

## CHAPTER SIX

# Genetic Improvement of Sheep and Goats

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### Objectives

1. To introduce basic concepts of inheritance in animal breeding.
2. To identify the basic tools for attaining genetic improvement.
3. To describe methods for characterization and conservation of small ruminant genetic resources in Ethiopia.
4. To describe selection methods for small ruminant improvement.
5. To describe crossbreeding methods for improvement of small ruminants in Ethiopia.
6. To describe the main features of a genetic improvement program that is applicable to Ethiopian conditions.

### Expected Outputs

1. Understanding of genetic concepts underlying sheep and goat breeding.
2. Understanding of methodologies and options in sheep and goat breeding.
3. Understand of the concept, rationale and methods of breed characterization and conservation.

## 6.1. Introduction to Genetic Concepts

The cell is the basic unit of life. At the center of the cell lies the nucleus, in which chromosomes are found. On these chromosomes are the genes which are the basic units of inheritance. Each animal species has a definite number of chromosomes arranged in pairs (called homologous pairs). Sheep have 27 pairs of chromosomes while goats have 30 (Table 6.1). Cells in the body are of two types, namely male and female somatic cells or sex cells, which are also called gametes. Male gametes are called sperm and female gametes are called eggs. The sperm and egg cells contain only one chromosome of each pair resulting in one-half the chromosome number (haploid) found in the somatic cells. When the sperm and egg unite, the full chromosome number (diploid) is achieved and the fertilized egg has all the genetic material needed for it to develop into a lamb or kid. Therefore, half of the genes each individual carries are contributed by either of the parents.

Genes are responsible for the many manifestations that we see within a trait, also called phenotype. For certain traits, the environment can also affect the phenotype. We can express this relationship as:

**P = G + E** where, **P** is the phenotype, **G** is the genotype or genetic makeup, and **E** is the environmental effect in which the animal makes its record.

Phenotype is what we can see or measure for a given trait. Examples are 2.2 kg for birth weight, 94 kg of milk for third lactation, 1.2 kg of wool at first shearing, red coat color, presence of horns, etc. Genotype (G) is the genetic contribution inherited from each parent, and environment (E) constitutes all the environmental (non-genetic) effects. Examples of environmental effects are plane of nutrition, frequency of deworming, ambient temperature, etc.

Certain traits are controlled by only one or a few gene pairs and are affected only slightly or not at all by the environment. These traits are called qualitative traits since they fall into discrete categories such as coat color or the presence of horns. An animal with the genetic makeup for hornedness will have horns regardless of the plane of nutrition, regardless of whether the animal is in Ethiopia, Somalia, or some other country, regardless of whether it is in the highlands or lowlands.

Other traits called quantitative traits are usually influenced by the action of many genes each with relatively small effects, and by the environment. Unlike qualitative traits, in quantitative traits the consequences of segregation of genes can no longer be seen because the different classes of the trait become more or less continuous. The continuity seen in quantitative traits increases as the number of genes involved increases. In other words, the number of possible gene combinations increases dramatically with an increase in the number of genes considered. An understanding of this is important when discussing heritability and potential for genetic improvement of animals.

Quantitative traits tend to differ among animals in degree rather than in kind. Most production traits are of this type. If the number of animals is large enough and the productivity of individual animals is plotted as a frequency distribution, such as a histogram, the distribution measuring phenotypic expression of a trait becomes continuous between the extremes. This frequency distribution often takes on a bell shape and approaches what is called a normal curve. In such a distribution, there are a few animals at each extreme – very low and very high performing – but the largest proportions are near the middle of the distribution with performance not far from the average. These traits are also influenced by the environment to which the animal is exposed. Growth and milk production in sheep and goats are examples of quantitative traits which show continuous distribution. The data in Table 6.2, histogram (Figure 6.1), and curve (Figure 6.2) show the distribution of weaning weight in Afar sheep. In our example of weaning weight, we

Table 6.1. Numbers of chromosome pairs in farm animals and humans.

Species	Number of chromosome pairs
Cow	30
Sheep	27
Goat	30
Swine	19
Horse	32
Chicken	39
Human	23

know that it can be affected by plane of nutrition, disease status, milking ability of the dam, season of lambing, etc. All of these are environmental effects.

The performance of some important traits, however, is distributed differently. These include traits like number of offspring in a lifetime and number of offspring born per birth, where distribution shows discrete classes of observation such as single or multiple. Such traits can generally be regarded as quantitative rather than qualitative, because of the fact that many pairs of genes are involved in affecting the outcome and they can be greatly affected by the environment.

These traits may often be controlled by an underlying characteristic which is more continuously variable. For example, there is greater and more continuous variability in ovulation rate, which sets limits to the number of young born at a given parturition, than there is for litter size itself. Similarly, levels of hormones control ovulation rate.

There are two ways of improving the performance of sheep and goats, namely improving the environment of the animals and/or improving their genetic potential or genotype. There is a need to balance efforts in environment and genotype by examining cost-benefit relationships; either option taken alone will not result in optimal productivity. The following points need to be noted in the genetic improvement of sheep and goats.

- Ethiopia (and the world) is endowed with numerous sheep and goat genotypes. Knowledge of their relative merits and appropriate exploitation of these merits is required. It is important to evaluate available genotypes before a decision is made to introduce exotic animals (genotypes). Breeds adapted to environments similar to where they are to be introduced may have better chance of survival and productivity.
- Animals with high genetic potential may require better management than animals with low genetic potential.
- The genetic potential of sheep and goats can be improved by selection or by introducing other superior animals (breeds) for crossbreeding with local stock. Total substitution of local genotypes with exotics can also be attempted.
- The choice of breeding method, pure-breeding alone or crossbreeding, is perhaps one of the most important decisions to be made when designing a breeding program.

Table 6.2. Data table of the distribution of weaning weight of Afar sheep.

Weight category (kg)	Number of lambs
5.1–7.0	71
7.1–9.0	189
9.1–11.0	421
11.1–13.0	788
13.1–15.0	877
15.1–17.0	494
17.1–19.0	140
19.1–21.0	30

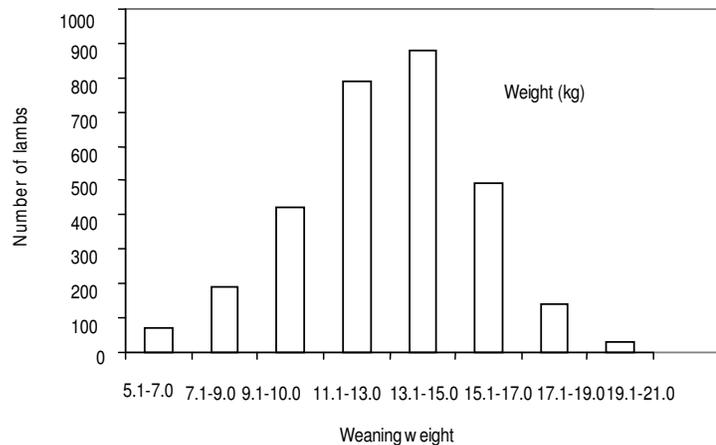


Fig. 6.1. Histogram of the distribution of weaning weight of Afar sheep.

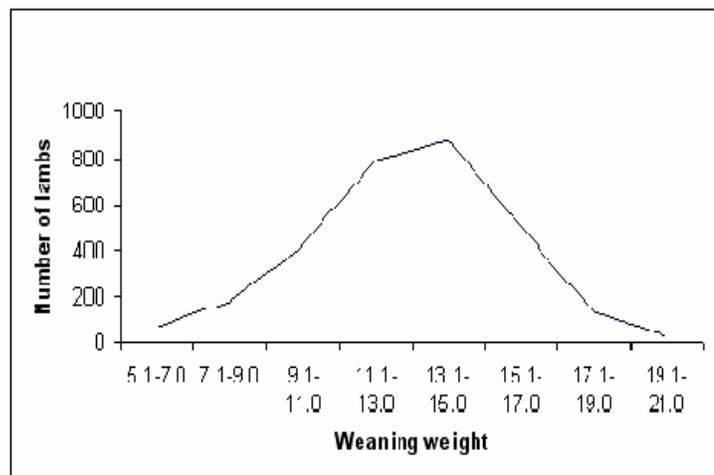


Figure 6.2. Frequency curve of the weaning weight of Afar sheep.

- Sheep and goats may show variation in productivity even when they are provided with similar management. Such variation which exists when animals are kept under similar management can be passed to their offspring.
- Selection allows animals with superior performance to be the parents of all or most of the next generation while those with inferior performance will not be allowed to mate.
- Some production traits have high heritability (greater genetic variability within the population and more responsive to selection) while others show low heritability.
- When there is no sizeable variation among animals of a given genotype or when the heritability of a desired trait is low, crossbreeding or replacement of the local animals could be considered.
- In a crossbreeding program, introduced animals and breeds should be selected very carefully for their own adaptability and the adaptability of their crossbred progenies.

### Designing breeding programs

A breeding program can be defined as the set of activities and decisions undertaken by a breeder (producer) towards improving animal performance for a given trait. There are a series of steps to be followed to achieve the breeding aim from the breeding plan.

Approaches utilizing the potential of higher-producing or better-adapted indigenous livestock breeds must be developed whenever possible. Realistic ways of breed improvement must be chosen and applied in the context of environmental constraints, socioeconomic demands and within the management resources available. Aspects of sustainability and provision of future genetic diversity are critical. A basic principle to follow should be based on the assumption that there is no better way of conserving a breed for future generations than consistently keeping the breed or population viable by using an efficient, demand-driven long-term breeding program suitable to commercial or cultural needs.

An important feature of a genetic improvement program is that the effects of selection accumulate over time. The economic benefits of selection also accumulate. Breeding programs should therefore be seen as investments for sustainable improvements of animal stock and its potential to produce food or other goods.

### 6.2. Breeding Objectives

Any breeding program for sheep and goats should be implemented to achieve a certain clearly defined objective. Therefore, the first step in a breeding program is to define realistic and attainable objectives.

The main objective is to maximize output (meat, milk, wool, skin) per unit input. The quality of animal products must target the requirements of the end-user or target market. This may be an export or domestic market. Meat is the most important product of small ruminants in Ethiopia. Milk is also a highly valued product in some pastoral, agro-pastoral or mixed agricultural areas. The quantity of meat produced depends on the number and weight of surplus animals at age of sale. The importance of reproduction rate must be stressed in relation to the number of meat animals for sale.

Meat quality is poorly defined in Ethiopia. The market may require lean meat or a fat tail that would be a delicacy in some cases and there may be specific flavor requirements in some areas. Skins are valuable byproducts from sheep and goats used for meat but there is no clear definition of skin quality within a breed. Currently, the only wool produced by some sheep breeds in Ethiopia is the coarse (carpet) wool. The wool color found in Ethiopia could be desirable, e.g., for making patterns in carpet production, as opposed to apparel wool where white wool is usually preferred.

The most important measure of productivity for milk is yield per lactation or per year. Quality is less important as sheep and goat milk in most cases is for home consumption. Goat milk may be desired because of its flavor, and sheep milk because of its high content of solids.

To ensure genetic improvement for a particular trait, the available variation in the current population and the heritability of the trait should be known. The selection intensity should be determined to achieve the target within the time limit envisaged.

### Example

Suppose the export market requires sheep with an average live weight of 30 kg as opposed to the current level of 27 kg.

**Breeding objective:** Increase the number of animals qualifying for the export market through genetic improvement of weight at marketing (e.g., yearling weight) with no or minor changes in management.

**Breeding goal:** Improve the average yearling weight of the breed from 27 to 30 kg (market requirement).

### 6.3. Breed Selection

There is a large variation among sheep and goat breeds in Ethiopia and the world. Different breeds have different environmental adaptability. Animals which are adapted to cool areas may not be suitable to hot areas. Animals which have evolved within a certain area are usually better adapted to that particular area than other breeds. Therefore, whenever possible, it would be wise to make use of such animals in improvement programs. In such programs, productivity improvement should come through selection and better management. Introduction of other animals (breeds) may be considered if their own – or that of their crosses with local breeds – adaptability to the area is proven and if their performance shows clear superiority to local animals under similar management conditions.

Selection among breeds must be based on performance data collected from groups raised in the same environment (cohorts). Comparisons need to be made in the actual environment in which animals will be raised, not on experimental stations. Comparisons must be thorough to give realistic estimates of not only lifetime production but also reproductive, mortality and morbidity rates.

### 6.4. Selection of Breeding Animals

You must develop a clear idea about the merits of individual traits to be successful in genetic selection. For selection to be effective, the selected traits must be: *heritable* (capable of being transmitted from parents to offspring), *variable* (differences must exist between animals for that trait), and *measurable*. Weight, for example, is an easy trait to measure because all that is needed is a weighing scale. Traits to be considered in a sheep and goat selection program include those that will enhance meat, wool, and milk production.

Where small ruminants are kept primarily for meat production, selection will be on the number and weight of offspring weaned per female per year. The number of offspring born per flock per year can be increased by decreasing the number of females which fail to lamb/kid, by increasing litter size, or by increasing the frequency of parturition. Females which fail to produce offspring after consecutive opportunities should be culled. With proper selection, it is possible to realize a sizeable increase in litter size. The acceptability of twins depends on the environment (particularly nutrition) and management system. Weights at birth, weaning, six months and one year are important in selection of animals for meat. Weight at birth would have an additional influence on survival of animals.

For wool sheep, selection is based on weight of fleece. Additionally, staple length could be important. In general, selection for increased fleece weight will also result in a longer staple, but it might be necessary to

pay particular attention to staple length for those sheep used for this purpose. Other wool quality aspects, such as crimp, diameter, etc., may not be important in Ethiopia, at least in the near future.

Selection of animals for milk is in terms of quantity of milk produced per year. This is a function of quantity of milk per lactation, lactation length and parturition interval.

Animals to be used for breeding purposes should be selected carefully and superior animals should be identified accurately. Sheep and goats can be selected based on records of performance and visual appraisal. Selection based on records is the best way to achieve good results. Additional visual appraisal of the selected animals is advantageous. Visual appraisal of a contemporary group of animals may be considered where record keeping is not practical or is nonexistent. Visual identification of superior animals is less successful compared to selection based on records. Differences among animals of the same age from similar dams (parity, age, condition) kept under similar management serve as indicators of genetic variability that can be exploited in a breeding program.

### 6.4.1. Visual appraisal

Selection of sheep and goats for breeding purposes based on visual observation is done by looking at the appearance, conformation and presence or absence of defects in the animal.

**Appearance:** Only an animal which is active, alert, healthy and attractive in appearance should be considered for selection.

**Conformation:** Sheep and goats to be used for various purposes would have different conformations. Animals meant for milk purposes have a different conformation than animals meant for meat. There are no specialized breeds in Ethiopia and animals are generally dual-purpose breeds. However, in areas where milk is an important product, it is wise to select animals with a conformation conducive for milk production. Milk animals should have a larger tract and udder. They have longer, thinner necks and a wedge-shaped appearance. Meat animals, on the other hand, have a stocky appearance and tend to have a rectangular shape.

**Defects:** Sheep and goats to be used for breeding should be free of defects, particularly those of genetic origin, including defects of legs, teeth and testes. In a number of goat breeds, polledness is associated with reduced fertility. Polledness in an otherwise horned goat breed should, therefore, be selected against.

**Legs:** Legs of sheep and goats (particularly males) should not be extremely hocked or curved. The rear (hind) legs should be wide apart and straight when viewed from behind. Poor leg conformation is usually of genetic origin and can affect mating ability of males. Muscling will be demonstrated by a thick thigh and the depth of the twist. Most sheep and goats in Ethiopia have thin thighs which results in lower meat output from the hind quarter.

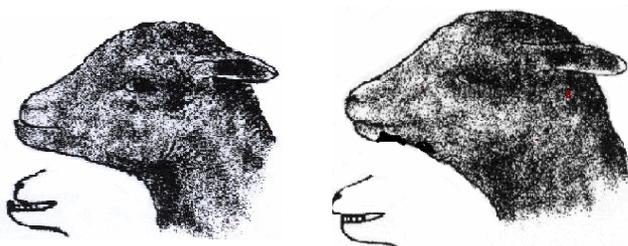
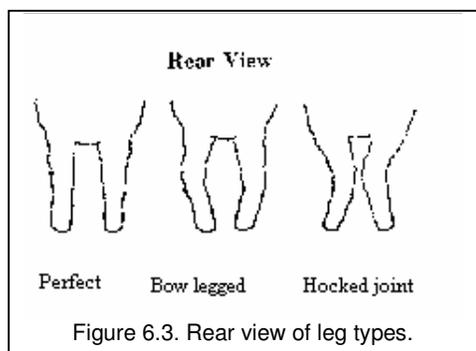


Figure 6.4. Undershot (left) and overshot (right) jaw.

**Teeth:** The incisor teeth on the lower jaw should perfectly meet the edge of the dental pad on the upper jaw for efficient grazing.

Adapted from Goodwin (1979).

Some sheep and goats have an overshot jaw where the upper jaw is longer than the lower while others may have an undershot jaw, in which case the upper jaw is shorter than the lower. In other cases, the teeth are deformed. Such animals, particularly males, should not be used for breeding.

**Testes:** Male sheep and goats selected for breeding should have two large, well-formed, functional, equal sized testicles in a single scrotum (some breeds normally may have a split scrotum). Sperm production is related to the size (circumference and length) of the testicles (Figure 6.5). More semen is produced by males with greater scrotal circumference. Avoid selecting males that show overly pendulous testicles. Males with very hard, small, unbalanced testes and those with scars, bumps and lumps should not be selected for breeding. In addition, the epididymis area at the neck of the scrotum should be free of lumps. These defects may result in low fertility and/or transmission of reproductive disease as some of these defects are caused by pathogenic organisms affecting the reproductive system.

**Udder:** Ewes and does should have well formed udders with good attachment and two well-formed teats. It is important that the udder is constructed in a way that allows offspring to nurse unassisted. The external genitalia of the female should be well developed and properly structured. Vulvas which turn up at the end can cause a problem when the male is serving the female and result in poor fertility. A female that has not given birth or exhibited signs of pregnancy by 18 months of age should be culled.

#### 6.4.2. Records

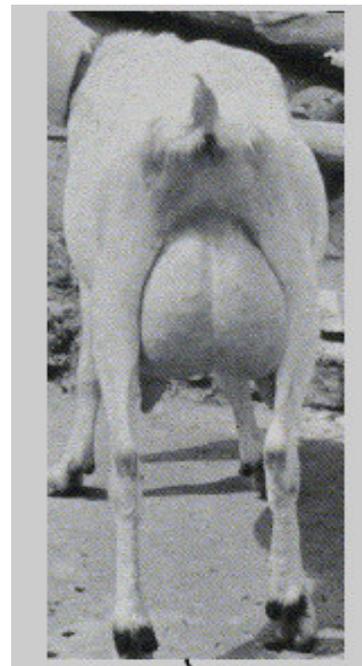
Wherever possible, selection of animals should be based on records of performance. Performance records are even more important for breeding schemes which involve the selection of superior animals from among a group. The interest of the farmer or the breeder could be performance of an animal at a certain age. In this case reliance on memory is of little value and very often not practical. An example would be selecting animals at 18 months of age for a particular market weight at 12 months of age. Unless records of animal weights at one year of age are kept, using personal memory would be valueless.

It is often necessary to keep simple pedigrees such as sire and dam, so that the performance of parents can be related to that of their offspring. This is essential for selection schemes. For crossbreeding, recording the breeds involved might be sufficient unless there is an additional requirement to avoid future inbreeding because of a small number of animals or a small geographic area.

Once a breeding program has started, more record keeping will be needed in order to execute the plan and assess progress. For the flocks from which actual breeding animals are chosen, or in which breeding animals are tested, all the animals should have the appropriate aspects of their performance recorded. In addition, at least a random sample of the herds and flocks associated with the improvement scheme should have performance records kept in order to monitor progress and assess the value of the breeding



Workneh and Rowlands (2004).



Source: Workneh and Rowlands (2004).

Fig. 6.5. Good udder placement in a doe.

program. This sample might be from commercial herds, in which some of the newly improved animals (perhaps rams, bucks or their semen) are used. Records should be restricted to:

- Those essential for the conduct of the improvement scheme and its cost-effectiveness.
- Records that can be maintained and sustained.
- Records that can be analyzed.

## 6.5. Breed Improvement Methods

### 6.5.1. Selection within a breed

Selection is usually done within cohorts within a flock, i.e., among animals of the same age which have been raised together. Genetic progress through selection depends on heritability, selection differential and generation interval.

**Selection differential:** The average superiority of the selected parents relative to their flock contemporaries. Fewer males are usually needed for breeding than females; therefore, selection differential is generally higher for males. Sometimes selection differential can be very large, as it is possible to select very few males with exceptionally high performance for use through artificial insemination.

**Heritability:** The proportion of the superiority of the selected parents which appears in the offspring. It is useful to have an estimate of the heritability for the trait to be improved in order to predict the likely progress from selection. It is preferable if this estimate is made from the population considered for selection before selection starts. This, however, is usually difficult because of unavailability of appropriate records. Published estimates from a similar population kept under similar conditions would be valuable.

Table 6.3. Estimates of heritability ( $h^2$ ) for some traits in sheep and goats.

Traits	Average $h^2$	Range of $h^2$
Sheep and goats		
Milk yield (lactation)	0.38	0.20–0.53
Milk yield (test day)	0.21	0.14–0.31
Birth weight	0.18	0.03–0.43
Weaning weight	0.34	0.08–0.62
Six-month weight	0.21*	
12-month weight	0.33*	
Adult weight	0.39	0.11–0.72
Fleece weight	0.36	0.17–0.57
Fleece quality traits	0.49	0.13–0.72
Number of lambs at birth	0.14	0.00–0.49
Litter weight at birth	0.06	0.00–0.12
Goats six-month weight	0.23**	0.10–0.71***
Goats 12-month weight	0.30**	0.13–0.60***
Goats birth weight	0.04**	0.05–0.68***
Three-month weight	0.16**	0.09–0.75 ***

Source: (Weiner, 1994); \*(Solomon, 2002 estimates for Horro sheep); \*\* (Horst and Mathur, 1991); \*\*\*Shrestha and Fahmy, 2007).

**Generation interval:** Generation interval is defined as the average age of the parents when their offspring or, more strictly, those offspring which are used to replace the parents, are born. The genetic changes which occur as a result of selection happen only when one generation is succeeded by the next. In sheep and goats,

the generation interval is affected by the age when the animals first start to breed. It is also influenced by the interval between successive parturitions and by the number of offspring born on each occasion which survive to breeding age. The earlier in the life of the parent its offspring are born, the closer parturitions follow each other and the more offspring per parturition, the sooner the number needed as replacements is reached. The generation interval for sheep and goats varies between 3 and 5 years.

In sheep and goat selection programs, depending on the objective, the focus could be on a single trait or on multiple traits. Selection for a single trait permits faster progress as compared with selection for more than one trait. Therefore, selection for more than one trait should be avoided unless it is very important (e.g., in case of negative correlation between traits).

### 6.5.1.1. Aids to selection

In selection of animals, different sources of information should be used. These include selection based on individual performance, ancestral performance, progeny performance and performance of other relatives (half sibs, full sibs, uncles and aunts).

#### Performance of an animal (Mass selection)

This is used when the animal's performance is a measure of its genetic merit. This is also used for traits of high heritability where an animal's performance is an accurate guide as to how its progeny will perform. Here, the best individual is selected from within a group of animals of similar age that have been similarly treated (cohorts or contemporaries).

When more than one record of an animal's performance is available (e.g., annual fleece weights or repeated litter performances of a ewe) there is a need to look into consistency of those repeated records to select an animal. Repeatability is a term used to indicate a relationship among consecutive records of an animal. High repeatability indicates consistency in repeated performances while low repeatability indicates a lack of consistency.

Repeatability of certain traits (Table 6.4) is useful in making culling decisions. If the repeatability of a trait is known to be high, the first one or two performance records of an individual animal are strong evidences of future productivity and are sufficient for basing selection decisions. The reverse is true if repeatability is known to be low. In cases of low heritability, all the records of an animal should be considered prior to selecting that individual for breeding.

Using both performance records and pedigree information provides the best base for correct ranking of potential breeding stock in developing countries, especially for animals held in nucleus herds with good record-keeping. Mass selection is also a valuable method for screening animals to form the initial nucleus population.

Animal selection systems that use existing indigenous traditional knowledge and simple methods such as scoring and ranking of only the top 5–10% of animals in the flock are good methods for using more accurate genetic evaluation methods, particularly where flocks are large as in pastoral or highland barley–sheep production systems. It should be noted that within traditional livestock production

Table 6.4. Some general estimates of repeatability for sheep and goats.

Species	Trait	Repeatability (%)
Sheep	Ovulation rate	60–80
	Lambs born per ewe lambing	30–40
	Birth weight	35
	Twinning	16
	60-day weaning weight	25
	Lamb growth (daily gain)	38–48
	Grease Fleece weight	40
	Wool traits (general)	50–80
	Staple length	60
Goats	Milk production (lactation yield)	36
	Daily milk yield	42
	Lactation length	9

systems, livestock keepers (e.g., pastoralists) can identify and rank their stock very accurately. Ranking methods used within these systems can be documented and practically applied if the livestock keepers are involved in the design of evaluation programs from the outset. For example, taking heart girth measurements at specific ages for part of the flock, and considering animals above a certain predetermined level is one method.

### Performance of parents (pedigree information)

For traits with low heritability, it is wise to look at the performance of parents; but for traits with high heritability, measuring an animal's individual performance is more useful in evaluating progress. However, considering pedigree is useful in selecting animals before they reach the age where they can express their performance, e.g., milk production and litter size. Thus, breeding animals can be selected based upon the performance of their parents and grandparents.

Pedigree-based selection might also be used if there is no information on the performance of the animals themselves, perhaps because the trait is related to the sex of the sheep or goat or can be observed only at a later age (milk production, for example). Pedigree selection requires accurate information on the performance of the ancestors of the animals in question. This information is unlikely to exist for sheep and goats in Ethiopia. But in selecting animals for breeding, progenies of animals with proven ability to give birth and wean multiple offspring may need to be considered. This should have a close relationship with the breeding objective.

Pastoralists and farmers try to keep females that have good twinning rates and mothering ability (as judged by lamb growth). But at times, this may be confounded by the environmental effect of preferential management provided to such animals.

### Performance of progenies

Sheep and goats can be selected on the basis of the performance of their own offspring. This is useful when the heritability of the trait is low, or where the trait can be measured only in one sex (milk production, for instance) or can be measured only after slaughter (carcass characteristics). To carry out a successful progeny testing scheme, a large enough number of offspring from each male may be required. This system may have limited value for the improvement of sheep and goat production in Ethiopia because of the time and cost required, as it prolongs the generation interval.

### Performance of other relatives (family selection)

Information from relatives other than ancestors and progenies can supplement the information from the individual itself and thereby improve the accuracy with which the individual's breeding value can be assessed. These include full sibs (brothers and sisters from the same father and mother) and half sibs (brothers and sisters from the same father or mother). This can be helpful for sex-limited traits and for traits which need measurements that cannot be taken on the candidate animal (e.g., carcass traits).

#### 6.5.1.2. Methods of selection for more than one trait

There are three methods of selecting for more than one trait; tandem selection, independent culling levels and index selection.

**Tandem selection:** This is selection for one trait or character at a time until it reaches an acceptable level followed by selection for a second trait, then a third trait, and so on. For instance, the milk yield of goats may be improved in the first case and then growth (meat production) would be addressed. Under tandem selection, if there is positive correlation between the traits to be considered, improvement can be realized in the second trait even as selection is applied only for the first trait. The disadvantage of this system is if a negative correlation exists between the two traits. In that case, performance of the second trait will decline

as a result of selection for the first trait or selection for the second trait will erode progress made in the first trait.

**Independent culling level:** Selection of sheep and goats based on independent culling level sets a certain accepted level of means for automatic culling of animals. It is like an examination system with different pass marks for each subject, but if the student fails one subject, then he/she fails in all. There is no compensation for poor performance in one trait by superior performance in another. This method is most useful when there are a small number of traits (usually two) and where selection is done at different stages in an animal's life. For instance, we may cull some animals for poor performance in weaning weight and then later for reproductive performance. The disadvantage of this method is that exceptionally superior animals for one trait cannot be selected if they perform below the standard set for the second trait.

**Index selection:** In an index selection, traits are combined to provide a single criterion merit, often economic-based. This type of selection is usually closer to the desire of farmers. With selection done on an index, deficiencies in any one trait can be compensated by outstanding performance in other traits; an option which is not available when using independent culling levels. While index is the most efficient of the three methods, an index is the most complicated to create and requires a team of experts to construct the index weights.

### 6.5.2. Crossbreeding (indigenous with indigenous; exotic with indigenous)

Crossbreeding aims to:

- combine all desirable characteristics of two or more breeds in one progeny type, and
- exploit the hybrid vigor or heterosis that occurs in crossbreeding. Heterosis or hybrid vigor refers to the superiority in the performance of a crossbred individual above the average performance of the two parents.

Crossbreeding may improve the performance of sheep and goats under good management conditions if the parental breeds involved in the crossbreeding are carefully chosen.

#### 6.5.2.1. The need for crossbreeding

Opportunities to raise productivity through the use of temperate breeds are minimal in many Ethiopian situations because these exotic breeds need an improved production environment, a costly exercise. Therefore, there is a need to improve indigenous breeds to raise their production potential. High-yielding exotic animals or their crosses could be maintained in specific niche areas where it is possible to provide high inputs. This could be targeted for specific markets where fast growing animals and more uniform products are required.

Native breeds are often well-adapted to local conditions — climate, nutrition, disease exposure and so on. These breeds are rarely thought to be perfect in all aspects and improvements in productivity are desired. Improvements in feeding and management will often, on their own, bring increases in animal productivity. However, changing the genotype will often improve productivity drastically, and may enable more efficient use of any extra feed and improved management that can be provided.

The most rapid way of making genetic change is to introduce some of the characteristics of a new breed by crossing it with an indigenous breed. The most popular way is to use males of the new breed either directly through natural mating or indirectly through semen used in artificial insemination.

The first expectation from crossing two breeds is that the performance of their progeny will be half-way between the average performances of the two parent breeds. A second expectation with crossbreeding is that of heterosis or hybrid vigor. Heterosis occurs to differing degrees for different traits of the animals and for

different breed combinations. The occurrence of heterosis is directly proportional to the degree of heterozygosity.

<b>Examples</b>	
<p><b>Example 1</b></p> <p><i>Performance of a crossbred : additive gene action</i></p> <ul style="list-style-type: none"> <li>● Post-weaning growth:           <ul style="list-style-type: none"> <li>● Breed A = 100 g/day</li> <li>● Breed B = 140 g/day.</li> </ul> </li> <li>● Expected post-weaning growth:           <ul style="list-style-type: none"> <li>● Crossbred = 120 g/day.</li> </ul> </li> </ul>	<p><b>Example 2</b></p> <p><i>Performance of a crossbred: the effect of heterosis</i></p> <ul style="list-style-type: none"> <li>● Post-weaning growth:           <ul style="list-style-type: none"> <li>● Breed A = 100 g/day</li> <li>● Breed B = 140 g/day</li> <li>● Crossbred = 132 g/day</li> </ul> </li> <li>● Average of breeds:           <ul style="list-style-type: none"> <li>● A + B = 120 g/day</li> </ul> </li> <li>● Difference (estimate of heterosis):           <ul style="list-style-type: none"> <li>● = (132–120)</li> <li>● = 12 g/day</li> </ul> </li> </ul>

Heterosis can be to the extent that the crossbreds could show performance over both of the parents. This is important if farmers plan to mate two breeds where each is successful in the locality (two different indigenous breeds) with the desired result of the crossbred being superior to the two foundation breeds. If this is not the case, it would be more sensible for farmers to replace the poorer of the two breeds by the better. This can be done directly or by grading-up.

The expression of heterosis is always at its maximum (100%) in the first cross between two breeds (F1). Varying amounts of the heterosis are lost in later generations of crossing because some of the heterozygosity in gene pairs is lost, which is called recombination loss.

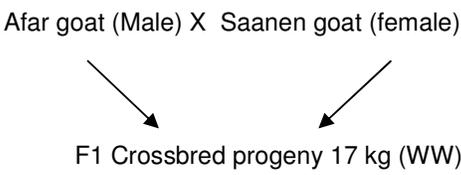
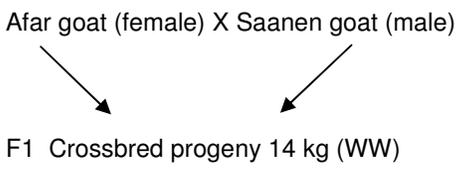
### Reciprocal crosses

For accurate comparison of crossbred performance with purebred performance, it is theoretically required that the cross should have been made in both of the two possible ways:

- females of breed A (e.g., local breed) mated to males of breed B (e.g., an exotic breed); or
- females of breed B mated to males of breed A.

These two variants are called reciprocal crosses. Though genetically alike, they differ because the reciprocal crosses have had a different maternal environment: one from dams of the local breed (breed A), the other from dams of the exotic breed (breed B). These maternal influences can be important for the offspring at the time of birth and, perhaps, up to the time of weaning. After weaning, the importance of the maternal effect usually lessens but sometimes never disappears completely.

The effect on the offspring arises because different maternal environments may provide the fetus and, later, the newborn animal with different advantages at the start of life. One breed may supply the crossbred offspring with better nutrition even before birth and may have better mothering abilities thereafter. Locally adapted dams may give the newborn a better supply of antibodies in the colostrum than dams of a recently imported or exotic breed.

<b>Examples</b>	
<i>Weaning weight (WW) of kids from reciprocal crosses of Afar and Saanen goats (hypothetical)</i>	
Afar goat (Male) X Saanen goat (female)  F1 Crossbred progeny 17 kg (WW)	Afar goat (female) X Saanen goat (male)  F1 Crossbred progeny 14 kg (WW)
<p>The first crossbred progeny has a dam breed known for its milk production. Therefore, kids are likely to get adequate milk and show better growth rate than kids born from Afar dams with lower levels of milk production compared with the Saanen.</p>	

With crossbreeding, in addition to the quantity of product being changed, quality may also be affected. Sometimes the change in quality could be in an undesirable direction. Therefore, sufficient information on quality aspects needs to be gathered before embarking on a large-scale crossbreeding operation. For example, skin from most sheep and goats in Ethiopia is desirable for the leather industry. With crossbreeding, the quality of the skin may become undesirable for the leather industry. On the other hand, skin from lowland sheep is usually undesirable and crossbreeding (particularly local × local) may improve the skin quality of animals from this area. Crossbreds may also produce meat with undesirable taste or fat content (lack or excess) and this also needs to be considered in selection of the improver breed for crossbreeding.

Crossbreeding should be considered if:

- the trait to be improved has a low heritability;
- the current management of local animals is good, or if there is an effective extension program that is improving management;
- the environment has the potential to allow real improvements in management;
- quick results are needed; and
- there are no changes in quality of products from crossbred animals or these changes are acceptable.

Crossbreeding should be considered only if the crossbreds are going to live in an environment that allows them to express their improved potential and perform well. To get real benefits from crossbreeding, the environment should have the potential for improvement.

One major advantage of crossbreeding, which is rarely considered, is the effect it can have on an extension program. The crossbred sheep or goat is a new animal, it may look different, it can certainly perform differently, and so it quite quickly captures the interest and enthusiasm of producers. This can be a vital boost to extension programs and, in the process of breed improvement, can motivate owners to adopt the improved management strategies being promoted simultaneously.

In choosing improver breeds for crossbreeding, the following factors need to be considered:

- **Environment:** The crossbred should have the ability to perform well under the environmental conditions where production would take place.

- **Desired production characteristics:** The crossbred should show the type and level of production which is set as a goal.
- **Desired adaptation characteristics:** The crossbred should show the desired adaptation in terms of ability to survive, reproduce and produce.
- **Past experience:** It would be very helpful if information is available on the performance of the crossbred in the area or other similar areas to which the crossbred is to be used.
- **Ease of access to new breed:** Sustainability of a crossbreeding program usually depends on the availability of the two parental breeds. This should be considered before embarking on a crossbreeding program.
- **Cost of new breed:** Paying prohibitive prices to acquire one or two of the breeds involved in the crossbreeding program can affect the profitability and sustainability of a crossbreeding program.

### 6.5.2.2. Types of crossbreeding

There exist different systems of crossbreeding which may involve two or more breeds. Different objectives demand different types of crossbreeding.

#### Grading-up

Grading-up is the name given to continuous back-crossing using males of one breed, or a crossbred type, first on females of the breed intended to be graded-up and then on the succeeding generations of crossbred offspring which arise from the matings. This increases the percentage of genes from the desired sire breed.

**Grading-up to an exotic breed:** Grading-up is most commonly thought of in terms of using males of a breed imported from another country. Grading-up can equally be carried out using one local breed to replace another by continuous back-crossing.

#### Example

##### *Grading up to an exotic breed*

The Awassi sheep breed is crossed with the Menz; the first crosses are mated again to the Awassi; and it continues like this for every successive generation.

The proportion of Awassi blood (Awassi genes) increases from 0.50 to 0.75 to 0.875 to 0.9375 to 0.96875 to 0.984375. After four generations, the crossbred animals are practically indistinguishable from purebred Awassi.

**Grading-up to 50% or 75% exotic genes:** Establishing a population of animals with 50% or 75% exotic genes can be done in 4–5 generations of continuous back-crossing. Females of a local breed are mated with sires having either 50% or 75% exotic genes. The succeeding generations are continually mated with sires having the desired gene mix, ultimately giving offspring with the desired proportion (50% or 75%) of exotic blood. This type of grading-up is appropriate when there is prior evidence that the optimum proportion of exotic blood is either 50% or 75% for the conditions under which the animals have to perform.

#### Continuous production of F1s

Two pure breeds are used repeatedly to produce only first generation crosses (F1s). In terms of the additive genetic effects, the F1 is halfway between the performance levels of the two parent breeds contributing to the cross. However, the F1 generation displays the whole of any heterosis which is achievable as a result of crossing the two breeds.

Consideration needs to be given to the relative importance of the additive genetic and heterotic effects, and to the proportion of the population which can be maintained as crosses. This information will determine whether continuous production of F1 is feasible.

### Rotational crossing

Two or more breeds are used in rotation. The males are always purebred. First one breed is used, followed by the second breed, and so on until the sequence is complete. It then starts again with the first breed used. The females to which the males are mated are purebred only for the first generation of mating. Crossbred females are used in subsequent generations.

**Rotation of two breeds:** The system of using two breeds in rotation, also called crisscrossing, produces the whole of the potential heterosis in the first generation (F1), half in the second (first back-cross) and variable proportions, between  $\frac{2}{3}$  and  $\frac{3}{4}$ , in subsequent generations. Due to the fact that all females are crossbred after the first generation, there is also the benefit of maternal heterosis for traits where this is important.

**Rotation of three breeds:** The males used are always pure and used in rotation, following the same principle as for crisscrossing.

Table 6.5. Example of rotational crossing using two breeds.

Generation	Parents*		Offspring	Genes (% from)		Heterosis (approx. %)
	Female	Male		M	A	
1	M	A	MA	50	50	100
2	MA	M	M/MA	75	25	50
3	M/MA	A	A/(M/MA)	37	63	75
4	A/(M/MA)	M	M/[A/(M/MA)]	69	31	62
5	etc.	A	etc.	34	66	69
etc.						

\* M = Menz A = Awassi

Table 6.6. Example of rotational crossing using three breeds.

Generation	Parents*		Offspring	Genes (% from)			Heterosis (%)
	Female	Male		M	A	D	
1	M	A	MA	50	50	-	100
2	MA	D	D/MA	25	25	50	100
3	D/MA	M	M/(D/MA)	63	12	25	75
4	M/(D/MA)	A	A/[M/(D/MA)]	32	56	12	88
5	etc.	D	etc.	16	28	56	88
6	etc.	M	etc.	58	14	28	84

\*M = Menz A = Awassi D = Dorper

### New breed formation (synthetics)

New breeds formed from two or more constituent breeds are called synthetic, composite or blended breeds. New breeds can be synthesized from crosses combining breeds in virtually any proportion, first crosses or various back-crosses of two breeds, or combinations of more than two breeds.

The desired breed combination has to be determined on the basis of the early performance of crosses and from an estimate of the importance of heterosis. The desired crossbred type is then interbred for several

generations. Selection can and should be used alongside this process to improve the production characteristics. This system has more sustainability once the new breed has been established.

Examples of new breed formation in the tropics and elsewhere are the Kenyan Dual-Purpose Goat, which involved two exotic breeds, i.e., Anglo-Nubian and Toggenburg and two indigenous breeds, namely the Small East African and the Somali-Boran goats and Dorper sheep which is composed of Dorset Horn and Blackhead Persian, hence the name Dorper.

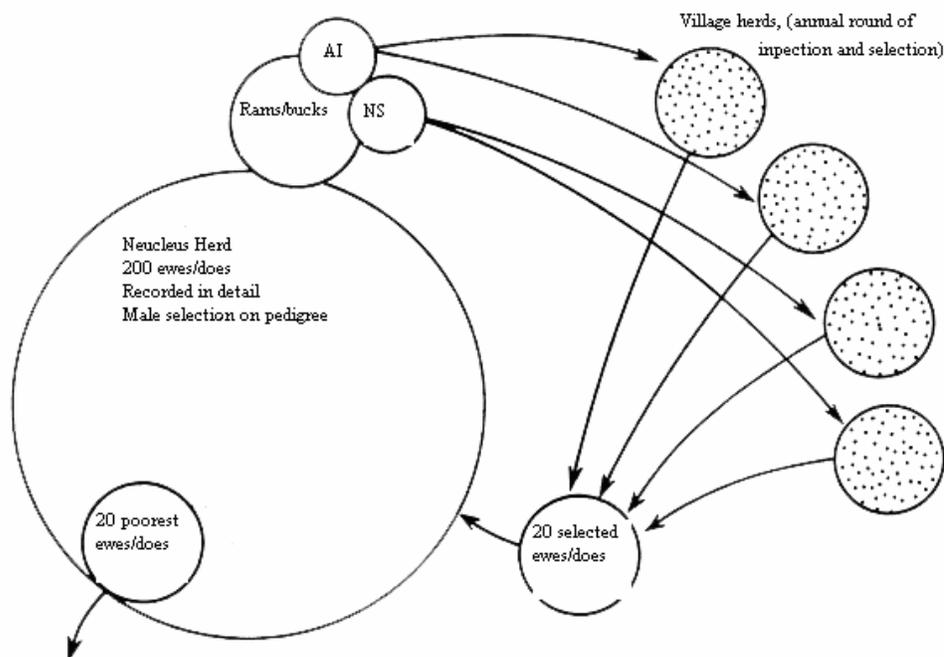
## 6.6. Breeding (Selection) Schemes

A selection scheme provides the framework for putting the various selection methods into practice. Sheep and goats in Ethiopia are kept in small flocks by individual owners. The small flock size limits selection. Selection works most effectively when large numbers of animals are involved. A system of selection by which farmers pool their sheep and goats together would be more appropriate.

### 6.6.1. Nucleus selection schemes

This is a system whereby a number of flock owners agree to cooperate by deciding on common breeding objectives and by pooling their animal resources. The key is the creation of a nucleus flock from the best breeding males and females from each participating flock. If the selection scheme goes according to plan, the animals in the nucleus flock will become genetically superior to any outside animals after a few generations.

If, however, the nucleus remains closed to all outside blood, whether from the cooperating flocks or from others, inbreeding may arise with deleterious effects. Also, the nucleus would not benefit from the introduction of exceptionally good animals which may occur in the cooperating flocks, or elsewhere. It is wise to keep the nucleus open to the introduction of animals for some generations. This is usually done by an annual introduction of the very best of the breeding females from the cooperating flocks. These females have to compete, in terms of their performance, with the females already in the nucleus. As a result of performance comparisons, they either replace some of the nucleus flock or are culled.



Adopted from Horst and Mathur (1991).

Figure 6.6. Open nucleus breeding scheme.

### 6.6.2. Practical breed improvement for individual farms

Breed improvement can take place at different levels in a sheep or goat population, e.g., from an individual or village flock standpoint. Individual owners should always try to improve their flock, whatever size it is.

What can an individual owner do to improve the genetic potential of his or her sheep and goats? In smaller flocks, there is little scope for selection, so the approach should be to try to counteract the negative effects of inbreeding, or grading-up through crossbreeding. In the Bako area, about 94% of the farmers sell either the best animals they have or sell indiscriminately. This eliminates the larger, faster-growing animals, leaving only smaller or stunted animals for breeding. This is negative selection and results in the production of inferior animals. Individual farmers should be cautioned against this practice.

A young male sheep or goat should be removed from its flock before it achieves reproductive maturity. This can be done through exchange sale or through castration. If the male is allowed to stay fertile in the flock in which it is born, then there is a high probability it will mate with its own dam and other full- and half-sib females. Females with ability to give and raise twins may be selected while females with poor ability to raise and bear twins are culled.

### 6.6.3. Sire rotation and utilization

Wherever possible, the best bucks in the flock should be selected and used for service. In order to reduce inbreeding, a buck should never be allowed to mate with his full sisters, his daughters, his granddaughters or his dam. Additionally, the number of years a male serves should be limited to one. The male should then be replaced either through exchange with other flock owners or through purchase of a new sire.

Farmers within a certain area may reach agreements to exchange the best rams from their flocks with other farmers engaged in the exchange on a rotational basis. If exchange is not done, males at the end of their service can be sold immediately or can be castrated for later marketing at good condition. In practice, farmers should be advised to exchange sires annually.

### 6.6.4. Problems in breeding schemes

Pure breeding schemes usually require a long period of time for realization of sizeable improvement whereas crossbreeding schemes result in fast change but may suffer from lack of sustainability. Use of F1 generations requires maintaining both parental breeds. This may be difficult, particularly if exotic breeds are involved.

The best option in many cases may be to form a stable breed (synthetic breed) after the formation of the F1 or after some grading up. Synthetic animals can mate among themselves and could result in a more sustainable system than production of F1 animals. Production of F1 animals could be considered if these animals would show exceptionally high levels of performance compared to the average of the two parents (positive heterosis), in which case, maintaining the two parental breeds could be beneficial. One important aspect of breeding at the smallholder level is absence of controlled mating. Male and female animals of reproductive age are herded together, and mating designed to bring genetic improvement is difficult to implement.

### 6.6.5. Inbreeding

Inbreeding results from the mating of related individuals, i.e., those with common ancestry. This may happen when the size of the breeding population decreases. Selection tends to increase inbreeding because it reduces the breeding population by restricting reproduction to a few animals, especially on the sire side. The key to searching a pedigree for evidence of inbreeding is to look for those 'common ancestors' that appear on both sides of the pedigree. If the parents of an animal (the subject of the pedigree) have common ancestors in the

recent pedigree, then the offspring will be inbred. This degree of inbreeding can be calculated and expressed as the 'inbreeding coefficient.'

The level of inbreeding depends on the closeness of the relationship between the parents. Either or both parents may be inbred themselves, but if they are not related to each other then the subject cannot be inbred. The common practice of keeping male and female animals in the same flock and using sires in the flock in which they were born will increase inbreeding.

The consequences of inbreeding in sheep and goats have two aspects: inbreeding depression and expression of recessive defects.

**Inbreeding depression** is the gradual lowering in performance of traits, particularly those associated with fertility, survival and size. It reduces traits such as growth rate, disease resistance, reproductive performance and viability. Tracing the problem of inbreeding depression may take time. A very rapid rise in inbreeding usually brings out problems more quickly than a slow build up and some traits are more readily and severely affected than others.

Some genes, which are responsible for **defects**, such as undershot jaw, dwarfism, odd colors and so on, usually express themselves only when they are in a homozygous condition and the homologous pair is dominant. These traits are rarely seen as animals carry these genes in a heterozygous state (carriers). Inbreeding increases the chance that the genes will combine in a homozygous state and the defect will appear. Whenever such defects appear in a sheep or goat, its parents are assumed to be carriers and should be culled. This is especially true for males as they have more chance of transmitting the defects.

Should inbreeding be suspected, a completely unrelated sire guaranteed free from the defect should be used for mating. Known carriers of these defects can be used to mate with other animals for testing. An example of this could be the mating of a ram or buck intended for widespread AI use to about 15 to 20 of his own daughters. If there are any recessive genetic defects in the male, they should appear in offspring of these matings. Then the breeder will decide whether to accept the animal as a semen donor.

Increases in population size and careful monitoring of mating programs help to avoid inbreeding or reduce its level to a minimum. An inbreeding level greater than 6% cannot be tolerated in most circumstances.

Table 6.7. Examples of different intensities of inbreeding expressed as a coefficient of inbreeding (%).

Generation	Self-fertilization	Mating full sibs	Sire × offspring	One-sire flock	Three-sire flock	Five-sire flock
1	50	25	25	2.5	0.8	0.5
2	75	38	38	5.0	1.6	1.0
3	88	50	44	7.5	2.4	1.5
4	94	59	47	10.0	3.2	2.0
5	97	67	48	12.5	4.0	2.5

Adopted from: Dalton, 1980.

## 6.7. Breed Conservation and Utilization

### 6.7.1. Rationale for conservation and characterization

Indigenous breeds of sheep and goats may produce less milk or meat than improved breeds. But they usually fulfill a wider range of functions for their owners and are much easier to manage. Many marginal areas can be exploited only by locally adapted breeds or species. For example, camels are the only livestock in areas with less than 50 mm of rainfall. If these animals die out, it will no longer be possible to use large areas of arid lands to produce food.

Additionally, the genetic diversity they embody enables breeders to respond to changes in production, marketing and the natural environment. The adaptation of different species and breeds to a broad range of environments provides the necessary variability that offers opportunities to meet the increased future demands for food and provide flexibility to respond to changing markets and needs. However, currently, there is a threat of loss of genetic diversity in livestock populations to the extent that some breeds may be approaching extinction. This calls for strong conservation activity.

The first step in conservation is to know which breed to conserve. This can be done through characterization. The main reasons behind characterization of animal genetic resources include:

- Threats to the indigenous livestock.
- The existence of a number of different breeds similarly named after a location, ethnic group or by physical characteristics that may not necessarily be genetically similar.
- Most animal censuses in developing countries are done by species, which does not allow an accurate depiction of the population trend of individual breeds over time in order to determine populations at risk of extinction.
- Little knowledge of existing breeds to understand:
  1. Unique qualities of the breed, e.g., particular adaptation to the local environment.
  2. The potential contribution to productivity if treated as improved breeds.
  3. The potential genetic variability that could be useful in the future.
  4. Determination of any special genes of merit.
  5. The genetic variability (within and between breeds) available for future needs.

### 6.7.2. Characterization and conservation methodology

Characterization consists of collecting information on available stocks and the environment in which the stocks are performing. Basic information includes:

- Preliminary characteristics such as type/breed/variety; predominant location and climatic conditions; utility, management and production systems; physical and special genetic characteristics; production traits; and population status, and
- DNA information about genetic distinctiveness, and genes responsible for valuable traits.

Basically, conservation is categorized into *ex situ* and *in situ* conservation.

*Ex situ* conservation is done through cryo-preservation of animal germplasm by storing sperm, oocytes and embryos and also through preservation of live animals of endangered breeds out of the area where they are originally kept. For cryo-preservation technique to be effective, progeny of at least 25 sires should be stored. The facilities in Ethiopia for this technique are not well developed. The germplasm can be collected in Ethiopia and may be stored in countries where facilities are available.

*In situ* conservation is the preservation, multiplication and utilization of indigenous breeds in their native habitats and maintenance of pure breeds or strains. The minimum number of animals recommended for sheep and goats is 60 and the maximum is 1500 ewes or does. Special conservation flocks can be established as part of the cultural heritage for endangered breeds or breeds in critical status. Nucleus breeding flocks can be established in cooperative breeding programs to supply breeding stock to farmers.

*In situ* conservation requires good management of the conserved flock. Local communities which keep indigenous animals are crucial in conservation of animals through sustainable utilization. Practical ways of

improvement in the productivity of indigenous animals would be an incentive to encourage local communities to continue keeping such animals.

The choice of conservation method depends on the safety offered and the cost involved. Breeds to be given priority in conservation programs should be selected based on their comparative advantage obtained through objective evaluation. Priority should be given to:

- Breeds that have reached critical or endangered status.
- Genetically diverse stocks.
- Breeds with unique characteristics.
- Stocks with high overall economic merit.

### Transferable Messages

- Sheep and goats can be productive if they are provided with the right type of management (environment) and if they have the genetic potential. Therefore, farmers should be advised on ways of manipulating both management and genetics to improve the productivity of their sheep and goat flocks.
- Increases in production through genetic means can be realized by keeping the best animals as parents of the next generation. Progress can be achieved by advising farmers not to sell (with the intention of getting more money from the sale) their best animals and not to sell indiscriminately. Rather, farmers should keep superior males for exchange and superior females for replacement.
- Nucleus breeding programs are expected to expedite genetic progress more than can be realized in individual flocks. In areas where farmers are willing to be involved in this activity, a nucleus flock needs to be established. Exchange of selected rams and bucks among farmers is another option to improve productivity under smallholder farmer conditions.
- When heritability of a trait is low, within-breed selection usually results in slow change or improvement. Crossbreeding, on the other hand, results in faster progress, given there is improvement in management. Depending on prevailing conditions, crossbreeding may need to be practiced.
- Because of the usually small flock size and because of mating between closely related individuals, inbreeding in sheep and goat flocks of Ethiopia is likely to be high. Farmers should be made aware of this and taught ways to avoid inbreeding and use of inferior males (through selection of the right type of male and sire exchange).
- The genetic diversity of sheep and goats needs to be maintained for current and future use. Different conservation methods should be considered when animals are at risk of extinction.

### Exercises

Describe how productivity in sheep and goats would be determined.

Under what situations do you decide to improve indigenous sheep and goats through

- Selection?
- Crossbreeding?

There are various aids in selection. What would determine the type of aid to be used?

What options do farmers have to improve small sheep and goat flocks?

What are the disadvantages of inbreeding and what advice can be given to farmers to avoid

inbreeding?

What is the importance of conservation?

## Glossary

**Breed:** Is either a sub-specific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species, or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity.

**Breeding (animal):** The practical application of genetic principles for development of lines of domestic animals suited to human purposes.

**Closed nucleus:** A nucleus flock that, once established, does not allow introduction of new animals.

**Conservation:** All human activities, including strategies, plans, policies and actions undertaken to ensure that the diversity of farm animal genetic resources is being maintained to contribute to food and agriculture production and productivity, now and in the future.

**Crossbreeding:** A mating scheme utilizing two or more breeds.

**Ex situ breed conservation:** Conserving a breed of animals by freezing sperm, oocytes, and embryos in liquid nitrogen.

**F1:** First generation offspring of a mating between two different breeds.

**Full-sibs:** Animals having the same dam and sire.

**Gene:** Basic unit of heredity that is located on chromosomes and affects a specific trait.

**Generation interval:** Average time between birth of an animal and birth of its replacement.

**Genotype:** The genetic make-up of an animal.

**Grading-up:** Repeated mating of females and their female offspring with sires of a particular breed to produce a crossbred animal indistinguishable from the desired sire breed.

**Half-sibs:** Animals having one parent in common.

**Heritability:** The amount of variation in a trait which is due to genetic differences.

**Heterosis:** The increase in performance associated with the crossbred animal when compared to the average of the purebred parents.

**Heterozygous:** A gene pair with different genes for the same trait.

**Homozygous:** A gene pair where both genes are identical.

**Inbreeding:** Mating of individual animals that have common ancestry and are closely related, e.g., dam and son, siblings, etc.

**Inbreeding coefficient:** A calculated numerical expression of the amount of inbreeding of an individual.

**Inbreeding depression:** Reduction in performance due to inbreeding.

**Independent culling levels:** A method of selecting for multiple traits where a minimum level of performance is set for each. Animals are culled when failing to meet any criteria.

**Index selection:** Combining traits, often based upon economics, to devise a single selection criterion.

**Individual selection:** Selecting parent stock based on performance or phenotype.

**In situ breed conservation:** Conserving a breed by preserving, multiplying and maintaining live animals of the breed.

**Locus:** The position on a chromosome where genes are found.

**Nucleus flock:** A flock or herd of the best animals available for the purpose of developing superior stock. A breeding scheme used by a group of producers to pool their best animals into one flock for the purpose of developing superior animals.

- Open nucleus:** Nucleus flock that continually allows introduction of superior animals from cooperator flocks.
- Pedigree selection:** Selection of breeding individuals based upon performance of their relatives.
- Phenotype:** The expression of genetic traits.
- Prolificacy:** Ability to reproduce; rate of reproduction.
- Puberty:** Period in time during which the reproductive system acquires mature form and function.
- Reciprocal crossing:** Mating both females and males of two breeds with each other to evaluate each breed's maternal and paternal effects.
- Rotational crossing:** Mating scheme using two or more breeds in succession.
- Selection:** Any natural or artificial process that permits an increase in the proportion of certain genotypes or groups of genotypes in succeeding generations in relation to others.
- Selection differential:** Average superiority of selected parents relative to flock contemporaries.
- Tandem selection:** A breeding scheme selecting multiple traits focusing on one trait at a time.

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