhan ranch, between the years 1994 and 2000, a total of 2503 crossbred rams were distributed to smallholder farmers on a cost-recovery basis. The crossbred rams were distributed all over the country (except in the former Afar and Issa and Illubabor provinces) with the majority distributed in the former Shoa province of Ethiopia. The records, however, had limited breed level information. From available information, it was found out that three-quarters of the 1055 crossbred rams dispatched for breeding were 75% Awassi × 25% Menz and the remaining one-quarter were 50% Awassi × 50% Menz crosses for fattening. Major problems of the crossbreeding programme were lack of clear vision where to bring an impact (since the crossbreds were distributed all over the country) and lack of recording at all levels, especially at smallholder farms.

Research undertaken on performance of the Awassi breed in Ethiopia indicated that the crosses of Awassi-Menz could fit into the cool Ethiopian highlands. Lemma *et al*. (1989) reported an increase in mean weight at birth, weaning, and annual greasy wool weights with increasing levels of Awassi blood. However, Hassen *et al*. (2002) found that the performance of 37.5% Awassi × 62.5% Menz was no better than the indigenous Menz sheep in a low-input system under smallholder management in the cool highlands of Ethiopia. The superiority of 37.5% Awassi × 62.5% Menz in birth weight was not maintained at weaning due to inability of the indigenous dam breed to support or provide milk to higher growth rate in the lamb. Limited natural pasture availability worsened by lack of supplementary feeding practice in the mixed crop-livestock production system limited the impact of 75% Awassi-Menz rams distributed to smallholder farmers for crossbreeding. In addition, relative susceptibility of the crossbred rams to helminthosis, particularly to *Fasciola hepatica* was reported (Tibbo *et al*., 2004a). Despite their higher marketing weights under on-station management, age at first

lambing delayed greatly and fertility was low in pure Awassi and its crosses as compared to the indigenous Menz sheep (Rummel *et al.*, 2005).

Genetic analysis of growth and survival in sheep

Growth rate of the indigenous sheep could be improved by way of genetic means provided that the required information is obtained. In young animals, the milk supply of the dam and the maternal care she provides largely contribute to their growth (Lewis & Beatson, 1999). Maternal effects are more important in sheep than in cattle because of the greater relative variation in litter size in sheep and the competition between lambs for their mother's milk supply. Maternal effect incorporates both similarities between litter mates (common environmental effects) and similarities between lambs born to the same ewe in different litters or parities (permanent environmental effects) (e.g. Abegaz *et al.*, 2005). Thus, to decide upon a viable selection strategy for growth traits, estimates of genetic and environmental parameters and correlations between direct and maternal additive genetic effects are needed. Previous report by Rege *et al.* (2002) working on the same breeds did not consider the common environmental effects alone or when combined with other genetic and permanent environmental components and therefore, these have to be estimated.

For improving lamb survival, selective breeding could be used (Haughey, 1993), but low heritability of survival traits limited genetic progress (Safari *et al.*, 2005). One reason for low heritability estimates of lamb survival could be that an improper estimation method has been used. The most commonly used method for estimating genetic parameters is the Linear Model (LM), where mortality is defined as a binary variable for survival to an arbitrary or predetermined time point (e.g., Lancelot *et al.*, 2002; Baker *et al.*, 2003). This method ignores the underlying continuous nature of the trait (Yazdi *et al.*, 2002) resulting in a loss of information due to an arbitrary choice of period, failure to account for censoring (animals that leave the study before the event has occurred), and failure to account for covariate interactions with time or covariates that vary with time (Allison, 1997; Southey *et al.*, 2003; Mandonnet *et al.*, 2003). A better option might be to use Survival Analysis (SA), which is based on failure-time. SA is a statistical method for studying the occurrence and timing of specific events, where the analyzed response time equals the time elapsed from a starting point until the occurrence of the event of interest (Ducrocq, 1987; Lee, 1992). SA has been used in animal genetics for the study of longevity (e.g., Ducrocq, 1994; Yazdi *et al.*, 2002), health (e.g. Carlén *et al.*, 2005) and reproduction (e.g. Allore *et al.*, 2001; Schneider *et al.*, 2005) in dairy cattle. Recently Pereira *et al.* (2006) used SA for the analysis of age at first conception, Forabosco *et al.* (2006) compared LM and SA for the analysis of longevity traits in beef cattle, and Mandonnet *et al.* (2003) used SA to estimate genetic parameters for survival traits in goats. However, no study is known to the author, which used SA for estimating genetic parameters for survival in sheep.

Aims of the thesis

The overall aim of this thesis was to investigate productivity and health constraints of indigenous Menz and Horro sheep breeds and crossbreds. More specifically, the aims were to:

1) assess between and within breed variation in lamb growth and survival, while identifying major causes of mortality

2) identify and quantify risk factors for mortality associated with respiratory diseases

3) estimate genetic and environmental parameters of growth using different models

4) estimate genetic parameters of survival using Linear Models and Survival Analysis

5) investigate causes of respiratory diseases outbreaks in ranches

6) evaluate cost-effectiveness of anthelmintic treatment and supplementation in indigenous Menz and Awassi-Menz crossbreds

7) discuss a framework for sheep breeding in Ethiopia considering productivity and health

Overall hypothesis

The general hypothesis is that there exist genetic and environmental dependent variation in growth and survival among and within indigenous sheep breeds and crossbreds that could be utilised to improve overall productivity and health of the Ethiopian sheep population.

Overview of the investigations

In this section, summary of materials, methods and main findings are presented briefly. Most of these studies (Papers I–IV and VII) were undertaken at the ILRI Debre Berhan Research Station except for two experiments (Papers V & VI) which were undertaken in Amed Guya and Debre Berhan governmental sheep ranches. Detailed descriptions of each experiment are found in each paper in the Appendix (I–VII).

Materials and methods

Experimental sites

The *ILRI Debre Berhan station* is located in the Ethiopian highlands 120 km northeast of Addis Ababa at latitude 9°36′ N, longitude 39°38′ E and altitude of 2780 m.a.s.l. (Figure 4.).
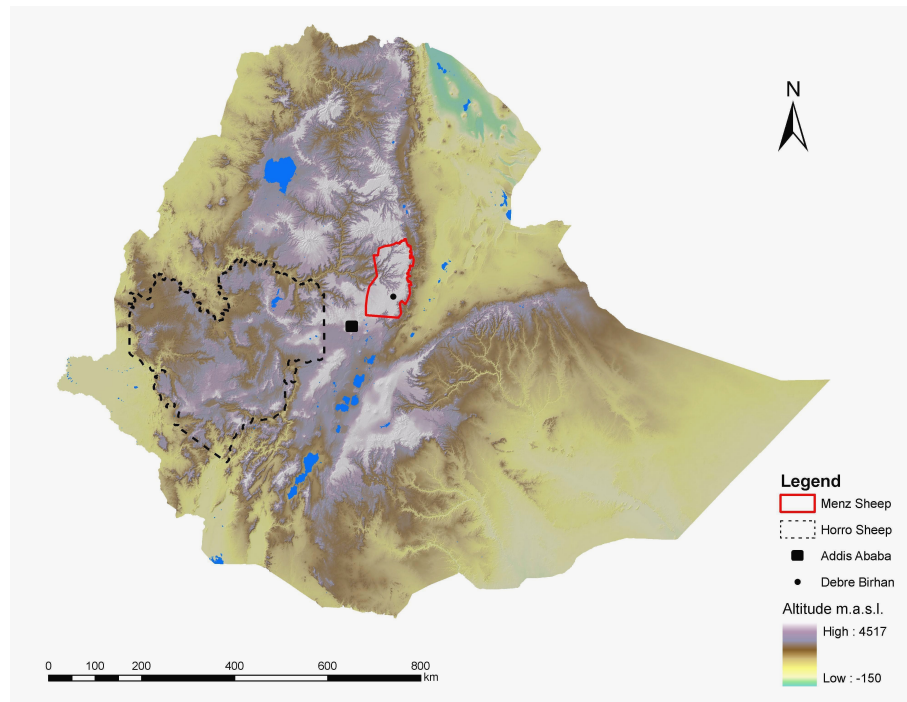
23

Figure 4. Approximate breed distribution map for the indigenous Menz and Horro sheep breeds in Ethiopia and experimental site (Debre Berhan)

Figure 5. The Horro (left) and the Menz (right) rams indigenous to Ethiopia

The climate is characterised by a long rainy season (June to September) accounting for 75% of the annual rainfall, a short rainy season (February/March to April/May) and a dry season (October to January). Annual rainfall recorded at the station averaged 920 mm over the study period. The average monthly minimum temperature ranged from 2°C in November to 8°C in August, while the average monthly maximum temperature ranged from 18°C in September to 23°C in June. The mean relative humidity was 60%. The natural pasture at the Debre Berhan

24

station, where the lambs were raised, is dominated by Andropogon grasses (*Andropogon longipes*) with a variable proportion of legumes (*Trifolium spp.*).

The *Amed Guya sheep ranch* was established in 1979 by the Baptist Mission of Ethiopia in the epicentre of distribution of the Menz breed (Figure 4), 300 km northeast of Addis Ababa at 2900 m.a.s.l. The *Debre Berhan sheep ranch* (Figure 4) was established in 1967 and is located near the ILRI Debre Berhan station (only 15 km away) at 135 km north of Addis Ababa and an altitude of 2790 m.a.s.l. Both ranches have large areas of land which is largely used for grazing. The annual rainfall of the Amed Guya ranges from 900 to 1100 mm, about 70% coming in the wet season from July to September. A long dry season from October to January is followed by the short rains from February to April. The average daily minimum temperature was 1.3–9.4°C and average daily maximum temperature was 18.6–23.4°C.

Study animals and management

The studies in Papers I, II, III & IV compared the Menz and Horro sheep breeds, which are both indigenous to Ethiopia. An approximate breed distribution map is given in Figure 4. The Menz sheep (Figure 5) are indigenous to the study area and a flock was already established at the Debre Berhan station at the beginning of the study. Menz sheep are concentrated in the central highlands between 2500 and 3000 m above sea level. It is a fat-tailed breed of relatively small size (mature ewes range from 25 to 35 kg). Age at puberty at 11.2 months (Toe *et al.*, 2000), fertility rate at 76% and litter size at 1.13 was reported for Menz breed from the same flock (Mukasa-Mugerwa *et al.*, 2002). Coat colours of Menz breed are principally black (22%), plain white (16%), plain brown (11%), light brown (10%), and a mixture of black and brown (6%), white and brown (6%), white and black (5%) or a combination of all three colours (Tibbo *et al.*, 2004b). White spots on the neck, head and legs are frequent and with an open fleece consisting of coarse hair and a woolly undercoat (Galal, 1983; Tibbo *et al.*, 2004b).

The Horro sheep (Figure 5) are found in western Ethiopia at an altitude of 1400–2000 m.a.s.l. with a dependable annual rainfall averaging 1000–1400 mm. It is a fat-tailed hair breed. Coat colours are mostly uniformly brown or light brown (83%); few of the sheep (10%) have white with brown, plain white (3%) or plain black (2%) colours (Tibbo *et al.*, 2004b). They are larger sheep than the Menz, with mature ewes ranging from 35 to 45 kg (Galal, 1983). Age at puberty at 10.3 months (Toe *et al.*, 2000), fertility rate at 67% and litter size at 1.14 was reported for Horro breed from the same flock (Mukasa-Mugerwa *et al.*, 2002). Results from a station closer to Horro's habitat revealed that fertility rate of 77%, twinning rate of 34% and mortality rate of 34% up to a yearling age (Abegaz *et al.*, 2002b). The Horro ewes and rams required to initiate the experiment were purchased from their traditional habitat in western Ethiopia and were quarantined for 2–3 months at Debre Berhan station before joining the experiment. Additional Menz and Horro rams were purchased as and when required over the study period.

Experimental design and data recorded

The Menz and Horro ewes were mated after synchronised oestrus to deliver their lambs either in June at the beginning of the wet warm season (long rains from July to September) or in October/November just before the onset of the dry cold season (November to January) (Tembely *et al*., 1998). Ewes were mated in single-sire groups of 20–25 ewes to a ram of the same breed. Single sire mating occurred in night pens for 30 days on average (range 25–42 days) and ewes were allowed to graze together during the day. When they are back from grazing, ewes are sorted by sire groups within breed at every evenings. Rams were subjected to a breeding soundness examination prior to each mating season. Each ram was used to produce progeny in one wet and one dry season and then approximately three quarters of the rams of each breed were replaced with new rams. Ten rams of each breed were used at each mating season and a total of ten mating/lambing seasons took place between May 1992 and January 1997 (Table 1). A total of 2393 Menz and 1968 Horro lambs were born in the study and these were the progeny of 43 rams and 2017 ewes for the Menz and 41 rams and 1670 ewes for the Horro. The ewes had the opportunity to produce lambs in different years and seasons of the study so that over the entire study 856 Menz ewes and 784 Horro ewes were used.

Table 1. Mating and lambing schedules for the ten lamb crops and the number of Menz and Horro lambs born

Group	Mating period	Lambing period	Season	No. of lambs born	
				Menz	Horro
1	May 1992	Oct / Nov 1992	Dry	153	136
2	Jan. 1993	June/July 1993	Wet	232	115
3	May 1993	Oct / Nov 1993	Dry	202	141
4	Jan. 1994	June/July 1994	Wet	247	228
5	May 1994	Oct / Nov 1994	Dry	196	172
6	Jan. 1995	June/July 1995	Wet	282	234
7	May 1995	Oct / Nov 1995	Dry	233	196
8	Jan. 1996	June/July 1996	Wet	312	283
9	May 1996	Oct / Nov 1996	Dry	265	245
10	Jan. 1997	June/July 1997	Wet	271	218
			Total	2393	1968
Data structure					
	No. of sires			43	41
	No. of dams			854	785
	No. of dams with own records			330	153
	No. of grand-sires with progeny records			33	30
	No. of grand-dams with progeny records			250	130
	Total lambs/dam			2.80	2.51
	Litter size at birth			1.13	1.14
	Mean lambs/sire			55.7	48.0

Birth weight, birth date, sex, and litter size were recorded at lambing. Lambs were ear-tagged at birth and parentage information recorded. Live weight was recorded when the lambs were 1, 2, 3 and 12 months of age together with other measurements for a large experiment on genetic resistance of the sheep breeds to

gastro-intestinal parasitism (Tembely *et al*., 1998; Mukasa-Mugerwa *et al*., 2002; Rege *et al*., 2002).

Ewes and lambs grazed together (Figure 6) during the day and were housed at night in covered pens with free access to grass hay, water and mineral lick blocks. Ewes and lambs were allowed to graze on 169 ha of pasture divided into eight paddocks which were grazed in a rotation at 3–4-week intervals or when needed to maximize forage production.

Figure 6. Experimental Menz (left) and Horro (right) ewes and lambs grazing at the ILRI Debre Berhan station in Ethiopia (dry season lambing)

Ewes received 200 g/head per day of a concentrate mixture comprising 33% noug cake (*Guizotia abyssinica*), 65.5% wheat bran, 1.0% limestone and 0.5% salt. Supplementation was increased to 400 g/head per day during the third trimester of pregnancy and during the peak of the dry season. Lambs had no access to feed other than that fed to their dams before weaning. After weaning at 3 months of age, however, they were supplemented with 50–150 g/head per day of the same concentrate until they were able to graze actively. Female lambs were separated from the male lambs after weaning, but exposed to the same grazing paddocks in a rotational grazing system until they completed the experiment at the age of 12 months.

Due to the topography of the ILRI Debre Berhan station and flooding during the wet season, and in order to minimize liver fluke infections, all sheep on the station were denied access to grazing in paddocks in the low-lying land during, and just after, the wet season (July to December). Ewes received 200 g/head per day of a concentrate mixture comprising 33% noug cake (*Guizotia abyssinica*), 65.5% wheat bran, 1.0% limestone and 0.5% salt. The allowance was increased to 400 g/head per day during the third trimester of pregnancy and during the peak of the dry season (from November to January). Lambs had no access to feed other than that fed to their dams before weaning.

Animals were drenched for liver flukes with triclabendazole (Fasinex 10%, Ciba Geigy, Switzerland, 12 mg/kg body weight) in November, December and January

27

of each year and oxyclozanide (Zanil, Coopers Animal Health, 15 mg/kg body weight) in August. In addition they were all vaccinated against sheep pox, pasteurellosis and clostridial infections twice a year. At the sampling at 2 months of age, individual lambs with a faecal egg count of 2000 epg or more were treated with either fenbendazole (Panacur, Hoechst, Germany, 10 mg/kg body weight) or levamisole hydrochloride (Nilverm Super, Coopers, Animal Health, UK, 7.5 mg/kg body weight). However, over the entire study period only three Menz and five Horro lambs had an epg count of 2000 or greater at 2 months of age. All lambs were drenched at weaning. Sick animals were attended to and the date and cause of sickness recorded. This permitted the number of times a lamb fell sick (health category) to be calculated. Data were also collected on mortality of sheep over the whole study period by performing post-mortem examinations on dead animals and recording of pathological findings and causes of death.

A retrospective case-control study (paper II) was conducted on 6718 sheep of two breeds (2772 Horro and 3946 Menz) on risk factors for mortality associated with respiratory disease (MARD), based on data collected between October 1993 and December 1997. The number of animals in this study is higher than in Table 1 due to the inclusion of the whole station flock (i.e. the main experimental flock and the multiplication flock). The multiplication flock received anthelmintics on a regular pre-planned strategic de-worming schedule as opposed to animals in the study examining genetic resistance to nematode parasites in the two breeds, which were treated based on worm eggs per gram (EPG) counts (Rege *et al*., 2002).

For a study on profitability of anthelmintic treatment and supplementation (Paper VII), a total of 109 yearling lambs of indigenous Menz (*n*=40), 50% Awassi-Menz (*n*=38), and 75% Awassi-Menz (*n*=31) were purchased from the Debre Berhan ranch. The experiment was completely randomised with a 2×2×3 factorial, involving two nutrition levels (supplemented and non-supplemented), two anthelmintic treatment groups (treated and non-treated) and three genotypes (indigenous Menz, 50% Awassi × Menz, and 75% Awassi × 25% Menz crosses). The allocation of sheep to the 12 treatment combinations was made by blocking by initial weight within genotype. The experiment involved natural infection and a fairly strict monitoring regime. Data were collected during the experimental period for ten months from about one year of age. Feed intake (concentrate and hay), live weight, eggs per gram (EPG) of faeces, packed cell volume (PCV), wool weight, and adult worm burden were recorded. Data were collected on actual market input and output prices.

Respiratory disease outbreak investigations (Paper V and VI) were made in the Amed Guya and Debre Berhan sheep breeding ranches. The initial study (Paper V) investigated causes of an outbreak of respiratory disease complex (RDC) in Amed Guya sheep ranch. The outbreak of RDC occurred in the Amed Guya ranch in October 1998. All genotypes including the indigenous Menz, Awassi-Menz crosses and pure Awassi were affected and they were mostly older than 2 years. The affected sheep were isolated in a separate barn until they had been examined, so as to avoid dissemination. The outbreak was investigated systematically through clinical, serological, microbiological, post-mortem and histopathological examinations. The health and basic record books of the ranch were examined and

analysed for the occurrence of the disease, morbidity, mortality and culling rates. Serum was collected from 137 randomly selected sheep, and submitted to CIRAD-EMVT (France), a reference laboratory of Office International des Epizooties (OIE) and to the National Animal Health Research Centre (NAHRC) in Ethiopia. The serum samples were analysed using a PPR competitive enzyme-linked immunosorbent assay (ELISA) for antibody detection (Libeau *et al.*, 1995). In addition, the collected whole blood was cultured in tryptose agar and incubated at 37°C overnight for bacteriological investigation. Smears from the colonies were stained with Gram's stain and examined under oil immersion. Identification of bacteria was done by the method described by Merchant & Packer (1983). Samples of pneumonic lungs were collected during necropsy, fixed in buffered 10% formalin, embedded in paraffin, sectioned at 4-5 µm, and stained with haematoxylin-eosin and Masson's trichrome techniques. The stained tissue sections were examined under a microscope for histopathological changes. Vaccination with a homologous PPR vaccine (National Veterinary Institute, Ethiopia) as means of control was applied by vaccinating three quarters (*n* = 2409) of sheep and leaving a quarter (*n* = 764) of them as unvaccinated control but both groups were drenched with levamizole-HCl and oxyclozanide (Levafas; Norbrook Laboratories Ltd, Kenya) against internal parasites.

A follow-up study (Paper VI) investigated the presence of antibody against maedi-visna (MV) virus in Amed Guya and Debre Berhan sheep ranches. Antibody against MV virus was assessed by collecting serum samples from 105 of the 200 sheep examined in the sick bay. Samples were also collected from 48 indigenous sheep from Debre Zeit (45 km south-east of Addis Ababa) and 70 goats from Adami-Tulu (165 km south of Addis Ababa) to check whether the disease is introduced or endemic to Ethiopia. The serum samples were analysed by the Agar-Gel Immuno-Diffusion (AGID Test Kit, VMRD, Veterinary Medical Research and Development, Inc. Pullman WA, USA). Effects of breed, sex, age, and location (seroprevalence of MV in the central highlands vs. two other regions) were assessed. In addition association of MV with clinical mastitis was also investigated.

Data analyses

The fixed effects, random effects, and covariates analysed in different studies are summarised in Table 2. For the study in paper II, the RISK, coded as 1 (death due MARD) and 0 (for live or dead due to other causes), was defined as the risk of MARD in any one month. For the Linear Model (LM) (paper IV), lamb survival was defined as a binary trait measured at weaning for pre-weaning (SURV1), at yearling for post-weaning (SURV2), birth to yearling (SURVT), and from birth until the animal left the station for survival from respiratory diseases (SURVRD). For the Survival Analysis (SA), the trait was defined as time (days) to respective periods (mentioned above for LM) for lamb surviving (right censored) and time to death (uncensored). Data analysis procedures applied and software used for various studies are presented in Table 3.

Table 2. Summary of fixed effects, random effects and covariates fitted in the models applied in the various papers

Paper	Traits	Fixed effects	Random effects	Linear covariates
I	BWT, WWT, ADG1, Pre- and post-weaning mortalities, causes	Breed, parity, season, year, lamb sex & litter size (BWT class, health category)*	Sire within breed	Birth date (for BWT); Age (for WWT)
II	RISK from MARD	Breed, sex, age, month		
III	BWT, WWT, YWT, ADG1 & ADG2	Breed, parity, season, year, lamb sex, litter size	Sire within breed	Age
IV	SURV1, SURV2, SURVT, SURVRD, BWT, WWT & YWT	Breed, parity, season, year, lamb sex, litter size	Sire within breed	
V, VI	Epidemiological rates	Breed, sex, age, health category and location		
VII	Feed intake, faecal output, weight gain, wool yield, marginal cost, marginal revenue, marginal profit	Genotype, anthelmintic treatments, supplementation, sex	Animal	Age

ADG1 = pre-weaning average daily weight gain; ADG2 = post-weaning average daily weight gain; BWT = Birth weight; WWT = weaning weight; YWT = yearling weight; SURV1 = pre-weaning survival; SURV2 = post-weaning survival; SURVT = survival from birth to yearling; SURVRD = survival from respiratory diseases
* BWT class and health category as fixed effect were used only when pre- and post-weaning mortality rates are analysed as response variables.

Table 3. Summary of software and procedures used for main statistical, genetic and economic analyses

Paper	Data analyses / procedures	Software used
I, II	PROC MIXED, quasi-log Linear Models, PROC LOGISTIC, PROC REG	SAS
III	PROC GLM, Genetic analysis (Univariate & Multivariate)	SAS, DfREML
IV	LIFETEST (Kaplan-Meier), Genetic analysis (compared Linear Mixed Models & Survival Analysis)	SAS, DfREML Version 3.0, Survival Kit V3.12
V, VI	PROC MEANS, PROC FREQ (CHISQ option)	SAS
VII	PROC MIXED (Partial budget analysis)	SAS

For the study in paper III, 12 models formed with inclusion or omission of maternal genetic, permanent environmental and common (litter) environmental variance components and the covariance between the direct and maternal additive effect on the basic additive genetic model, were used. Details of statistical assumptions and analysis can be found in the respective papers (Papers I–VII).

Main Findings

Growth

Effects of breed, lamb sex, season of birth, year of birth, litter size, and dam parity on weights at birth (BWT), weaning (WWT) and yearling (YWT), and pre- and post-weaning average daily gains (ADG1, ADG2) were studied (Papers I & III). Horro lambs were heavier than Menz lambs at birth (2.40 vs. 2.06 kg), at weaning (9.48 vs. 8.64 kg) and at yearling (19.0 vs. 17.1 kg) and therefore had faster pre-weaning (78.0 vs. 72.6 g per day) and post-weaning (31.0 vs. 29.1 g per day) growth. BWT increased significantly ($P<0.001$) from the first to third parity (2.0, 2.3 and 2.5 kg, respectively), was higher for lambs born as singles than as multiples (2.6 vs. 2.0 kg, $P<0.001$) and was heavier for male than for female lambs (2.3 vs. 2.2 kg, $P<0.001$). BWT was higher for lambs born in the wet than in the dry season (2.5 vs. 2.1 kg, $P<0.05$).

Factors that significantly influenced BWT were also found to affect ADG1 and WWT. In particular, lambs born in the wet season grew faster than their contemporaries born in the dry period (74 vs. 54 g per day, $P<0.001$) and they also had heavier WWT (9.4 vs. 7.9 kg, $P<0.001$). There was a breed × season interaction for ADG1 and WWT ($P<0.001$), the ADG1 differences for Horro lambs born in the wet compared to the dry interval being greater (80 vs. 54 g per day) than for the Menz (68 vs. 54 g per day) breed. Similarly, the difference in WWT for Horro lambs born in the wet relative to the dry season was about twice as large (10.7 vs. 8.1 kg) as that observed for Menz sheep (9.1 vs. 7.7 kg).

Within breed, sires were a significant source of variation for BWT ($P<0.001$), WWT and ADG1 ($P<0.01$) in both breeds, YWT ($P<0.001$) in Menz and ADG2 ($P<0.05$) in the Horro breed (Figure 7). For example, progenies of best and worst sired (upper and lower Quartile) Horro lambs had 2.44 vs. 2.29 kg BWT, 10.31 vs. 9.69 kg WWT and 83.3 vs. 76.5 g/day ADG1. The corresponding figures for best and worst sired Menz lambs had 2.14 vs. 1.99 kg BWT, 9.51 vs. 8.81 kg WWT and 76.7 vs. 69.9 g/day ADG1.

At the beginning of the study (Paper VII) on profitability of anthelmintics treatment and supplementation, the 75% Awassi × Menz were significantly ($P<0.0001$) heavier by at least 31% than the 50% Awassi × Menz and indigenous Menz sheep. During the experimental period, however, the 50% Awassi × Menz had higher weight gain ($P=0.07$) than the indigenous Menz and 75% Awassi × Menz genotypes.
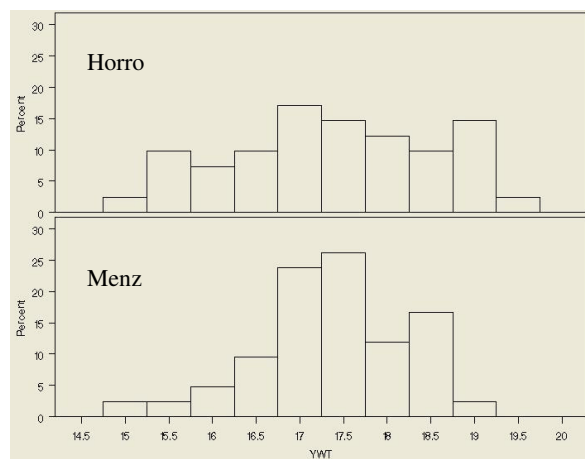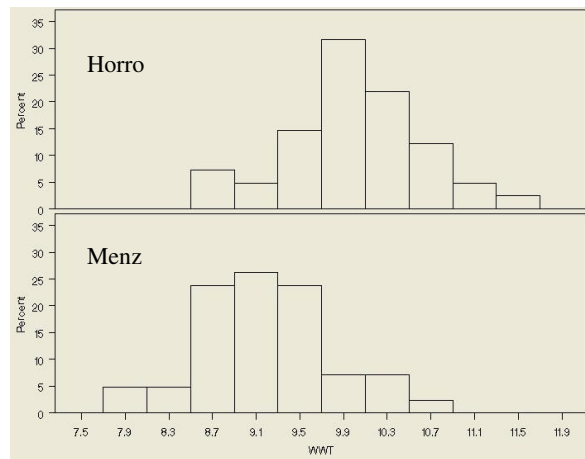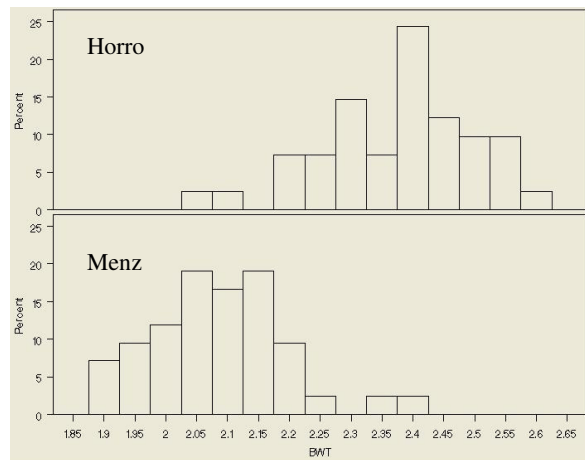
Figure 7. Sires within breed distribution (percent) for average progeny weight at birth (BWT), weaning (WWT) and yearling (YWT) in the Horro and Menz breeds

Overall, response to feed supplementation as reflected in weight gain was significantly ($P<0.001$) variable and largest in the crossbred genotypes. Anthelmintic treated lambs (Paper VII) gained more weight ($P<0.0001$) compared to their non-treated contemporaries.

Genetic parameters of lamb growth

Results of univariate genetic analyses in the Horro and Menz breeds compared twelve models (Paper III). These were formed with inclusion or omission of maternal genetic, permanent environmental and common (litter) environmental variance components and the covariance between the direct and maternal additive effects on the basic additive genetic model. The maternal genetic components were important for BWT, WWT and ADG1. The contribution of the permanent environmental component in the model was also substantial but less important than the common (litter) environmental component. Total heritability estimates for Menz and Horro were generally moderate or on the low side at 0.22 vs. 0.26 for BWT, 0.15 vs. 0.12 for WWT, 0.21 vs. 0.04 for YWT, 0.14 vs. 0.11 for ADG1, and 0.11 vs. 0.11 for ADG2.

Results from multivariate analyses revealed that direct genetic correlations were moderate to high and positive among most growth traits in the Menz breed ranging from 0.48 to 0.99 except among BWT & ADG1, BWT & ADG2, and WWT & ADG2 due to large standard errors. The estimates for Horro breed suffered high standard errors and were largely non significant. Maternal genetic correlations were moderate to high and positive among all growth traits in the Menz breed ranging from 0.32 to 0.96. The maternal genetic correlations among growth traits for Horro breed were also significant and high (range = 0.87 to 0.99) although they in some traits had high standard errors and hence were non-significant.

Lamb survival

Results of preliminary analysis on lamb survival (Paper I) indicated that the overall flock pre- and post-weaning mortality averaged 20 and 24%, respectively, leading to a flock mortality rate of 44% (including 1.6% stillbirths) up to 1 year of age. Mortality rate was influenced by many factors whose importance varied with lamb age. The pre- and post-weaning death rates (Paper I) were 25.3 and 34.2%, respectively, for Horro in contrast to 8.8 and 19.3% for Menz sheep. As a consequence, mortality up to 1 year of age was about twice as high for Horro than Menz lambs (59 vs. 28%, respectively).

In the final analysis when all lambs were included in the analyses (Paper IV), the pre- and post-weaning mortalities were 33.1% and 54.5% for the Horro and 19.2% and 25.9% for the Menz sheep. Consequently, mortality up to yearling (Figure 8) was more than twice as high for Horro than for Menz lambs (69.6 vs. 30.2%). The trend of proportional hazard (Paper IV) revealed two critical age periods for mortality (especially for the Horro lambs), the first 3 to 4 weeks and the other 4 to 7 months of age, the latter hazard follows weaning at about 3 months.
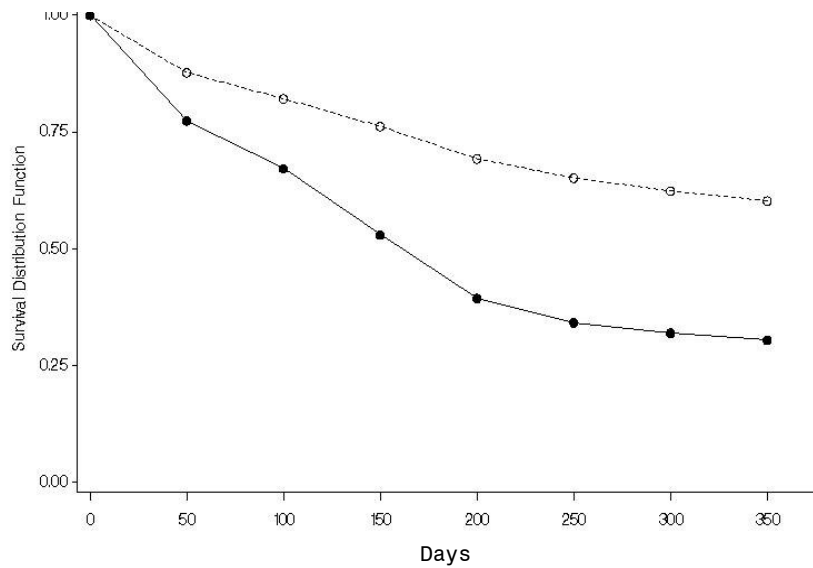
Figure 8. Survivor curves from birth to yearling (SURVT) for the Horro (solid line) and Menz (dotted line) – survival is plotted against time (days)

The effect of sex was significant for SURVT and SURVRD; females survived better than males in both cases ($P<0.001$) particularly during the perinatal period and after the age of 6 months. As expected, lambs born to first parity ewes (maiden) had significantly lower SURVT than lambs born to higher parities in both breeds. Single-born lambs had consistently higher survival at all stages than lambs born as multiples. In both breeds, lambs that were born during the dry seasons had lower SURV1 and SURVRD than those lambs born during the wet seasons. For SURVT, the Horro lambs that were born during dry season had significantly lower survival than those born during the wet season, whereas there was no significant season difference for SURVT in the Menz lambs. There was a tendency of increasing risk over the years studied.

Relationship between BWT category and SURVT is presented by breed in Figure 9. There was a positive relationship between BWT and lamb survival within breed at all ages ($P<0.001$). Survival for lambs born light (<2 kg BWT) was lower at least by 13% in Horro and 17% in Menz lambs than those with medium BWT (2–3 kg BWT). Likewise, survival in lambs with medium BWT was lower by 10-20% in the Horro and 10% in the Menz lambs than heavy lambs at birth (3 kg BWT or more).

Genetic parameters of lamb survival

Sires were a significant source of variation (Paper I) for lamb mortality at 6, 9 and 12 months ($P<0.05$–0.001) but not earlier ($P>0.05$). The best and worst Horro ram sired progeny groups had mortality rates up to 1 year of age of 22 vs. 80%, respectively. The corresponding estimates in Menz ram sired progeny groups were 11 and 48%, respectively.
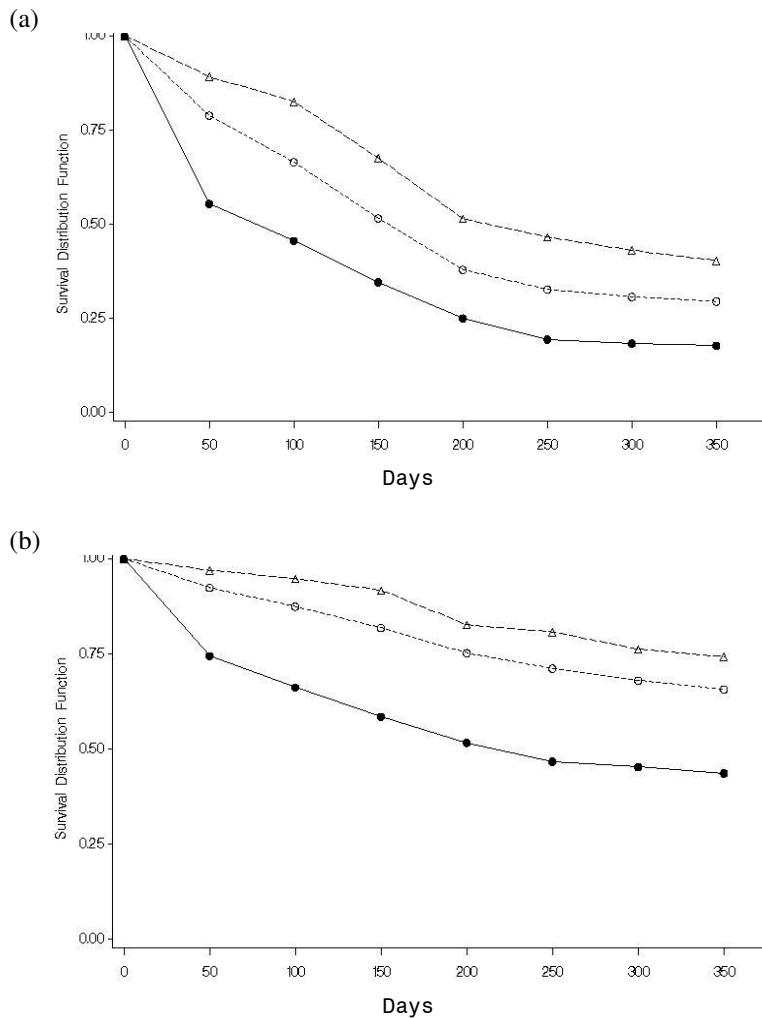
34

(a)

(b)

Figure 9. Survivor curves for SURVT by BWT class for Horro (a) and Menz (b) *Solid line* is for BWT class 1 (i.e. <2kg or light); *dotted line with circle* is for BWT class 2, (i.e. 2–3 kg or medium); and *dotted line with triangle* is for BWT class 3 (i.e. >3kg or heavy).

Heritability estimates from the univariate analyses of Linear Model (LM) for lamb survival ranged from 0.5 to 5.6% (Paper IV). Model comparisons among animal models with and without maternal genetic effect in a univariate LM revealed that the maternal genetic component is important for lamb survival and ignoring it can inflate the direct heritability estimates. Estimates of the direct heritability for SURV1 with bivariate analyses ranged from 3 to 4% in both breeds. The heritability estimates from the bivariate analyses were closer to those from the Survival Analysis (with the exception of the high estimate for SURV2 in Horro from Survival Analysis). Maternal heritabilities from the bivariate analyses for survival traits ranged from 2 to 7%, the higher values (6-7%) for SURV1 for both breeds.

35

The heritability estimates from Survival Analysis (SA) ranged from 0.3 to 18.5%. Comparison of the LM and SA methods revealed that accuracies of breeding values were higher for the traits analysed with SA (0.19 to 0.80) than with LM (0.28 to 0.60). The differences between estimates from the two methods were greater for survival in older ages.

Genetic correlation estimates (Paper IV) had large standard errors, and only some of maternal correlations were significantly different from zero. Maternal genetic correlations among survival and growth traits were significant ranging from 0.38 between SURV1 and BWT to 0.72 between SURVT and WWT for the Menz breed. Likewise, the maternal genetic correlations among survival and growth traits for Horro breed ranged from 0.49 between SURV1 and BWT to 0.77 between SURVT and WWT. Phenotypic correlations were also significant for the Menz breed: those lambs that were heavy at birth also had higher SURV1 and SURVT (phenotypic correlations were 0.23 and 0.19, respectively). The phenotypic correlation was 0.19 between SURV1 and BWT and 0.20 between SURVT and WWT for the Horro breed.

Causes of mortality

In the preliminary analysis based on post-mortem examinations (Paper I), pneumonia was the most widespread cause of mortality. More than half of the deaths in Horro and Menz lambs were attributed to pneumonia (53.4 vs. 54.2%, respectively). Other causes of mortality for Horro and Menz were digestive and gastro-intestinal problems (14.4 vs. 11.5%), endoparasitism (8.7 vs. 13.1%), the SME complex (9.7 vs. 7.3%), septicaemia (3.4 vs. 1.6%), stillbirths (2.5 vs. 5.6%) and undetermined causes (6.6 vs. 5.1%). Endoparasite infections as a cause of mortality were of limited importance in both breeds and were primarily confined to infections from tapeworms (*Moniezia spp.*) in very young lambs, and liver flukes (*Fasciola hepatica*) and verminous pneumonia (*Dictyocaulus filaria*) in older lambs.

Risk factors for major causes of mortality

Odds ratios (Paper I) indicated that Horro lambs had a greater risk of dying of any cause than Menz lambs. Birth weight was also a major risk factor for pre-weaning mortality (Figure 9). In comparison to heavy weight lambs, lambs born light had a bigger risk of dying from SME/malnutrition, endoparasitism or septicaemia. This was in agreement with the observation that lambs born multiple and/or lambs born lighter were also more likely to die of any cause than single-born lambs except those suffering from septicaemia. Likewise, lambs born in the dry season were more likely to die from the SME complex, endoparasitism and septicaemia than contemporaries born in the wet period. In addition, males had a bigger risk of succumbing to the SME complex, respiratory and endoparasitic ailments than females.

In the final analysis for pneumonia (Paper II), MARD accounted for 54.4% of total deaths. Annual MARD rate was 14.4 ranging between 6.3 and 19.0%. MARD (%) was high between October and March whereas relatively low between April and September with a pattern of U-shape, high levels in the early part of the year, a

36

substantial reduction between the months of April and September followed by another steep increase in the last third of the year. The Horro breed had higher overall annual MARD than the Menz breed (16.5% vs. 12.4%). Similarly they had higher monthly MARD than the Menz sheep. Males had higher annual MARD than females (15.1% vs. 13.8%). Age was also an important risk factor for MARD: there was a strong polynomial relationship between MARD and age; the risk was high if a sheep was young. Air temperature was an important factor for MARD and a negative correlation (r = –0.59, $P<0.01$) between average monthly MARD and monthly average minimum air temperature with a cubic relationship, the quadratic component having a negative slope. In addition, a strong positive exponential relationship between average monthly MARD and monthly average daily deviation of minimum temperature from maximum temperature with a strong positive correlation (r = 0.69, $P<0.001$).

Causes of respiratory disease outbreak

Estimated rates for RDC outbreak (Paper V) were 2.8 to 4.0% for incidence, 17% for prevalence, and 18% for case fatality rates despite the culling of pneumonic sheep. In addition, 49% of the morbidity and 36% of the mortality in the study period was due to RDC and affected animals were mostly adults (older than 2 years). Menz sheep were more susceptible to RDC than the Awassi-Menz crosses. Age was also a significant source of variation in mortality. Adult and weaner Menz had higher morbidity and mortality than the crosses, while the lambs of the crosses had a higher mortality than the Menz lambs in the same age group. Causes of mortality in this young group were poorly documented at the ranch. Major clinical signs of RDC were dyspnoea, polypnoea, fever, dry coughing and progressive emaciation. Grossly lungs were greatly enlarged, attached to the parietal pleura, and firm to very firm in consistency with greyish raised foci of gland-like consolidation with hepatisation (red-and grey). Mediastinal and peri-bronchial lymph nodes were also enlarged. Microscopic lesions revealed maedi-visna like lesions, with or without a verminous- or broncho-pneumonia complex. Serological examinations revealed that 72.3% of the examined animals were positive for antibody against the PPR virus. Bacteriological examinations revealed *Streptococcal spp*. and *Staphylococcal spp*. and fungi to have played some role.

A follow-up study (Paper VI) on affected sheep of the Amed Guya and Debre Berhan ranches indicated that 74% (148/200) of the sheep examined had signs of respiratory embarrassment and serological analysis for maedi-visna antibody revealed that 74% (78/105) of sheep tested for maedi-visna were positive. Maedi-visna prevalence varied from 48% in Awassi sheep to 92% in Menz sheep with a significant genotype difference (*P*<0.001). There was no significant difference in infection-prevalence between sheep from Amed-Guya (70%) and Debre-Berhan (76%) sheep ranches. None of the 48 sheep examined from Debre-Zeit, and the 70 goats from the Rift Valley was positive for the infection.

Profitability of anthelmintic treatment and supplementation

Profitability of anthelmintic treatment and supplementation using partial budgeting in the indigenous Menz and Awassi-Menz crossbred sheep genotypes was studied

in Paper VII. The supplemented lambs had higher marginal profit (MP) per sheep than the non-supplemented sheep (ETB = 32.86 vs. 4.49, $P<0.0001$). Likewise, anthelmintic treated sheep performed significantly better than their non-treated contemporaries (MP = ETB 29.34 vs. 8.02, $P<0.01$). The indigenous Menz and 50% Awassi × Menz crosses were significantly ($P<0.01$) more profitable during the experimental period than the 75% Awassi × Menz crosses. This was due to higher weight gain per unit of input of the indigenous Menz and 50% Awassi × Menz crosses than the 75% Awassi × Menz crosses during this period. Ranking of genotypes changed with age due to high initial weight of the 75% Awassi × Menz crosses, and whether skin value was accounted for or not.

General discussion

Materials and methods used

One flock – many experiments

In sub-Saharan Africa livestock data recording is rare, making livestock improvement difficult. In the present study it was possible to maximise the use of information generated from the Menz and Horro breeds that were maintained at the ILRI Debre Berhan Research Station. The major experiment, which looked into genetic resistance to gastro-intestinal nematode parasites among and within the two breeds, was part of a Pan-African research programme in sheep and goats (Baker *et al*., 1998; Rege *et al*., 2002). Age at puberty for ram and ewe lambs (Rege *et al*., 2000; Toe *et al*., 2000) and adult ewe reproductive performances were studied from the same flock (Mukasa-Mugerwa *et al*., 2002). When ram lambs attained one year, they exited the major study and were used for fat-deposition studies (Awgichew, 2000; Ermias *et al*., 2002; 2006; Ermias and Rege, 2003). At ILRI Debre Berhan Research Station, recording was excellent. The pedigree was particularly deep for the Menz breed which had been maintained on station for a long period prior to the initiation of the main project in 1992. The data used in this thesis from this flock (Papers I–IV) was therefore perfectly suitable for the analysed traits.

Mixed linear models for growth and economic analyses

The mixed linear models (PROC MIXED of SAS) that fit the fixed and random effects had an advantage over the generalised linear models (GLM) as it accounts for random effects in addition to fixed effects (SAS, 1996). In mixed models repeated measurements, which refer to data sets with multiple measurements of a response variable on the same experimental unit, can also be included. The MIXED procedure of SAS provides a number of covariance types from which to select. The covariance structure selected in the present analyses was "unstructured". That is, no mathematical pattern was imposed on the covariance matrix. The decision process in choosing the covariance structure can be assisted by using two model-fit criteria computed by PROC MIXED, Akaike's Information

Criterion (AIC) and Schwarz' Bayesian Criterion (SBC). These are essentially log-likelihood values penalised for the number of parameters estimated (SAS, 1996). The covariance structure with values of the criteria closest to zero was considered most desirable.

Partial budget analysis (Paper VII) is the method employed to analyse gains and losses due to a relatively minor change (marginal) in farming technology (Ehui and Rey, 1992). That means, partial budgets consider only those items of income and expenses that change. Anthelmintic treatment, supplementation as well as crossbreeding were considered as changes in technology. Crossbreeding was included since it had substantial and negative impact on skin value. Partial budgets should measure change in income and returns to limited resources, provide a limited assessment of risk and suggest a range of price or costs at which a technology is profitable. The advantage of the method is that less data is required than whole-farm budgeting since fixed costs are not determined, which allows early conclusions about the adaptability of a new technology. However, this method has limitations due to the risk associated with neglecting farmers' limited resources and knowledge about resource base may be lacking. In the present experiment, however, these pit-falls have largely been considered. Analysis was made on individual animal basis using the mixed Linear Model procedures (SAS, 1996). One limitation in the present study was lack of life-time growth and health data to arrive at final conclusion on genotype choice.

Models for genetic analysis of growth traits

Among the 12 models used, best model was chosen based on results of log-likelihood ratio tests (Swalve 1993; Meyer 1997). A random effect was considered significant when its inclusion in the model caused a significant increase in the log-likelihood as ascertained by chi-square test at $\alpha = 0.05$ and one degree of freedom.

Several studies (e.g. Cloete *et al.*, 2001; Maniatis & Pollott, 2002) confirmed that the including of maternal genetic variance, permanent environmental variance and direct-maternal genetic covariance would improve the fit of models for growth performance in sheep. However, due to low twinning rates in many sheep breeds and analytical problems that might arise when maternal genetic, permanent environmental and common environmental (litter) effects are fitted simultaneously, there are few reports that have considered the importance of the litter variance in model choice. Improved fit of analytical models by the inclusion of a common environmental (litter) component (fitted with other components) has been reported recently for Horro sheep from Ethiopia (Abegaz *et al.*, 2005) and elsewhere (Saatci *et al.*, 1999; Van Wyk *et al.*, 2003). The twinning rate of sheep from those studies was greater than 30% and it was recommended that common environmental (litter) effect could be significant for incidence of twinning rate as low as slightly above 30% (Abegaz *et al.*, 2005). In the present study, however, much lower twining rate (Mukasa-Mugerwa *et al.*, 2002) was found to be significant for the common environmental (litter) effect in the Menz and Horro breeds, which is an important finding.

Mixed Linear Models versus Survival Analysis of lamb survival

Survival in livestock has often been analysed as binary trait (0/1 for alive or dead) at arbitrarily defined time points. It is also generally accepted that the overall mortality to specific time points could reliably be analysed using Linear Models (Nguti, 2003). Notwithstanding, an important finding of the present study is that Survival Analysis proved to be superior to Linear Models even in cases where survival is analysed at arbitrarily defined time point improving accuracy of breeding values. This was because censored and uncensored observations are combined in a single analysis, which allowed inclusion of the actual failure time. Yazdi *et al*. (2002) found loss of information when failure time was analysed through a logistic rather than a Survival Analysis approach. Another major advantage of the Survival Analysis approach over that of Linear Model is the ability to incorporate covariates that vary with time such as body weight. In fact, it was possible to clearly see within breed variations in survival among different birth-weight classes.

Parameter estimates from two-trait survival and birth weight analyses are rare in the literature. The analytical problem notwithstanding, the analysis of survival with birth weight is likely to benefit in terms of improved accuracy, even when both were analyzed using linear method for observed data. Ramirez-Valverde *et al*. (2001) showed that a higher increase in accuracy of prediction can be obtained in multiple trait models with respect to single trait models than with threshold over Linear Models. Additionally Varona *et al*. (1999) suggested that predictive ability for a categorical trait could be improved by a bivariate analysis with a continuous trait.

Limitations of Survival Analysis are difficulty of handling continuous traits (e.g. production traits) in a multiple trait analysis for correlations (e.g. with the survival traits) and difficulty of including maternal effects in the analysis. The Linear Models allow inclusion of animal in both the univariate and bivariate analyses. Indeed, the estimates with the bivariate analysis of Linear Model for survival trait were close to the estimates with the Survival Analysis. In an attempt to overcome this problem of Survival Analysis, Damgaard (2005) managed to show that it is possible to analyse a normally distributed continuous trait or a threshold trait using a Bayesian approach and applying Gibbs sampling. For large scale applications, approximations have been proposed (Tarrés *et al*., 2006).

Variation in lamb growth and possibilities for improvement

Genetic factors

Live weight and growth rate are economically critical features, requiring particular attention in any breeding programme intended to improve overall productivity since lambs are mainly raised for mutton. The higher weights and growth rates of the Horro at all ages compared to the Menz breed is consistent with previous reports from Debre Berhan (Gautsch, 1992) and other results from the same station (Rege *et al*., 2002). The Horro sheep were able to express their growth potential regardless of their ill-adaptation to the climatic stressors and health challenges (e.g.

cold, pneumonia) of the experimental area for which the Menz breed is native. Compared to its performance at ILRI Debre Berhan station, the Horro breed performed well on a research station near its original homeland (Abegaz *et al*., 2002a). This suggests a possible genotype × environment interaction. In this study, however, we did not investigate this since different experimental design is needed in which offsprings of the same sires in the two locations should be evaluated.

Compared to growth rates of indigenous Adal and Blackhead Ogaden sheep (Galal, 1983) of Ethiopia, the two indigenous Horro and Menz breeds from this location had relatively slow growth rate. This could partly be due to their genetic make up, high disease challenge (e.g. pneumonia), level of nutrition both in quality and quantity, and other factors. Notwithstanding, the present study has revealed that there is untapped genetic potential among and within the Horro and Menz indigenous breeds for growth (Papers I & III). Particularly, sires within breed were a significant source of variation for growth traits (Figure 7). This is an important finding because it revealed the possibilities for improvement of growth through selection within breed.

In the study on profitability in Paper VII, different growth patterns between the genotypes were observed and ranking of genotypes in weight gain changed with age. At the start of the experiment, the indigenous Menz sheep were inferior to the 75% Awassi-Menz in live body weight (16.6 vs. 23.5 kg). During the 10 months experiment, however, the indigenous Menz had about the same (or slightly higher) growth rate as the 75% Awassi-Menz. But both genotypes had lower growth rate than the 50% Awassi-Menz. This variation is important for economic reasons because the 75% Awassi-Menz had already attained the marketing weight of Menz sheep at the start of the experiment. That could mean that keeping 75% Awassi-Menz longer than a year can be costly compared to other genotypes, reducing profit. Instead this cross could have been marketed much earlier than indigenous Menz. Information on costs of production from birth to one year, including figures on possible differences between the genotypes in fertility and mortality rate, however, is needed to draw clear conclusions on the final value of the different genotypes.

Genetic analyses (Paper III) revealed that total heritabilities for growth traits in the Horro and Menz breeds are in close agreement with weighted mean heritabilities in literature (Safari *et al*., 2005). The direct-maternal genetic correlations (0.25 to 0.99) for the Menz breed were moderate to very high and positive. This is in agreement with the findings by Safari *et al*. (2005) who reported positive direct-maternal genetic correlations at 0.37 for WWT and 0.74 for adult weight in wool sheep breeds. This indicates the absence of genetic antagonism either using sire-line or maternal-line selection for these growth traits. The negative direct-maternal genetic correlation of BWT (-0.29) and positive direct-maternal genetic correlation of WWT (0.27) for Horro are also in agreement with literature (Abegaz *et al*., 2002a; Safari *et al*., 2005).

Maternal genetic effects were significant for growth traits which indicate the need to consider it in genetic evaluations. Substantial inflation of the direct heritabilities was seen in growth traits in models that ignored maternal additive genetic, permanent and common environmental components. This is consistent

with literature reports (e.g. Torshizi *et al*. 1996; Näsholm & Danell 1996; Maniatis & Pollott 2002). The carry-over effect of the maternal genetic effect for growth traits up to one year of age (particularly for Menz breed) observed in the present study is in agreement with previous literature (Torshizi *et al*., 1996; Safari *et al*., 2005; Abegaz *et al*., 2005).

Permanent environmental effects were also significant for growth, which is in agreement with Matika *et al*. (2003) who reported the persistent permanent environmental effects up to the age of 12 months. Lewis & Beatson (1999) also reported the same effect as important between 8 and 12 months of age. The proportion of common (litter) environmental variance to the total variance for BWT and WWT from the present study is within the range of 0.04 to 0.44 in literature reports (Lewis & Beatson, 1999; Saatci *et al*., 1999). This effect of common environmental variance was more important than the permanent environmental effect.

The observed moderately high (0.48) to very high positive (0.99) genetic correlations among growth traits for the Menz breed are consistent with literature reports (Torshizi *et al*., 1996; Abegaz *et al*., 2002a, 2005). The strong positive genetic correlations among growth traits in the Menz breed indicate that selection for BWT should result in correlated improvement of WWT and YWT. The absence of genetic antagonisms among these traits for the Menz breed also suggests that none of the traits should be affected adversely through correlated responses. The estimates for Horro, however, suffered large standard errors and were non-significant. Estimation of maternal effects and associated genetic parameters is inherently problematic and, due to the confounding of direct and maternal effects, subject to large sampling errors (Meyer 1997). Estimation of cross-correlations between the direct effect of a trait and maternal effect of another trait, which was not done in the present study, could also help in making appropriate decisions on genetic improvement.

Non-genetic factors

The higher growth rates at all ages of male lambs in comparison to female lambs is consistent with other reports in Ethiopia (Olsson & Beyene, 1990; Rege *et al*., 2002) and elsewhere in Africa (Yapi-Gnaoré *et al*., 1997). This could be due to hormonal differences in their endocrinological and physiological functions (Ebangi *et al*., 1996).

Single-born lambs were heavier at all ages and grew faster compared to multiples, which concurs with previous findings (e.g. Yapi-Gnaoré *et al*., 1997; Gbangboche *et al*., 2006). This could be due to the inability of ewes to provide sufficient nourishment for the development of foetuses and extra milk for lambs (Rajab *et al*., 1992) or competition for resources (reduced milk intake in smaller lambs, particularly litters with low birth weight in the cases of multiples) (Christley *et al*., 2003). Singletons are the sole users of their dams' milk and their higher weight advantage they had at birth favours their growth in subsequent periods.

That ewe parity affects BWT and subsequent growth rates of lambs with higher lamb weights with increasing parities also concurs with literature (Yapi-Gnaoré *et*

al., 1997; Gbangboche *et al*., 2006). Indeed, maiden ewes are still growing, therefore the competition between foetal growth and maternal growth could be an explanation for this phenomenon (London & Weniger, 1996). In addition, the reproductive organs of first parity ewes are also less developed to bear large foetus in which case the physiology adjusts the foetal size.

The higher growth rate for lambs born in the wet season than in the dry seasons could be due to seasonal variation in feed availability both in quality and quantity since the lambs largely depend on natural pasture. Similar observations were also made from the same station (Mukasa-Mugerwa *et al*., 1994; Rege *et al*., 2002) and elsewhere in Ethiopia (Hassen *et al*., 2002; Abegaz *et al*., 2000). Different to the present results in West Africa, where humidity together with ambient temperature favours the development and survival of infective larvae of nematodes, a decreased growth rate of lambs during the wet season was reported (Gbangboche *et al*., 2006). Nematodes challenge in the highlands of Ethiopia was not so severe on the experimental station (Tembely *et al*., 1998), and the infective larvae are available on pasture for only eight weeks (Tembely, 1997). Thus, seasonal lambing could be used to better utilise the wet season births to improve the overall productivity.

The yearly variation in growth traits could partly be associated with the rainfall amount and distribution pattern which affects forage availability and quality. For example, year 1995 was the worst year hit by drought as opposed to 1992 and 1996, which are the best years at least for birth weight. Year 1992 was the best in all growth traits. Year 1996 was the wettest year in 30 years (Segele and Lamb, 2005) and resulting in better pasture availability.

That supplementation improved growth and profitability (Paper VII) was in agreement with the findings by Shapiro *et al*. (1994) who also studied Ethiopian highland sheep. Anthelmintic treatment also improved growth rate and profitability, but did not agree with results by Shapiro *et al*. (1994) who concluded that anthelmintic treatment did not improve weight gains, but added production costs, thus reducing profits. This could be due to lower levels of parasite challenge in the study by Shapiro *et al*. (1994) as opposed to the sub-clinical helminthosis challenge in present study.

Variation in lamb survival and possibilities for improvement

The first month of life was very critical for lamb survival (Paper I & IV) in both Menz and Horro breeds (Figure 8), which is in agreement with several studies (e.g. Yapi *et al*., 1992; Mukasa-Mugerwa *et al*., 1994; Malik *et al*., 1998). Lamb mortality up to 7 days accounted for 36% of the pre-weaning mortality and 17% of the annual losses in the Menz and Horro breeds. Peterson & Danell (1985) reported perinatal death of lambs to account for 12 to 20% of all deaths in Swedish sheep breeds. The finding that the risk of dying decreased with time (age) in the present study also concurs with literature (e.g. Petersson & Danell, 1985). The second critical period for lamb survival was between 4 and 7 months which follow a weaning stress that predisposes lambs to infections, when the immune system of the young animal is developing (e.g. Nguti *et al*., 2003).

Lamb birth weight was the single greatest factor influencing lamb survival (Figure 9). Lambs born light had low lamb survival as compared to lambs born with medium or higher birth weights. Several authors (e.g. Dalton *et al.*, 1980; Scales *et al.*, 1986; Ahmad *et al.*, 2000) have also demonstrated that increasing birth weight result in a decrease in mortalities but with an inverted U-shaped distribution of birth weight with survival. In the present study, however, birth weights on the higher end of the range are not detrimental to survival. Birth weight is influenced by ewe prenatal nutrition, litter size, placental size and foetal genotype (Haughey, 1993). Factors which contribute to low birth weight also tend to reduce foetal lipid reserves, limit neonatal vigour, impair colostrum production and restrict ewe milk production (Mellor & Murray, 1985a, b). Data on birth weight consistent with optimal lamb survival in tropical breeds are scarce. However, this information is vital to the design of strategies that are more appropriate for farmers who have a chronic shortage of supplementary feeds. These farmers need to know, for example, that indiscriminate supplementary feeding of ewes (the non-pregnant, the single- and twin-bearing ewes) is wasteful because they have varying needs.

Genetic factors

The Horro breed had invariably lower survival than the Menz breed at all ages. Similar observations were reported earlier (Gautsch, 1992; Rege *et al.*, 2002). However, Abegaz (2002) reported 80% SURV1 for the Horro breed at Bako Research Centre, which is located in Ethiopia closer to the centre of habitat of the breed. This supports the contention that introducing the breed to a higher altitude could be part of the reason for the observed breed difference in survival. This suggests a possible genotype × environment interaction. Breed variation when survival is considered as a trait of the lamb (e.g. Gama *et al.*, 1991; Matos *et al.*, 2000) and response to selection in rearing ability of ewes (Haughey, 1983; Cloete & Scholtz, 1998) has been reported.

An important finding of the present study was substantial within breed variation in lamb survival due to sires (Paper I). This is the first report showing such variation for sheep from tropical regions. The results suggested that lamb survival could be enhanced if this parameter was adequately stressed in sheep genetic improvement programmes. Knight *et al.* (1979) recorded 8 and 17% improvements in lamb survival rate for single- and twin-born lambs sired by high survival versus low survival Romney rams.

Breed differences in susceptibility to respiratory infections was documented in this study. The Horro sheep were more susceptible to pneumonia than the Menz sheep (Paper II). They were also more susceptible to *Mycoplasma mycoides* subspecies *mycoides* LC (large colony) than the Menz breed (Roger, 1996). The short hair coat of Horro sheep as compared to coarse wool in the Menz is a disadvantage in a relatively cold climate of the higher altitude of the study area, and this might have predisposed them to pneumonia. Nonetheless, the Menz sheep had higher infection rate for maedi-visna than the crosses or exotic Awassi genotypes (Paper V, VII). It appears that Menz sheep constitute a naïve population with respect to MV infection though this needs further investigation. Some breeds

44

may be more susceptible to MV infection than are others (De la Concha-Bermejillo, 1997). Breed differences for mortality associated with respiratory diseases have also been reported in studies elsewhere (e.g. Nash *et al*., 1997).

The heritability estimates ranging from 1.2% to 5.1% for lamb survival estimated with Linear Models are within the range of 0 to 15% estimates in literature (e.g. Lopez-Villalobos & Garrick, 1999; Morris *et al*., 2000; Abegaz, 2002). The present estimates are much closer to the weighted mean average heritability of 3% from 16 published studies (Safari *et al*., 2005). The heritability estimates of 0.3% to 18.5% for lamb survival with Survival Analysis were higher than estimates with Linear Models. Survival Analysis improved accuracy of breeding values, on average, by 17% though the method was no better than Linear Model for pre-weaning survival owing to low number of uncensored records. Based on the increased accuracies, a gain in genetic progress would be expected by analysing lamb survival with Survival Analysis instead of Linear Models for post-weaning survivals. To the knowledge of the author, so far there has been no study where Survival Analysis has been used to estimate the heritability of lamb survival. Nguti *et al* (2003) reported greater variability when using the Survival Analysis but could not estimate heritability due to computational constraints.

The maternal genetic component was important for lamb survival. Indeed, the maternal heritability for lamb survival was as large as or larger than the direct heritability. Safari *et al*. (2005) analysing published literature, have reported similar observations. This indicated the need to include maternal components in genetic analysis of lamb survival.

Estimates of additive genetic correlations among survival and growth traits were all non-significant due to large standard errors; no genetic antagonism was encountered though. Abegaz & van Wyk (2002) reported high genetic correlation (0.64) between pre-weaning survival and birth weight. Selection can be applied for traits which have a higher heritability and at the same time have a high correlation with the traits of interest as a means to overcome low heritability constraint of the other. Birth weight was found to have a strong relationship with survival, though both low and high extremes of birth weight are reported to reduce survival (Knight *et al*., 1988; Christley *et al*., 2003). In the Menz and Horro sheep, it appears, however, that birth weights on the higher end of the range were not detrimental to survival (Figure 9). Similar observations were made by Abegaz (2002) for the Horro breed. Therefore, selection for increased birth weight should result in a correlated increase in lamb survival in these breeds.

Other means for improving survival could be using indirect selection on ewes' multiple-rearing ability (Cloete & Scholtz, 1998). In the present study, we found that mothers that gave high birth weight in their lambs also had higher survival of lambs indicating that selection using a maternal line could be a possibility since the maternal effects on weights of lambs at birth and weaning were also significantly positively related to maternal effects on SURVT.

Non-genetic factors

Sex differences in lamb survival observed in the present study concur with literature (Mukasa-Mugerwa *et al*., 1994; Malik *et al*., 1998). Lower survival in male lambs than in females could be associated partly with hormone effects on immune function. This was demonstrated by Schuurs & Verhuel (1990) that castrated males had similar risk with females and lesser risk compared to non-castrated males. Differences among sexes could also be behavioural if ewe lambs had increased access to colostrums or attention from dam, giving ram lambs a disadvantage when exposed to pathogens (Nash *et al*., 1997). Norwak (1990) reported, in twin-born lambs, that dam recognition ability of female lambs was superior to their male counterparts after separation. Dwyer (2003) found out that male lambs were slower to stand and suck than female lambs in Suffolk sheep breed, but not in Blackface breed. Therefore, some level of preferential treatment in favour of male lambs may be necessary to improve perinatal survival. That males were more susceptible to pneumonia than females (OR = 1.09 to 1.32) is consistent with findings by Nash *et al*. (1997) who reported higher OR at 1.9 for male vs. female.

Higher survival in single-born lambs compared to multiples observed in the present study is in agreement with previous findings (Yapi *et al*., 1992; Mukasa-Mugerwa *et al*., 1994; Malik *et al*., 1998). Multiple-born lambs had reduced viability compared to singletons in many studies as reviewed by Dawyer (2003). Multiple-born lambs were more susceptible to pneumonia than single-born lambs (OR = 1.48). Therefore, improving nutritional conditions of the pregnant ewe and thereby increasing birth weight could be an effective means to improve survival of multiple born lambs in difficult tropical environments.

Dam parity is also another important non-genetic factor for lamb survival (Paper I & IV). In the present study lambs born to maiden ewes had significantly lower survival than lambs from higher dam parities. Similar observations were reported in literature (Dalton *et al*., 1980; Morris *et al*., 2000; Dawyer, 2003). Fostering this vulnerable group during the first few days of life may improve survival.

Season of birth (Paper IV) was an important factor affecting pre-weaning survival and survival from respiratory diseases (in both breeds) and overall survival (in Horro breed). Lambs born during the wet seasons had higher survival compared to those born during dry seasons, which is consistent with literature (Wilson *et al*., 1985; Njau *et al*., 1988a). During dry season, grazing is depleted and pregnant ewes may not get enough nutrients which resulted in reduced weight of lambs at birth. Reduced availability of forage can also have effect on colostrums and milk yield by the dam after delivery reducing lamb viability and survival. Supplementing ewes during dry season could increase lamb survival which eventually mean that less number of ewes may be required to produce the same number or higher number of marketed lambs. The implication of this on land use and natural resource management would be enormous.

Dry season is also characterised by low ambient temperature and had significant association with mortality associated with respiratory diseases (MARD). Particularly, MARD was higher between October and March owing to the high

46

number of cases of pneumonia in the dry season (Paper II). In particular, the high MARD in the two months of the short rainy season (February and March) mirrors the high number of cases in late dry season, which subsequently died in these months after protracted clinical course of pneumonia. In addition, the beginning of the short rainy season (February/March) coincides with inadequacy of grazing, which may predispose animals to infections. Lambs were not supplemented until weaning except that they shared what was provided for their dams. This, plus the fact that supplementation regime of dams was not strictly linked to quantitative assessment of nutrition available from pasture, may have inadvertently subjected lambs to undernutrition, thus predisposing them to pneumonia. Strategic feed supplementation and improving housing (e.g. providing beddings) may reduce lamb mortality in dry cold months.

The effect of year on mortality was also noted in this study and there was a tendency of increasing risk over the study period. This could be partly due to build-up of respiratory diseases (the single most important cause of mortality) in the station flock (Paper II). Another reason could be the annual variations in climatic conditions and the availability of feeds in different years. For example, rainfall amount and distribution among years can seriously affect quality and quantity of pasture available to the lambs. Bunge *et al*. (1993) also reported year of lambing as an important source variation for lamb survival.

Causes of mortality

Respiratory diseases have been the single most important cause of mortality in all sheep breeds studied (Papers I, II, V, VI). The aetiologies involved as observed in this study (Papers V & VI) and other reports (e.g. Bekele *et al*., 1992a, b; Roger, 1996; Ayelet *et al*., 2004) were multi-factorial. These are bacterial (*Pasteurella multocida*, *P. hepatica*, *Streptococcus aureus*, *Staphylococcus spp*., *Corynebacterium pyogens*), mycoplasmal (*Mycoplasma mycoides* subsp *mycoides* LC, *Mycoplasma ovipneumoniae*, *Mycoplasma agalactiae, Mycoplasma arginini*), viral (*Peste des Petits Ruminants* – PPR, Parainfluenza-3 virus, Maedi-visna (MV) virus; Border-disease virus, Adenovirus) and parasitic (*Dictyocaulus filaria*, *Mullerius capillaries* and *Protostrongylus rufescens*). PPR virus has been demonstrated in pneumopathies without classical expression of PPR (Paper V) and serving as a predisposing factor (principally for immuno-suppressive effect). The role of MV in the outbreak of RDC was considerable. *Mycoplasma agalactiae* could also play a role in causing contagious agalacia reducing milk production by ewes. Several relapses were noted indicating the existence of pathogens resistant to antibiotics. MV virus causes multi-systemic diseases in sheep, and to a lesser extent, in goats (Paper VI). Economic losses due to MV result from death or culled sheep, increased replacement rates due to increased culling rates to replace ewes with poor body condition, indurated udders, whose lambs grew poorly, and depressed pre-weaning growth of lambs due to mastitis in the ewes. MV predisposes to secondary infections and loss of trade due to export restrictions of breeding sheep from an MV virus infected country. The disease has entered into several sheep producing countries including Ethiopia through importation of exotic sheep breeds. In Ethiopia, MV prevalence ranged from 1.4% in smallholder flocks to 74% in on-station flocks from the two ranches. The average seroprevalence in

47

smallholders flocks have recently reached to 6.6%. The annual cost of MV disease for Ethiopia is estimated at US $ 25.47 million (Tibbo, 2006). MV has become a bottleneck for intensification and crossbreeding programmes in the Ethiopian highlands.

Combined efforts which include planning of mating for lambing to occur in March/April, flock health and nutrition management routines, and improving housing are important to alleviate the problems of respiratory diseases.

Gastro-enteritis was a common ailment, particularly in lambs (Paper I). The extent to which this is attributable to bacteria is, however, difficult to ascertain. This is because enteritis is also commonly associated with helminthosis and dietetic diarrhoea. In this study no attempt was made to identify the aetiologies involved. Investigation into specific pathogens involved in gastro-enteritis in lambs should help the control of this disease complex which eventually improves lamb survival.

Abomasal impaction mostly occurred during dry season when young lambs, which could not get sufficient milk from their dry dams, nibbled the dry, fibrous grass, leading to the formation of phytobezoars. These bezoars then became mixed and compacted with milk. Death occurred when these bezoars lodge at the abomaso-duodenal sphincter and block the passage of digesta from abomasum to intestines resulting in abomasal impaction and/or bloat. Similar observations were made by Njau *et al*. (1988b) and Bekele *et al*. (1992a). Supplementing lambs born during dry seasons with concentrate may partly alleviate this problem.

Gastro-intestinal nematode parasites identified at ILRI Debre Berhan Station were predominately *Longistrongylus elongata* and *Trichostrongylus spp*. with a small proportion of *Haemonchus contortus* (Tembely, 1997; Tembely *et al*., 1998). However, these nematodes as a cause of mortality had limited significance in the present study. Similar observations were made by other authors (Njau *et al*., 1988a; Bekele *et al*., 1992a, b). Studies on genetic resistance to gastro-intestinal nematodes of Horro and Menz breeds revealed no substantial breed difference (e.g. Rege *et al*., 2002) though the Menz breed has been genetically better adapted to survive in the higher altitude (where this experiment was undertaken). This was explained by the fact that they had higher PCV values and higher survival rates during both pre- and post-weaning periods than the Horro breed. *Fasciolosis* has been a very important trematode parasite in the highlands of Ethiopia. Since it was controlled by strategic deworming in the present study its real effect was not seen. However, among endoparasites it was the most prevalent cause of mortality even with strategic interventions at ILRI station. Fasciolosis can be prevented by strategic use of anthelmintics, grazing management and nutritional supplementation. In the present study, *monesiasis* has been another important cestode infection in lambs at about 2 months of age. Sometimes lambs experienced heavy worm-load even before this age at about 1 month and 3 weeks warranting close monitoring particularly when large numbers of lambs are grazed together. Though the importance of this tape worm is still a matter of debate in western countries (e.g. van Schalkwyk *et al*., 2005), the cestode has been responsible for a number of deaths in lambs in the present study. Treating lambs for moneziasis with

niclosamide at about 2 months of age and availing proper nutrition could minimise losses.

Starvation-mismothering-exposure (SME) complex (Paper I) involves starvation, mismothering-exposure, hypothermia, aberrant parent-offspring behaviour, and inadequate milk supply. In this study, some dams, particularly primipara, failed to suckle their young and sometimes neglected them. Others did not have enough milk to suckle, dependent on their body condition. Some lambs were weak, could not suck and were unable to survive hypothermia. Synchronised lambing may aggravate the occurrence of SME complex due to high number of lambs born at a time. In comparison to heavy lambs, lambs born light were at a greater risk of dying from SME. Selection for maternal rearing ability together with nutritional management of twin-bearing ewes and other managemental routines could minimise losses from SME complex.

Profitability of anthelmintic treatment and supplementation in different genotypes

Cost-effectiveness is an important issue in disease control and breeding programmes, especially where integrating available animal genetic resources into existing production systems is an absolute necessity. In low-input systems where input supply such as feed and anthelmintics is a major limiting factor, investigating both biological and economical factors affecting livestock productivity and profitability is important. The present study (Paper VII) has shown that anthelmintic treatment against sub-clinical helminthosis in the Ethiopian highlands is biologically practical and economically beneficial. Likewise, we demonstrated that supplementation is economically feasible even where sub-clinical helminthosis prevails. Etter *et al.* (2000) documented that increased level of digestible protein in sheep has improved resistance against nematodes.

One of the alternatives to alleviate the problems of chemotherapeutics is breeding of sheep for resistance to nematodes. The ability of sheep to resist helminth parasites varies substantially among and within breeds and is controlled by several genes (Amarante *et al.*, 2004; Baker *et al.*, 2004). The indigenous Menz breed was superior in helminth resistance compared to the 50% Awassi-Menz and 75% Awassi-Menz genotypes (Tibbo *et al.*, 2004a). Rege *et al.* (2002) found out that the Menz sheep was superior to the Horro breed in maintaining PCV, and controlling EPG and worm burden. In the present study there was a tendency for marginal profit from anthelmintic treatment to be higher for the crossbred sheep indicating greater benefits of anthelmintic interventions for relatively less adapted genotypes.

Due to the genotype difference in growth rate before this experiment, the 75% Awassi-Menz were superior by Ethiopian Birr (ETB) 41 in crude revenue to the indigenous Menz sheep at the start of the experiment (Paper VII). During the experimental period, however, the indigenous Menz were superior to the 75% Awassi-Menz by ETB 32 including the skin value. Lack of information on costs from birth to one year, including figures on possible differences between the genotypes in fertility and mortality rate throughout the whole period does not allow

drawing clear conclusion on the final total value of the different genotypes. Considering the variable growth patterns and marketing age (at about 20 months) in Ethiopia, the present tradition seems to fit well with the growth pattern of the indigenous Menz, but that a much earlier age for marketing of the crossbreds, and especially the 75% crosses, could be recommended, as it does not pay off to keep these lambs for such old age. One practical issue here is that producing 75% Awassi-Menz crosses at farmers' level is problematic since the breeding policy was distributing 75% Awassi-Menz rams. Unless there is some other mechanism, it is not easy for farmers to get 75% Awassi-Menz as main producing flock at farmers' level. Nonetheless, in intensive production systems the 75% Awassi-Menz crosses should be considered since they reach marketing weight many months earlier than the indigenous Menz sheep.

The value of skin has caused profit in favour of the indigenous Menz. The indigenous Menz sheep were just as good, even slightly (though not significantly) better than the 50% Awassi-Menz crosses. The market price of skin of the indigenous Menz sheep was 3 to 4 times higher than that of the crosses. This was because of lack of demand for skin of crossbreds by tanneries in Ethiopia. Ethiopian highland sheepskins have international reputation particularly for making gloves. Skin quality has not been previously taken into account when designing crossbreeding programmes in Ethiopia. This is despite the fact that skins and hides have been the second most important export item after coffee for Ethiopia for many years. Results of this study emphasize the need, in designing crossbreeding programmes, to critically look at the market demands for the various animal traits and products that might be affected by the planned programme.

A framework for sheep breeding in Ethiopia

Introduction

Sheep breeding in Ethiopia is at its infantile stage. The sheep population is huge, nearly 24 million, but off-take very low, with an average lamb carcass weight of 10 kg. The initial breeding attempt (which started in 1960s) focused on crossbreeding of the indigenous breeds with exotic breeds to improve growth and wool yield. This programme suffered from poor planning; it failed to involve livestock owners and stakeholders in decision making and ownership of the initiatives, and it had also a low regard to the potential of indigenous breeds. Had they been successful, those initiatives would have to a large extent substituted the adapted indigenous breeds with exotic breeds and crosses. In the light of failures and successes (if any) of those initiatives, and key factors that impact a breeding programme, a framework for sheep breeding in Ethiopia is seriously needed.

Various factors would impact a proposition for a framework of sheep breeding. These are (1) sheep genetic diversity and distribution; (2) productivity levels of indigenous breeds and inspected crossbreds; (3) sheep production (farming) systems in relation to land use; (4) market opportunities (access) and/or demand for various sheep products; (5) lessons from past efforts; (6) community-based

knowledge and practices; and (7) available capacity in terms of infrastructure and trained human resources.

Ethiopia has sizeable sheep genetic diversity (DAGRIS, 2004). The indigenous sheep breeds are highly adapted to low-input systems or are naturally selected for survival under sub-optimal and disease ridden environments. Yet mortality rates are found variable but often unacceptably high. Sheep are found in all agro-ecological zones in Ethiopia and are mostly kept under smallholder subsistence production system where input supplies are low. They produce on marginal, marshy and often uncultivable lands. The low off-take per ewe is partly a result of keeping too many unproductive animals thereby limiting feed supply and contributing to land degradation.

Between breed variation: Due to slow growth rate of indigenous sheep breeds the desired marketing weight of 35–40 kg at one year of age for export market is easier said than done in the short-term. The current yearling weight of most indigenous breeds is between 20–25 kg although some breeds (e.g. Horro) can weigh up to 34 kg under on-station management (Table 4). Adult Horro males (full mouth) could attain as high as 80 kg when well-fed on an experimental station closer to its original habitat (Abegaz, personal communication). Published reports reveal that some indigenous breeds have great potential for growth (Table 4).

Table 4. Growth performances of some indigenous sheep breeds under variable on-station climate and management levels

Breed	BWT (kg)	ADG_{1-90} (g/day)	WWT (kg)	YWT (kg)	Reference
Horro	2.9	134.4	15.0	34	Gojam *et al*. (1998)
	2.6	100.4	12.0	24	Abegaz (2002)
	(1.0-4.5)	(21-230)	(5-23)	(11-45)	
	2.8	92.6	11.0	19	Paper III
	(0.9-4.8)	(28-164)	(6-15)	(8-35)	
BHO	2.7	127.8	14.2	25	Galal (1983)
Adal	2.5	116.7	13.0	26	Galal (1983)
Arsi-Bale	2.8		13.5		Brännäng *et al*. (1987)
Menz	1.9-2.7		13.4	23	Mukasa-Mugerwa *et al*. (1994), Wilson (1991)
	2.4	84.9	10.1	17	Paper III
	(0.9-4.0)	(30-192)	(6-15)	(7-31)	

ADG = average daily weight gain; BHO = Blackhead Ogaden; BWT = birth weight;
WWT = weaning weight; YWT = yearling weight
Within trait figures in parenthesis are ranges.

Breed variation for growth is high as can be seen on daily gains, weaning and yearling weights. Abegaz (2005) found pre-weaning daily gain as high as 230 g, weaning weight up to 23 and yearling weight up to 45 kg for Horro breed. Nonetheless, it is obvious from Table 4 that there are small breeds with low growth rate. On top of within breed selection, upgrading through crossbreeding or synthetic breed development should be considered for these breeds (e.g. Menz,

Tukur). However, such crossbreeding or breed substitution must consider the needs for these breeds to be adapted to tropical climate under low-input systems and to many stressors.

Based on their performance and unique attributes, the indigenous sheep breeds of Ethiopia could be clustered into five main groups:

(i) Large breeds (e.g. Horro, Bonga, Dangila/Washera/Agew) adapted to per-humid to sub-humid and moist agro-ecological zones

(ii) Medium-sized breeds (e.g. Wello, Arsi-Bale) adapted to moist and sub-moist high altitude regions

(iii) Small breeds (e.g. Tukur, Menz) adapted to moist and sub-moist precipitous high altitude regions where feed (grazing) is scarce

(iv) Unique breeds (e.g. Abergelle, Afar, Blackhead Ogaden/Somali, Gumez, Rutana, Sekota-Agew) adapted to semi-arid to arid harsh climate (water and feed scarce areas) with low to high growth potential

(v) Others for which information is limited (Akale Guzai, Barka, Farta)

Market access: Sheep of Ethiopia are mainly sold live, both in domestic markets and for export. A sizable amount is exported to the Middle-East countries as chilled mutton. Sheepskins from Ethiopian highlands are highly valued in the world market (ELICO, 2006). Due to the geographical proximity of Ethiopia to the Middle East and the emergence of large supermarkets in the Gulf States and the Middle East, market opportunities for mutton particularly in processed form are enormous. However, substantial intra-annual price fluctuations for sheep in the Ethiopian highlands have been reported by Andagachew & Brokken (1993). Furthermore, according to Aklilu *et al*. (2005), sheep and mutton from Ethiopian highlands, however, are said to be less "demanded" by exporters compared to those from the Ethiopian lowlands for alleged darkening of meat after slaughter. This 'defect', however, is recognised neither by sheep owners nor by consumers in Ethiopia.

There are emerging initiatives to promote export of livestock and livestock products from Ethiopia (Aklilu *et al*., 2005). The FAO's EXCELEX programme (the FAO's Support to Livestock Exports from the Horn of Africa) has been monitoring and certifying livestock moving into international markets. Furthermore, the Save the Children (USA) and CARE (Cooperative for American Remittances to Europe) have organised pastoralist cooperatives to assist marketing of livestock to abattoirs in the Southern Tier zones. The PARIMA (Pastoral Risk Management) has been addressing alternative income generating activities with a focus on small ruminants. The USAID has been supporting livestock price surveys to be broadcasted to the public. The single most important limiting factor for livestock export from Ethiopia, however, has been livestock diseases. A number of diseases are identified, whose control is complicated due to porous borders among East African countries. In view of this, recently Ethiopia has received substantial funding through the USAID for a project titled "*Ethiopia Sanitary and Phytosanitary Standards (SPS) and Livestock and Meat Marketing (SPS-LMM)*

Programme" (Fitzhugh & Eugster, unpublished). The objectives of the project are to increase the competitiveness of Ethiopia's livestock and meat subsectors by improving the country's SPS/food safety system and strengthening regional, national and international market interventions, in order to increase the sales and exports of livestock and meat products, thereby raise rural household incomes and food security.

Breeding strategies: Strategies for genetic improvement could follow three pathways: (i) selection between breeds (or strains), (ii) selection within breeds (or strains), and (iii) crossbreeding or synthetic breed development. A framework for sheep breeding in Ethiopia should start with between and within breed selection even to meet the needs for crossbreeding selected indigenous breeds with improver exotic breeds. Since crossbreeding with breeds from temperate regions failed due to incompatibility of the genotypes with low-input production systems of Ethiopia, crossbreeding or synthetic breed development should be used with limited scope where farmers' resources and market allow. Furthermore, molecular and reproductive techniques such as identifying markers, artificial insemination (AI), multiple-ovulation-embryo-transfer (MOET) and *in vitro* ova collection and maturation techniques could at first only be attempted in experimental stations for selection and dissemination of improved stock in targeted areas when the basic framework for selection and distribution of rams to farmers is in place.

National sheep productivity improvement pathways

The overall national sheep production to consumption goal for Ethiopia should aim at improving production per sheep instead of keeping huge number of mediocre animals contributing to land degradation and feed scarcity. Eight alternative (ALT) hypothetical scenarios in comparison to the current sheep production situation are illustrated in Table 5. These alternatives revolve around reducing lamb mortality, improving ewe fertility and lamb growth, reducing marketing age and reducing number of ewes kept. This could be achieved through genetic means and modifying the environment (re-allocating feed resources to 'best' ewes and lambs by e.g. culling mediocre animals, shift to more favourable lambing season, and anthelmintic control management). This in turn would improve ewe weight at mating and lamb weight at birth, thus improving survival in subsequent periods (Papers I, III & IV) and allowing more and heavier lambs in the flocks and being marketed much earlier in life time. The hypothetical alternatives in Table 5 are briefly described as follows:

- The first alternative (ALT 1) focuses on reduction of the current mortality by 10%. That allows keeping fewer ewes by 1.25 million for the present level of total lamb carcass produced per year. This would result in an improvement of production per ewe by 14% and allows a reduction of the total sheep population kept by about 3 million.

- The second alternative (ALT 2) is based on improving fertility to 1.2 lambs per ewe per year. This will allow keeping fewer ewes by 3.29 million for the present level of total lamb carcass production. This result in an improvement

of ouput per ewe by 26.7%, allowing a reduction of the total number of sheep kept by about 5 million.

- The third alternative (ALT 3) is based on reducing marketing age by 6 months (i.e. lambs are marketed at 12 months of age), and reducing of mortality by 10%. This allows keeping fewer ewes by 1.25 million and a reduction of the total sheep population kept by as much as 7 million.

- The fourth alternative (ALT 4) was based on reducing marketing age by 6 months, mortality by 10%, and improving fertility to 1.2 lambs per ewe/year. This allows keeping fewer ewes by 3.29 million and a reduction of the total sheep population kept by as much as 9 million.

- The fifth alternative (ALT 5) is based on improving marketed live weight by 10 kg per lamb (by improving lamb growth) and reducing mortality by 15%. This eventually allows keeping fewer ewes by 1.25 million. In this alternative, more than 30 million kg of lamb carcass would be produced even with animals fewer by 3 million head compared to current situation.

- The sixth alternative (ALT 6) is based on improving marketed live weight by 10 kg per lamb (by improving lamb growth), improved fertility to 1.2 lambs per ewe/year, and reducing mortality by 15%. This eventually allows keeping fewer ewes by 3.29 million. Compared to the current production, in this alternative an increase of more than 30 million kg of lamb carcass would be produced with a decrease in total number of animals by 5 million.

- The seventh alternative (ALT 7) is based on reducing marketing age by 6 months, improving marketed live weight by 5 kg per lamb (by improving lamb growth), improving fertility to 1.2 lambs per ewe/year, and reducing mortality by 20%. This allows keeping fewer ewes by 2.61 million. Compared to the current production, in this alternative, more than a 30 million kg of lamb carcass increase would be produced with animals fewer by 7.54 million.

- The last alternative (ALT 8) combines all four measures, i.e., reducing marketing age by 6 months, improving marketed live weight by 5 kg per lamb (by improving lamb growth), improving fertility to 1.2 lambs per ewe/year, and reducing mortality by 20%. This alternative assumes equal number of sheep as ALT 1. Compared to the current production, an increase of more than 58 million kg of lamb carcass would be produced with animals fewer by 3 million, but an almost unchanged total number of ewes (less by 0.53 million).

Table 5. Different hypothetical scenarios or alternatives (ALT) for sheep improvement in Ethiopia

	Current	ALT 1	ALT 2	ALT 3	ALT 4	ALT5	ALT 6	ALT 7	ALT 8
Marketing age (months)	18	18	18	12	12	18	18	12	12
Marketing live weight (kg)	25	25	25	25	25	35	35	30	30
Number of lambs born per ewe/year*	0.92	0.92	1.20	0.92	1.20	0.92	1.20	1.20	1.20
Lamb survival at marketing age	0.70	0.80	0.80	0.80	0.80	0.85	0.85	0.90	0.90
Number of ewes (million)**	10.00	8.75	6.71	8.75	6.71	8.75	6.71	7.39	9.47
Kg of lamb carcass weight/ewe/year***	6.44	7.36	9.60	7.36	9.60	10.95	14.28	12.96	12.96
Total kg of lamb carcass per year (million)	64.40	64.40	64.40	64.40	64.40	95.80	95.80	95.80	122.73
Number of growing lambs (million)	13.80	12.08	12.08	8.05	8.05	12.08	12.08	8.87	11.36
Ewes and lambs (million)	23.80	20.83	18.78	16.80	14.76	20.83	18.78	16.26	20.83
Output per sheep (%)	100.00	114.29	126.71	141.67	161.26	170.00	188.48	217.71	217.71

*Number of lambs born per ewe per year = litter size of 1.15 × fertility rate of 0.8 = 0.92; or litter size of 1.50 × fertility rate of 0.8 = 1.20.
** Current number of ewes represented 42.4% of the total population of 23.6 million, which is extrapolated using a study by Mekoya *et al*. (2000).
*** Lamb carcass weight per ewe per year = Marketing live weight × dressing percentage of 40% × number of lambs born per ewe/year × lamb survival
ALT 1 = reduced mortality by 10%
ALT 2 = reduced mortality by 10%, improved fertility to 1.2 lambs/ewe/year
ALT 3 = reduced mortality by 10%, reduced marketing age by 6 months
ALT 4 = reduced mortality by 10%, improved fertility to 1.2 lambs/ewe/year, reduced marketing age by 6 months
ALT 5 = reduced mortality by 15%, improved marketed live weight by 10 kg per lamb
ALT 6 = reduced mortality by 15%, improved fertility to 1.2 lambs/ewe/year, improved marketing weight by 10 kg per lamb
ALT 7 = reduced mortality by 20%, improved fertility to 1.2 lambs/ewe/year, improved marketing weight by 5 kg per lamb, reduced marketing age by 6 months
ALT 8 = reduced mortality by 20%, improved fertility to 1.2 lambs/ewe/year, improved marketing weight by 5 kg per lamb, reduced marketing age by 6 months

Although the scenarios and their assumptions are simplified, the results point at important areas for improvement as is shown in this thesis. Reduction of lamb mortality and increased growth rate by re-location of resources favouring pregnant and suckling ewes should lead to earlier marketing age of lambs. A doubled market output per sheep kept in the population is clearly achievable. As traditions are strong and the animals are kept for social security and other reasons an acceptable alternative might be based on an unchanged number of ewes but a higher turn-over rate of the lambs, allowing more resources to be used for priority groups of ewes and lambs. Both genetic and environmental interventions would be needed and supported by further research and extension services.

Within breed improvement

Within breed selection should involve measuring and selecting on productivity such as growth, survival and litter size. In the tropics, however, small flock size, single-sire flocks, lack of animal identification, lack of performance and pedigree recording, low level of literacy and organisation shortcomings (Kosgey *et al.*, 2006) have been major problems. In a pastoral production system, flock mobility is an additional problem to the aforementioned ones. Components of within breed improvement include defining the overall development objectives, characterising the production system, identifying breeds to be used and improved by selection, identifying a list of breeding goal traits and deriving goal values for each of the breeding goal traits.

Breeding goal traits must have the following characteristics: (i) reasonably large genetic variability; (ii) easily and cheaply measurable; (iii) if not easily and cheaply measurable then, must have a high genetic correlation with a trait (indicator trait) that is easily measurable, has a higher heritability or can be measured earlier in life than the goal trait it represents; and (iv) desirable economic value, either as a marketable commodity or as a means of reducing production costs. The overall breeding goal for sheep production in Ethiopia could be improving growth to achieve a yearling weight of 35–40 kg, and survival of 85–90% at yearling. Since the stated yearling weight is demanded by importers of sheep and mutton from Ethiopia, stakeholders which include exporters of sheep as live or mutton, should be involved at all phases. If a lamb could attain a high weight at 12 months of age, subsequent fattening for 3 months after castrating could fetch high market prices even in domestic markets. Measuring breeding goal traits with components of production and reproduction (e.g. number and weight of offspring per year) in smallholder farms, however, is not easy. The difficulty to measure and value the intangible benefits (Kosgey *et al.*, 2006) derived from sheep presents more complications. Therefore, systems of utilizing government ranches and research flocks as nucleus breeding units, where proper livestock recording could be anticipated, should be looked for.

Open-nucleus breeding scheme

Application of open-nucleus breeding schemes (ONBS) might be a feasible strategy for genetic improvement of sheep in Ethiopia as is schematically laid out

56

in Figure 10 (Philipsson *et al*., 2006). ONBS could be utilised for conservation of genetic resources (including breeds, desirable genes, genotypes, etc) through improvement and proper utilisation (Yapi-Gnoaré, 2000; Philipsson *et al*., 2006).
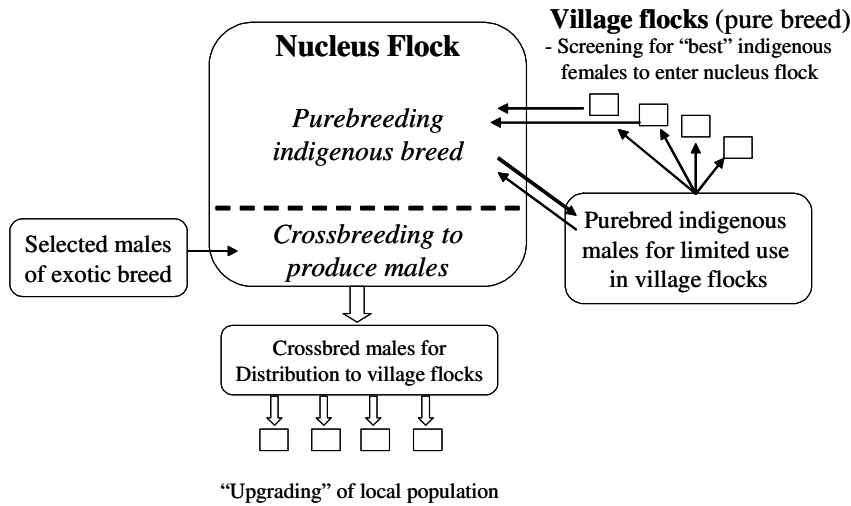

Figure 10. Open-nucleus breeding scheme for improvement and conservation involving purebreeding and crossbreeding (adapted from Philipsson *et al*., 2006)

This scheme allows an in-flow of high potential breeding animals for crossbreeding as well as from village flocks for purebreeding to nucleus flocks in the ranches (Figure 10). Thus, ONBS can serve for both purebreeding and crossbreeding, and dissemination of improved genetic materials allowing conservation and improvement of the indigenous sheep breeds. Crossbred rams, however, should be distributed to targeted village flocks with maximum care not to mix indigenous rams with crossbred rams. Based on breeding values for the breeding goal traits, ewes born to superior rams would be selected and bought for transfer to nucleus flock. Nucleus flocks can be set-up in the governmental breeding ranches or similar settings (e.g. research stations). Subsequent genetic evaluations and selection for superior rams would be undertaken in the nucleus flocks where animals from different sources are evaluated in the same environment. Dissemination of superior rams could be made to participating farmers on cost-recovery basis.

An example of a structure for a possible open-nucleus breeding scheme for the Horro breed of Ethiopia which consists of 2 million ewes is illustrated in Figure 11. It is based on a three-tier system: *nucleus*, *sub-nucleus* and *village* flocks. It is assumed that there will be 10 nucleus flocks and each nucleus flock will consist of 4 000 breeding ewes and 160 fertile breeding rams. Thus, each ram will annually be used for 25 breeding ewes. Nucleus flocks could be placed within governmental ranches, research centres or any suitable setting. However, it should be situated closer to animals' habitat and evaluation should be in the environment where they are going to be used. Litter size of 1.34 for Horro breed was obtained from the

study by Abegaz (2002). Survival of lambs at yearling was set to be 90% as a breeding goal and fertility rate of 85% allows each ewe to produce 1.03 lambs per year in well managed nucleus flocks. About 4% best rams each year should be selected at nucleus flocks for own use. From the remaining rams in the nucleus flocks, 30% of the second best rams should be used to cover the need of rams for the sub-nucleus flocks.

The sub-nucleus flocks are those owned by first level participating sheep owners. Sheep owners in this tier could be selected based on ease of access to farm, availability of enough grazing and water, size of flock, ability to follow prophylactic programmes, supplement their animals during critical periods, and willingness to use controlled breeding (use selected rams from nucleus flocks and castrate mediocre unselected rams of their farms). In these tier flocks, a litter size of 1.2, survival rate of 85% at one year of age, and fertility of 80% would mean that a 0.82 lamb is produced per ewe/year. About 11% best rams each year will be selected at sub-nucleus flocks to be distributed (sold) to village flocks. Village flocks here are flocks owned by people who are hardly accessed for monitoring and detailed evaluations. At this level evaluation methods to select best animals should be kept very simple. Best ewes would move upwards from sub-nucleus flocks to nucleus flocks, as it may be possible to keep some basic records on pedigrees and production at the sub-nucleus level.

At litter size of 1.34, survival rate of 90% and fertility rate of 85% result in 1.03 lambs per ewe per year; hence, from 40 000 ewes, 20 500 ♀ and 20 500 ♂ are produced. Best 4% ♂ selected each year for own use in the nucleus flocks (i.e. 800 new rams/year). The remaining 30% second best category ♂ (i.e. 6 000 new rams for replacement per year) will be used in the sub-nucleus flocks.

At litter size of 1.2, survival rate of 85%, and fertility rate of 80% result in 0.82 lamb per ewe per year; hence, from 450 000 ewes, 184 500 ♀ and 184 500 ♂ are produced. Best 11% ♂ selected each year (i.e. 20 000 new rams per year) to be used at village flocks.

Nucleus flocks (10)

40 000 ♀
1 600 ♂ for 2 yrs

Best ♀ **Sub-nucleus** Best ♀
Flocks

450 000 ♀
18 000 ♂ used for 3 years

Village flocks

1 510 000 ♀
60 400 ♂ used for 3 years

Figure 11. Example of a possible open-nucleus breeding scheme for the Horro sheep breed consisting of 2 million ewes

58

General organisational set-up

Briefly, an organogram with important links among main actors in Ethiopia is presented in Figure 12. There is a need for establishing a national Animal Genetic Resources Institute (AnGRI), and enact a bylaw stating the roles and responsibilities of all stakeholders for all activities related to AnGR management, improvement and utilisation. AnGRI is suggested to be responsible for developing the breeding programme and estimation of breeding values and economic weights for indexes to be used. Furthermore, it could oversee the monitoring of the breeding programme (including quantifying extent of genetic progress) and electronic data processing. AnGRI also designs a system of mating and exchange of breeding animals between locations and flocks at different tiers, and delivers breeding advice, training of staff to work in the breeding programme, and ensures participation and co-operation through extension and education. The institute could be placed under the Animal Science and Fisheries Programme of the Ministry of Agriculture and Rural Development and could be managed by a board of stakeholder representatives and assisted by a technical advisory panel from different research and public institutions (e.g. EIAR & ILRI). At regional level (within the country), the department of AnGR could be established in the Regional Bureau of Agriculture, which should have a viable link with the national AnGRI. The department of AnGR could be responsible for all regional AnGR activities. The department of Animal Science and Fisheries at district/Woreda may have an AnGR section, which should coordinate and execute breeding programmes, training of sheep owners, and collect data, enter, and carry out preliminary analyses. This section should work with governmental ranches and be backed up by nearby research centres.
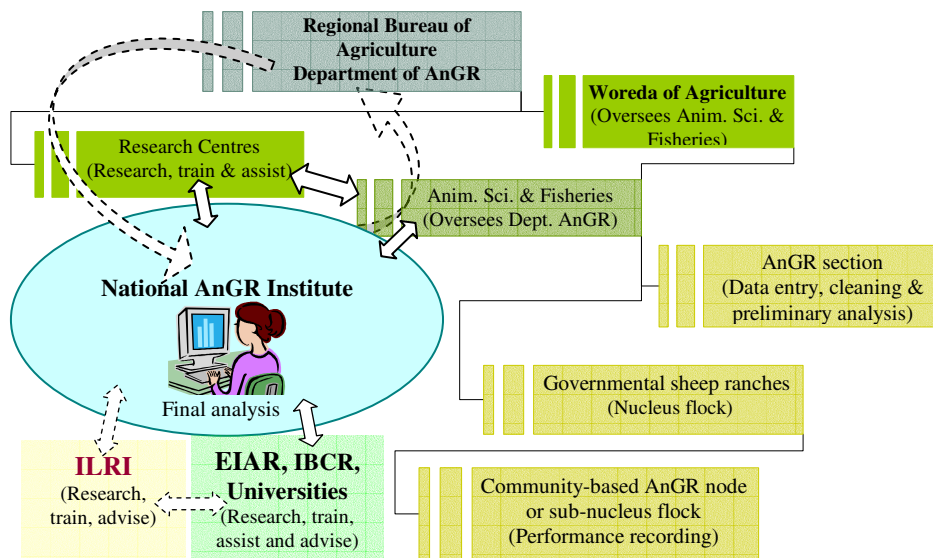
Figure 12. Organisational structure for community-based breeding programme

59

At village level, community-based AnGR nodes are proposed to be established through community participation (using Participatory Rural Appraisal tools). At this level, the development agent could coordinate a number of such nodes in at least three peasant associations. Each node should have a reliable community-based elected leader, elected by the community. This leader should coordinate AnGR activities including ensuring collection of relevant records on the sheep flocks of the area. The node could be at communal grazing land level or any other suitable grouping e.g. *got* (Amharic) or watershed approach.

Implementation

Initially sheep breeding could be first launched in very strategic and realistic places. The governmental breeding ranches are ideal for their comparative advantage as nucleus flocks. Selection of farmers for establishment of sub-nucleus flocks of the initial breeding programmes may be based on the factors previously mentioned for this tier of flocks. These farmers should agree to practice controlled breeding. Their capacity should, however, be raised through community trainings to increase their understanding of the programme and enabling them in recording allowing them to make informed decisions. Animal performance data and pedigree recording could be done at this level with major involvement and facilitation by extension services. At this level, recording should be kept simple. More sophisticated recording and genetic evaluations should be done at nucleus flocks in the ranches. Data entry, cleaning and preliminary analysis could be done at district/Woreda level with assistance from nearby research or training institutions as appropriate. Final data analysis may be done at national level (Figure 12). BLUP animal models and Survival Analysis can be used to estimate breeding values. However, training at all levels is vital to carry out these activities.

Participating farmers need to share the cost and should agree to a minimum level of management not only to realise the benefits of genetic improvement, but also to make genetic evaluation possible. Financial assistance through subsidy is important at the start but should be kept to the minimum to ensure sustainability. A Trust Fund in any suitable form could be established. Social organisations (e.g. *Ekub*, *Edir*) are viable means to lay ground for such initiatives. Participating farmers need to pay for the services they receive (e.g. cost per improved ram distributed). Otherwise, the project cannot be sustainable, especially when external assistance pulls out. Such issues should be clearly discussed before the project initiation phase. Participatory Rural Appraisal (PRA) tools can be used here. Donors may be approached for restricted funding as a means of supporting sustainable development instead of focusing only on food-aid during emergency crisis.

Possible constraints and risk assumptions

The success of the programme is dependent on careful monitoring, i.e. measuring the performance of the progeny of distributed rams. Extension staffs at district/Woreda level are responsible for this monitoring. Failure of the project would have far-reaching effects. Lack of grazing area might also be a problem due to possible conflict among participating and non-participating farmers for common resources. Related to this, a problem may arise because non-participating farmers

60

leave their inferior uncastrated rams in the communal grazing land which unduly affects the programme. If there are members unwilling to castrate their rams, the programme should ensure physical separation once improved rams are introduced by relocating them to either their distant relatives or close friends. With regard to land tenure, there is no clear policy that protects grazing areas and the land belongs to the government and individual farmers have no right to apply any progressive farming methods resulting in land degradation. Assumptions are that the quality of the sheep produced would lend itself to effective marketing; resources (land, water, genetics and general infrastructure) will be adequate to effect change; extension staff can be sufficiently trained in the process; there will not be a major disaster (e.g. severe drought, disease outbreak); communal farmers will accept some drastic changes to their current way of producing animals (e.g. using identification tags for their animals).

Crossbreeding or synthetic breed development

Crossbreeding between highly productive, genetically divergent and adapted breeds may result in superior overall performance. The choice of breeds to be used in crossbreeding should match the level of inputs, which can vary substantially both within and amongst target areas and production systems (Philipsson *et al.*, 2006). Therefore, this method should be adapted to fit the potential to the different target production system. For example, market-oriented private farms and financially well-off farmers may afford to utilise these methods depending on market opportunities. Nonetheless, the incremental costs of crossbreeding need to be justified by added benefits that accrue to the system. In any case, ONBS should be central to these breeding programmes. Governmental sheep ranches and research centres have important roles to play in crossbreeding and synthetic breed development. This is particularly because of their past experience in such activities and availability of human and infrastructural capacities. The AnGRI in collaboration with national and regional research institutions are proposed to oversee the overall activities.

The results presented in this thesis and also other results (e.g. Beyene, 1989; Hassen *et al.*, 2002) indicate the existence of significant variations in growth within and among different crossbred sheep genotypes in Ethiopia. Hassen *et al.* (2002) reported that insufficient milk of indigenous dam-breed was a reason for slow growth in crossbred lambs (37.5% crossbreds). Similar observations were made at the Arsi sheep ranch (Beyene, 1989). These results indicate that there is a need to seriously think about dam-breed along with supplementary feeding when crossbreeding is to be used to improve productivity. For example, 50% crossbred dams could be used as a dam-breed for faster growth in crossbred lambs. With regard to exotic breed or genotype to be used, the Awassi breed has been the only breed with promising results in the Ethiopian highlands. Due to disease introduction risk (e.g. maedi-visna), however, currently this breed is under ban from use. Indigenous breeds should also be considered for crossbreeding. For example, substantial improvement through selection within breed for small breeds may take several decades. Crossbreeding and eventually synthetic breed development may be used as a means to improve productivity using such breeds.

61

Within breed selection may be combined with crossbreeding with other larger breeds at some stage to speed up genetic progress. However, information on level of genetic diversity within and among populations is important for any sound breeding plans. An on-going ILRI project on genetic characterisation of Ethiopian indigenous sheep is hoped to provide important information for such plans.

The advantage of developing and using a synthetic breed is that it is easier to handle than systematic crossbreeding under practical conditions. Secondly, response to selection when using synthetic breeds is greater than that on parental breeds because of the increased genetic variation or increased additive genetic merit in the synthetics. Developing a synthetic breed, however, is a long-term process that needs more resources, a large number of animals, detailed recording and analytical facilities. Therefore, development of synthetic breeds should be carried out on-station in a nucleus flock, particularly in research stations where recording, feeding and management is likely to be under better control than in the field.

Conclusions

Comprehensive genetic and production characterisation studies as demonstrated in the series of studies in this thesis reveal the tremendous potential of indigenous Ethiopian sheep breeds for improved productivity and health considering the following conclusions.

- Within and between breed variations for growth and survival was significant

- Sires within breed were an important source of variation for lamb growth and survival

- Heritability estimates for growth traits were low to moderate, and indicate that genetic improvement is feasible

- Heritability estimates for survival were low but still could be used in selection since there was no genetic antagonism between growth and survival traits

- Maternal genetic effects were important for growth and survival traits

- Lamb sex, birth type, dam parity, season and year of birth were all significant for both growth and survival traits

- Birth weight within breed was the single most important source of variation for lamb survival

- Permanent environmental and common (litter) environmental components were important for growth traits

- Lamb mortality was a limiting factor for productivity, particularly in the Horro breed at high altitudes compared to the Menz sheep and may have a link to genotype-environment interaction

62

- Respiratory diseases were the most important cause of mortality accounting for more than half of the overall mortality

- Risk factors for pneumonia were, breed, sex, birth type, age, birth weight category, month of the year, and ambient air temperature

- Maedi-visna virus as a cause for ovine progressive pneumonia has emerged as an important bottleneck for crossbreeding; its introduction into Ethiopia is believed to be connected to breed importations

- Compared to mixed Linear Models, Survival Analysis for lamb survival improved accuracy of breeding values by 17% but has some important limitations

- Anthelmintic treatment and supplementation against sub-clinical helminthosis in indigenous Menz and crossbred sheep were economically profitable

- The indigenous Menz were superior to the 75% Awassi-Menz crosses in profit margin when skin value was considered during an experimental period of 10 months after yearling age, and the value of skin caused profit shift in favour of the indigenous Menz. Yearling weight of 75% Awassi-Menz crosses indicated that they can be marketed at 12 months of age instead of 10 months later for purebred Menz sheep.

- Ethiopia's vision in sheep breeding shall be improving production per animal and re-locate resources (e.g. feed & water) to selected ewes that produce more and better growing lambs through combined efforts in planning, management and selection with careful consideration of breed (genotype) × environment interaction.

- Different scenarios for sheep production in Ethiopia show that the output per sheep kept could be doubled by environmental and genetic interventions that reduce mortality and increase fertility, growth and yearling weight so that lambs could be marketed at an earlier age.

- Breeding programmes are proposed to be based on open nucleus flocks utilizing government ranches at the top of a three tier system of flocks. Such schemes could be used for conservation and improvement of indigenous breeds as well as for crossbreeding

Recommendations

- Good farm routines need to be introduced that would increase birth weight, reduce climatic stress, limit malnutrition, starvation and exposure, promote maximum ewe-lamb contact during the first few days after birth; vaccinate ewes against clostridial infections to help them pass colostral immunity to their lambs

- The wide within breed variability in growth and survival could be exploited more permanently through ram progeny tests. Community-based within breed

improvement using open-nucleus breeding schemes with breeding goal traits of weight at weaning (17 kg) and yearling (30 kg) and survival at yearling (85-90%), need to be initiated first in pilot learning sites (e.g. ranches) with full participation of sheep owners and stakeholders.

- Mortality from respiratory diseases could be minimised by timing of mating to ensure that lambing occurs in the late short rainy season (March/April) so that lambs are weaned at the beginning of the rainy season (June/July). Improving flock health and nutritional management, and housing (e.g. providing bedding); close monitoring for, and proper identification of, pneumonia are important.

- Maedi-visna virus could be prevented through a test-and-slaughter policy of reactors, raising lambs on heat-treated colostrum or on cow milk (when possible), isolating with follow-up of clinical signs, and cull mediocre, progressively emaciated sheep which do not seem to recover in areas where definitive diagnosis is difficult

- Sheep flocks have to be vaccinated against pasteurellosis with multivalent vaccine which includes all predominant *Pasteurella spp* and serotypes; against PPR with PPR homologous vaccine; against lungworms with anthelmintics drench strategically (Tembely *et al.*, 1998)

- Importation of exotic sheep breeds should be assessed carefully for disease freedom according to international regulations and should be quarantined and assessed by subject-matter-specialists

- An open nucleus flock structure of three tiers to produce improved rams for village use utilizing government ranches and research herds are proposed. Such a system may be used for purebreeding as well as for crossbreeding when found relevant. An organizational structure to ensure the different steps of the breeding programme is suggested.

Future research

To improve productivity and health of indigenous sheep breeds and crossbreds, there are still some more research questions, which have not been dealt with during the time frame and scope of this study.

- On-station evaluation of growth and survival variability in other promising indigenous sheep breeds (could be linked to open-nucleus breeding scheme)

- Investigating productivity and economics of low versus high litter size in difficult agro-ecosystems of tropical environments

- Investigating the use of satellite imagery and modelling to predict risks of respiratory diseases by making use of information generated from area-specific climatic and health data

64

- Investigating the role of genotype × environment interaction for lamb survival, and resistance to infections (pneumonia, fasciolosis and lungworms)

- Possibilities for improvement in the Survival Analysis methodology to incorporate multiple traits and maternal genetic effects when analysing survival data

- Alternative selection strategies for open-nucleus flocks and their achievements at village level

- Life-time assessment of profitability of indigenous and crossbred sheep breeds

- Suitability of open-nucleus breeding schemes in pastoral flocks

- Post-harvest 'defect' of meat from highland sheep breeds or darkening of the meat after slaughter which is 'less liked' by importers

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