Genetic Improvement and Crossbreeding in Meat Goats
Lessons in Animal Breeding for Goats Bred and Raised for Meat

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Unit Objective

After completion of this module of instruction the producer should be able to use breeding terminology and concepts and distinguish between facts and old wives tales for the development of a genetic based breeding program that over time will improve the genotype of your goat operation. The producer should be able to evaluate the individual goat herd and select bucks that will improve and enhance the financial structure of the goat program. The producer should be able to complete all assignments with 100% accuracy and score a minimum of 85% on the module test.

Specific Objectives

After completion of this instructional module the producer should be able to:

1. Match specific terms associated with animal breeding to the correct definition.
2. State the purpose of genetic change in meat goats.
3. State the key component of a breeding goal.
4. Identify key life-time doe productivity traits.
5. State the purpose of keeping accurate production records.
6. Define breed. State the basic characteristics of each of several breeds used in producing market goats.
7. Identify the basic tools for making genetic improvement.
8. Identify the two aspects of artificial selection.
9. Identify some observable traits within the meat goat.
10. Identify some measurable traits within the meat goat.
11. Name the person that gave us an understanding of basic genetics.
12. Identify the number of chromosomes in goat body cells.
13. Distinguish between homozygous and heterozygous genotype.
14. Identify Mendel's two fundamental biological laws as applied to inheritance.
15. Identify the two exceptions to the law of independent assortment.
16. State the percentage of chromosomes contributed by the doe and the buck.
17. Distinguish between additive and non-additive gene action.
18. Match the degree of dominance to the correct definition.
19. Distinguish between simply-inherited and polygenic traits.
20. Match the basic genetic model for quantitative traits to their definition.
21. Match terms related to statistics and their application to quantitative traits, to the correct definition.
22. Select the three basic aspects of covariation.
23. Distinguish between heritability and repeat ability.
24. Match selected traits to their heritability value.

25. Identify factors affecting the rate of genetic change.
26. Select some factors that influence birth weight.
27. Select several factors that influence weaning weight.
28. Identify the four factors which are involved in determining rate of genetic change through selection.
29. Identify factors affecting accuracy of prediction.
30. State the meaning of multiple-trait selection.
31. Match the different mating systems to the correct definition.
32. Select the two bases of mating strategies.
33. Distinguish between random mating and planned assortive mating.
34. Select mating strategies which are based on pedigree relationships.
35. Identify the two most important genetic reasons to outbreed.
36. Identify criteria that should be used to evaluate a crossbreeding system.
37. Distinguish between a rotational crossbreeding system and a two-breed rotational system.
38. State the meaning of composites.
39. Evaluate the current breeding program of your individual goat farm.
40. Explain any modifications in the animal breeding program currently being used on your goat farm.

Module Contents

Why Are You Interested In Breeding and Genetic Change?

Let's guess! You want to breed a meat goat that grows fast, is heavily muscled, gives birth unassisted to a large number of kids, weans them all at heavy weights, is an easy keeper and robust in constitution, produces regularly, is not bothered much by internal parasites, is attractive to the eye, produces plenty of milk for the kids, and sells for a seasonally high price. Now, if you can just purchase the right buck, all these things will come true. Right?

Wrong. Why? Well, there are a number of reasons. In this first section we will focus on some of those reasons, and perhaps create more reasonable expectations. It is not our business to burst your dreams. What we want to do is to transfer information that will allow you to evaluate your expectations on the basis of a fundamental understanding of the scientific facts as we know them now.

You are correct in noting that most serious research in meat goat breeding is of recent advent, and there perhaps has not been enough time and effort expended to add much to the pool of information that can be recommended. This would justify your continuing to base selection and mating decisions on the old wives tales or electronic chat-rooms; many of which still include incomplete information or misinformation. Upon completing this module, you will now have a useful understanding from genetics and breeding research from other livestock species, and enough from meat goats specifically, to set some records straight.

The unique feature of making genetic change is that it is permanent. That means that within any particular generation, once the genetic code is set at conception, it will not likely change … it is extremely rare that any sort of sustainable change will occur. This means that all non-genetic variables, management if you will, can be tailored to a particular collection of genes --- a genotype. Once the genotype is set, it will not change and does not need daily attention. Sires do not get genetically better over time; but more on that later.

Seeing the whole picture

In breeding better goats, we are mainly concerned with changing animal populations genetically. From a breeding standpoint you want to know not only the most desirable phenotypes, but the most desirable genotypes as well. That is because a goat's genotype provides the genetic background for its phenotype. Consider the equation:

$$P = G + E$$

where, P represents an individual goat's phenotype (appearance or level of performance), G = genotype or genetic make-up, and E = environmental effects; all non-genetic factors. An animal's phenotype is determined by its genotype and the environment in which it is working. *Changing "G" is the overarching goal of a goat breeding program. Defining breeding objectives and setting up a strategy spring forth from that overarching goal.*

For most characteristics both the genotype and the environmental effects will play a measurable role. For any particular trait, the genotype refers to just those genes and gene combinations that affect that trait, e.g. rate of growth. We can also speak of the genotype in general, as meaning all the genes and gene combinations that affect the whole list of traits of importance to your production system. Most production systems will include these four components:

- Animal genotypes
- The physical environment
- Fixed resources and management factors
- Economic and social considerations

Purpose of genetic change in meat goats

Contrary to conventional wisdom, the purpose of breeding better goats is not to genetically change individual animals, but to improve populations of individuals; to improve future generations of goats; to make permanent change at the cellular level. Breeding for a better goat is a process that does take "daily" attention. There are data to collect, observations to be made, disposition and behavior to observe, mating decisions to make, and selection decisions to be made. It is an on-going process, and we have included in this module several tips and guidelines to help you avoid big mistakes and gain the most use of your goat breeding knowledge.

Breeding goals

What do you want to achieve? A focus on lifetime productivity makes a lot of sense. What are the components? There is an underlying genetic basis for virtually all traits or characteristics on which to focus. It is fair to suggest there are no *"right" nor "wrong"* goals. It is useful to understand that generally the more traits included in a breeding program, the slower will be the progress in each one. So a key to moving ahead with a reasonable amount of speed is to *identify and focus on only the key components of the goal* — lifetime productivity.

People raise meat goats for a variety of reasons, including reasons that have no focus on financial return. In those cases there may be no identifiable breeding goal. Survival of the animals may be the only production goal involved. There may be no focus on particular breeds or their improvement. This module may not hold interest for goat owners in that situation. That's ok.

Breeding for performance will involve a number of traits. Performance in that case a composite measure, such as life-time productivity will be the focus. There is little regard to traits such as color or color pattern. Life-time productivity includes elements of survival, fertility and prolificacy, udder characteristics and milk production, growth rate and ability to maintain body condition. While these traits may seem to focus primarily on females, it is the young sons of those females that should be chosen to sire the next generation.

Life-time doe productivity is a composite trait that includes components of

- fertility level,
- prolificacy,

- milk production,
- genetic merit in growth,
- seasonality in fertility, and
- health

As an example, the components of lifetime doe productivity could include the following elements:

- An accelerated kidding program (three kid crops in two years) is followed.
- The doe's useful productive life of 5.33 years during which we could expect her to:
    - Give birth to 14 kids
    - Raise 13 kids
    - Wean the kids at 100 days of age, weighing 45 pounds each.
- She would have produced 585 pounds of product, creating between $585 and $735 of income.
- Obviously her very precise nutrient requirements would need to be available on a daily basis, and
- The buck used to impregnate her would need to be fertile and mate aggressively.

Records

Keeping *accurate* records is a key aspect in identifying the does that have a high level of productivity and efficiency in production. Efficiency in this case refers to the ratio of outputs (kids marketed) to inputs (operating costs and a portion of fixed costs --- shelter, breeding stock value, and fences). A record-keeping system does not need to be elaborate, expensive, or computerized but it must be more just than hand notes jotted down on the outside of feedbags. A simple record system is more likely to be consistently followed than one that is highly complex.

The showring

Where do show-ring winnings fit into this? If showring winners are backed up by individual and/or progeny performance information and recorded data, then the show ring can be a useful tool for bringing attention to the breeding establishment. If showring winnings reflect only the ability to fit animals, and are based on traits that have little commercial application, then it is just another dog and pony show; fun but not of much relevance to the product.

One of the challenges of producing this module is to create a framework for reviewing the role of show ring endeavors in breed improvement. Identifying the best, for any particular environments, must be done on the farm or ranch in a working environment. Once the best have been identified at home, and there is a system in place for continuing to identify the better performers in your environment, then it may be appropriate to participate in shows. The purpose of participation will be to create the opportunity to talk to people and provide meaningful information to people who can become customers.

The bottom line is that producing showring winners may create an artificial niche market for show-winning breeding stock, but it is in the pasture and woods where those animals must prove they can provide sustainable earnings from their productivity. An earnest meat goat breeder maintains a focus on the pasture, and on the environment in which breeding stock will be working.

Role of pedigrees

A pedigree is simply a written record of the ancestors of the individual of interest. Animals with written pedigrees are "registered" with some breed association or herd book. The mechanics of doing this is more or less common to all livestock registries. Until recent decades the pedigree information was simply a structured record with animal names and identification numbers. Little performance information was included. Many species of farm animals, including dairy goats, now include performance information on pedigrees.

In the case of meat goats, pedigrees include a record of ancestors and performance in the show ring only. However pedigree information can still be rather useful in interpreting the information one hears in informal discussions of animal performance in commercial conditions. Sons and grandsons of certain individual sires and sire lines will tend to produce offspring that do well or fail to make the grade in local environments. That informal information circulates among breeders and can be used in knowing which lines of breeding tend to be most useful.

Pedigree information is critically important in maintaining control of inbreeding. As the degree of inbreeding increases, the general level of performance tends to decrease. While mold forms of inbreeding, such as linebreeding, can be useful in breed improvement; in most cases close matings are to be avoided. Using a son of your current sire to mate with your young replacement does, is probably not a good idea. Studying pedigrees will allow the producer to avoid these kinds of close matings. If the same animal does not appear in the most recent two generations of a pedigree, then unwanted inbreeding is likely to be avoided. Years ago before performance information was available for any livestock species, a good job of managing inbreeding was accomplished, because farmers paid attention to pedigree information.

In cases where inbreeding has become a problem for a producer, the solution is quick and easy. The inbreeding cycle can be broken in one generation by using an unrelated buck. Currently, many meat goat breeders rely solely upon pedigrees to make purchasing and breeding decisions. The pedigree is a valuable tool in minimizing inbreeding. Consideration should be given by breeders who work well together, to the formation of a buck circle. A buck circle can enhance genetic improvement for the several affiliated producers. It will help minimize inbreeding and maximize economic returns.

Goal setting and breeding objectives

Achieving goals and resetting goals is a mark of success in this and any other business. Goals should be set to create a challenge but be realistic enough to be achievable. Generally with goats raised for meat, the type of animal in the breeding goal will need to fit the environment in order to achieve sustainable levels of production. The best animals the breeder produces should be those that are best for the end user. Breeding objectives can become distorted. There are several reasons this distortion occurs:

- Competition among breeders. In an effort to convince buyers of animal superiority, a breeder may find it profitable to emphasize qualities that set her animals apart but for which there may not be much importance, e.g. color, country of origin, mature weight, or record of ancestors. Even in the presence of performance records and expected progeny difference values, the competitive spirit can move the breeder away from balance.
- Undue reliance on opinions of breeders who may be working in an environment or system different than your own. End users of breeding stock should be able to objectively evaluate their needs and then communicate them back to breeders whose function it is to meet those needs. However, objective information is often scarce and end users make choices based on information that is easily available---the opinion of breeders in promotional materials.

The way to avoid distortion in your breeding objectives is to keep the end user in mind; to define and describe the optimum animal accordingly.

Available Genetic Resources - Breeds

Breeds are inbred populations; that is, animals of the same breed tend to be more closely related than the general population of goats in the world. Inbreeding occurs when individuals more closely related than the average of the population are mated.

Genetically speaking, we expect individuals of the same breed to share a higher frequency of the same genes than individuals of a different breed. This is what makes the characteristics of animals of the same breed more or less uniform and somewhat predictable generation to generation. Generally it takes a new breed about five generations to become established and to become sufficiently *homozygous* at all the *loci* controlling important traits that function and form are reasonably predictable.

Within the U.S. goat sector there are several breeds from which to choose. Each breed has certain average characteristics, some of which will be useful in achieving breeding objectives and some that may not be of much use or even detrimental to the objectives. Not only characteristics but availability is a factor that determines which breed(s) are used in the enterprise. Availability includes physically and financial components.

Selecting specific breeds will be based on an understanding of their characteristics (both positive and negative attributes), personal preference, and most importantly the needs of end users --- for breeders that would be the commercial producers, and for commercial producers that would be the consumers. The breeds most often used in commercial goat meat production are listed alphabetically and briefly discussed in Appendix A.

How Are Meat Goat Populations Improved Genetically?

It is appropriate to first define the term “population”, as used in this learning module. First, it is a group. A population may be small or it may be large. In the case of meat goats it is generally a herd or a breed, or goats owned by members of a particular breed association. The larger the population, the more rapid progress can be made. The basic tools for making improvement in future generations (the current generation is already genetically fixed) require making decisions. The two tools which are available include:

- **Selection**
    - Deciding which individuals become parents.
    - Deciding how many offspring they may produce.
    - Determining how long individuals will remain in the breeding population.
- **Mating plans**
    - Deciding which of the selected bucks will be bred to which of the does we have selected.
    - Bucks and does may have come for our own herd or from another population.

Selection

Although "natural selection" fuels the significant evolutionary force that brings about genetic change in all living things, but "artificial selection", which is selection under human control, is the tool which can be applied to our populations. Artificial selection has two components:

- Replacement selection
    - Deciding which does or bucks become parents for the first time.
    - Selecting new animals to replace parents that have been culled.
    - Usually, replacements are young animals but if you decide to use for the first time a well-known older buck via artificial insemination that would be replacement selection. The buck is not young but is being used in your herd for the first time
- Culling
    - Deciding which parents (does or bucks) will no longer remain parents.

Replacement selection and culling are in a sense two sides of the same coin. They involve different sets of animals but their purpose is the same — to determine which animals reproduce.

What traits?

When we describe meat goats, we usually characterize them either in terms of appearance, or performance, or some combination of both. Regardless, the term "trait" needs to be defined here so there is a common understanding. A trait is any *observable* or *measurable* characteristic of an individual goat.

- Observable traits might include color, color pattern, set of jaw, size, set of legs, head shape, degree of muscling, and the like.
- Measurable traits include those to which reference would be made in describing how an animal has performed. Examples include weaning weight, milk yield in dairy goats, postweaning daily gain, prolificacy, feed utilization efficiency, loin-eye area and the like.

There can be many discrete (single) and composite (combinations) traits of interest in meat goat breeding. The more traits included in a selection program, the slower will be the change in any particular one. All traits have an underlying genetic base. The expression of genes is called the phenotype. Phenotype is influenced by one of several kinds of gene action at the cellular level.

Lay breeders tend to use the word phenotype when referring to an animal's appearance, often giving the impression that "phenotype" means appearance only. Actually a goat has as many phenotypes as there are traits to be observed or measured.

Before continuing further on the details of selection and mating systems, it will be worthwhile to pause and review some of the fundamentals of genetics so that all people continuing through this module will be at the same level of understanding in the basics.

The Genetic Model for Quantitative (Polygenic) Traits

Making genetic progress in the meat goat business requires the breeder to identify genotypes of individuals for loci of interest and select those individuals with the most favorable genotypes. In selecting for polygenic traits such as weaning weight, growth rate, internal parasite tolerance, identifying specific genotypes is out of the question.

The goat breeder must therefore try to identify *breeding values* of individuals for traits of importance and to select those individuals with the best breeding values. This is not as straight forward as it may seem because a breeding value is an abstract, mathematical idea. It can never be measured directly, and because it is a relative concept its numerical value depends upon the breeding values of all other individuals in the population, e.g. herd or breed.

To understand breeding values we need a conceptual framework or a model in order to grasp definitions in a logical and consistent way. This framework is designed to be used with quantitative traits: traits in which phenotypes show continuous and numerical expression. The basic genetic model for quantitative traits can be written as follows:

Phenotypic value = Population mean + Genotypic value + Environmental effect

- Phenotypic value is an individual performance record. It is the measure of a meat goat's own performance for some specific trait.
- Genotypic value refers to the effect of the goat's genes --- singly and in combinations, on its performance for the trait. Unlike phenotypic value, it is not directly measurable.
- Environmental effect is comprised of all non-genetic factors influencing an individual's performance for a particular trait and is not directly measurable.

Those of you who are somewhat familiar with this concept may not understand the purpose of including the population mean. The purpose for adding the mean is to emphasize that in goat breeding, genotypic values and environmental effects, and all the other elements of the framework or model are relative — relative to that population being considered. They are not absolutes. Their numerical values depend on the average performance of the population, and they are therefore expressed as *deviations* for the population mean. Although we might put numerical values in hypothetical situations, in reality we cannot know an individual's genotypic value or environmental effect. All that can be measured directly is the phenotypic value.

Example 1. A young buck weighed 40.5 pounds at weaning. The population mean was 45 pounds. Therefore the phenotypic value deviation is a minus 4.5 pounds, or 10 percent below the mean…..not good. This might prevent the buck from being selected to produce offspring, which would be appropriate if he is genetically inferior. It is conceivable however that the genotypic value of this buck is 2.5 pounds above average, but his actual performance is below average due to a very poor environment which put a 16 percent drag on the buck. Perhaps his mother developed mastitis in one half of her udder. In that case we might have overlooked a genetically superior sire because of poor animal husbandry.

Example 2. Another buck was in a population in which mean postweaning average daily gain equals .50 pounds per day. This guy recorded an ADG of .45 lb per day. The environmental effect accounted for .04 lbs of this negative deviation and his genotypic value accounted for .01 pounds. In the end this buck should not be selected for breeding because although he experienced worse than average environmental effect, he also had a lower than average genotypic value for ADG.

Example 3. Our final buck weighed 100 pounds at seven months of age which was about 20 percent above the population mean of 83 pounds. Obviously this buck should be considered as herd sire material and be put in the "for sale pen" of higher priced bucks. What we do not know at this point is that the genotypic value of this buck is only 6 percent above the population mean, and that a positive environmental effect added an extra 14 percent to allow him to reach the 20 percent superiority. Although he has a higher than average genotypic value, the rate of growth of his offspring may be less than expected.

The breeding value of an individual is contained in the genotypic value, which includes independent gene effects (additive effects or breeding value) which are passed along to the next generation, and gene combination effects which are not passed because the law of recombination breaks up the combinations on the way to the next generation.

One can think of genotypic value as the value of an individual's genes to its own performance, and breeding value as the value of an individual's genes to its progeny's (offspring) performance.

Fundamental genetics for understanding what is happening in cells

During the late 19th and early 20th century, the Austrian monk Gregor Mendel and later on several of his successors identified the fundamental mechanisms and rules of inheritance. This knowledge allows you to better comprehend the important concepts of goat breeding. These concepts apply generally to meat goats like they do to other livestock. There is no evidence that goats are an exception to any of the basic biological principals. Appendix B provides the reader with detailed information on these basic concepts, and acquaint the learner with the useful jargon of genetics.

Simple Statistics and Their Application to Quantitative Traits in Meat Goat Breeding

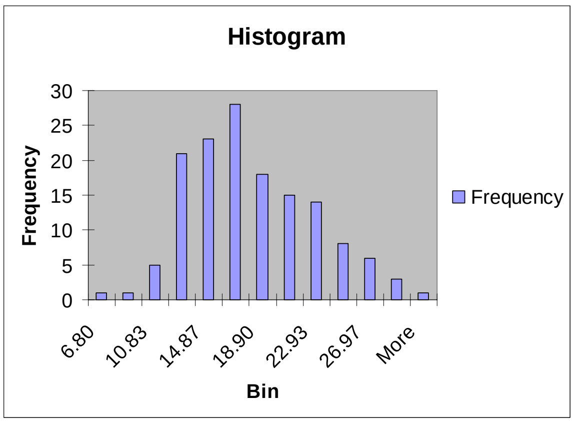
This section deals with interpreting statistical values and how to make sense of those measurements. Just briefly we will consider a few basic concepts in statistics which will lead to a more complete understanding of how to evaluate performance numbers and breeding values. In meat goat breeding we are concerned not only with performance values in individual goats, but also with the distributions of and relationships between values in a population.

Normal distribution

Values of individual animals, when viewed across an entire population, tend to follow a certain pattern or distribution. For example most of the phenotypic values for weaning weight in meat goats tend to be within 10 pounds of the average weaning weight for the population. Only about a third of all weaning weights are more than 10 pounds heavier or lighter than the population mean. Weaning weights more than 20 pounds heavier or lighter than the average are quite rare.

This pattern is typical of quantitative traits in general and is known as a normal distribution. This distribution appears graphically as a symmetric, bell-shaped curve.

Weaning weight (kg) of meat goat kids from Fort Valley State University, 2002/2003.



The horizontal axis represents levels of some value, e.g. phenotypic value or breeding value. The vertical axis represents the frequency of different levels of the value in the population. The area between the curve and the horizontal axis and bounded on each side by a given interval of values represents the proportion of observations in the population likely to be within that interval. For most quantitative traits most observations are near the mean value and relatively few observations occur at the "tails" of the distribution some distance from the mean. The reason quantitative traits are normally distributed is because they are affected by many genes. When the environmental effects are added to the mix, the number of classes and levels on the continuum increase substantially. For an understanding of the more important statistical measures that help us understand and describe normally distributed data, read through Appendix D.

The Concepts of Heritability and Repeatability

Nearly everyone who has an interest in breeding better meat goats has heard of *heritability*. It tells us to what extent the differences observed in animal performance are due to inheritance. But, what does that really mean? What causes some traits to be more heritable than others? Does the heritability level influence our priorities in traits for which to select?

Heritability has been defined in various ways, but for our purpose we will consider it to be a measure of the strength or consistency of the relationship between performance or phenotypic values and breeding values for a trait in a population. Recall that breeding values are an indication of how much genetic value is passed along to the next generation. Our definition of heritability is a reflection of the degree to which offspring performance is a reflection of the performance of their parents.

From a practical standpoint, when a trait is highly heritable the performance of animals reveals a lot about their breeding values. In contrast, when a trait has a low heritability, a breeding goat's own performance is not likely to be a good indicator of its breeding value. Under those circumstances, the offspring of high performing parents will probably not perform much differently than the offspring of low performing parents.

Mathematically, heritability values are always positive and theoretically ranging from zero to one on percentage terms, e.g. 12% or 35%. In livestock species, heritability values above .7 (70%) are extremely rare. Typically heritability estimates below:

- .2 (20%) are considered lowly heritable,
- traits with heritabilities between .2 (20%) and .4 (40%) are considered moderately heritable,
- and traits with heritabilities above .4 (40%) are considered highly heritable.

Appendix E contains more useful basic information on heritability and a related notion known as Repeatability.

Factors Affecting the Rate of Genetic Change in a Herd or Breed

Before considering those specific factors, there are some management strategies and mathematical techniques that are important tools for improving rate of genetic change in meat goats. They are discussed briefly in Appendix G.

Selection and genetic change for breeders

The effectiveness of selection is typically measured by the rate of genetic change that results. The task of selection is not a simple one. You would like to maximize the rate of genetic change. The challenge is to choose those breeding goats with the best breeding values as parents. Unfortunately we can not know breeding value in advance and so we must work with predictions. Fortunately we do know the factors affecting the rate of genetic change from selection in meat goats. Our focus will be change in the mean or average breeding value of a population caused through selection. There are other factors that cause genetic change in a population, including mating systems such as inbreeding and crossbreeding. The four factors are involved in genetic change through selection include:

- Accuracy of selection
- Selection intensity
- Genetic variation
- Generation interval

Genetic change is directly proportional to the first three, and inversely proportional to generation interval. Knowing about these four factors will help you develop selection strategies and design an appropriate breeding program.

Accuracy of selection

You should be particularly interested in the accuracy of breeding value prediction. The reason for this is because the more accurately you can predict breeding values, the more likely that the animals you choose to be parents will actually be the best parents. Accuracy ranges from zero, when there is no performance information used, to almost one, when there is an abundance of information. Accuracy is never negative.

Accuracy of selection depends on a number of factors:

- Heritability – the higher the heritability of a trait, the better each piece of performance information is as a predictor of underlying breeding value. Any steps a breeder can take to increase heritability will increase accuracy of selection:
    - Managing animals uniformly
    - Taking careful measurements and checking measuring instruments
    - Adjusting for known environmental effects
    - Using contemporary groups
- Genetic prediction technology – accuracy can also be increased by using more information and more sophisticated genetic prediction technology. Performance information on individuals and potentially large numbers of relatives can be combined to provide more accuracy in predicting breeding value. For this to happen, breeders must be dedicated in recording information in the first place.

Differences in accuracy of selection can be large. Selection based only on individual phenotypic record, particularly if the trait under selection is lowly heritable, is not very accurate. Alternatively, selection of potential parents (usually bucks) on the basis of expected progeny difference (EPDs) derived from large volumes of progeny data is very accurate. The key elements here are *collecting the data*, and accumulating *large amounts* of it. These are key elements for breed directors who want to involve the newer technologies to genetic prediction — need data and large amounts of it.

Selection intensity

Selection intensity measures how particular meat goat breeders are in deciding which individuals are selected. If selection criteria are reasonably accurate (reasonable predictors of underlying breeding values, then intensely selected parents should be far better than average, genetically. The next generation should be equally superior and the rate of genetic change should be fast. Mathematically, selection intensity is determined by the difference between the mean performance level of those goats selected to be parents and the average performance level of all potential parents within the herd. This difference is sometimes called the *selection differential*, wherein the potential impact of the selected parents is expressed in the units of the trait or characteristic. Selection intensity will regularly be different on the sire side as compared to the doe side. Because parents contribute equally to the genotype of the offspring, both the sire and the dam will contribute to the selection intensity involved. Keep in mind however, that because a single sire contributes genes to the whole herd, his impact is proportionally larger than individual does. This means that selection of herd sires is very important to genetic change.

Accuracy and intensity are independent concepts. You can select intensely regardless of the accuracy of the performance data. Even it you have good indicators of what is the best animal, if the accuracy is not high there will be a slower rate of genetic change. It should be evident then that when the product of these two factors in rate of genetic change is a small number, the rate of change will be slow. This relationship is direct.

Genetic variation

This is the raw material with which meat goat breeders work. It refers to the variability in breeding values within a population for a trait under selection. With lots of variation, the range between the best animals and the worst is large. The best animals are far superior genetically to the worst. If there is little genetic variation, then even the best individuals will be only a little better than average, so will their offspring, and the rate of genetic change will be slow. Unlike accuracy and selection intensity, genetic variation is not a factor that is easy to manipulate. It tends to be relatively fixed within a population. A lot of genetic variation exists in most populations of meat goats, so the loss of genetic variation is unlikely to be a constraint to genetic change.

Generation interval

The shorter the generation interval, the faster will be the rate of genetic change. Generation interval refers to the amount of time required to replace one generation with the next. Although it will be influenced by environmental factors, including management, it is somewhat species specific and tied to the biology of the reproductive rate. The generation interval in meat goats will be shorter than in cattle. It will not be as short as that of laboratory mice. Both the gestation length and the nursing period are shorter, and the age at puberty is lower. Mice are capable of producing 150 generations in the time it takes humans to produce one. This is why mice are such desirable animals in genetics laboratories where theories of genetic change are tested.

In populations that are closed to genetic material from the outside — the generation interval can be defined as the average age of parents when their selected offspring are born. This "average age" definition works well for herds that are truly closed (providing all their own replacements — male and female). It works well for entire species or breeds. It becomes inappropriate when animals are imported from outside a population. For example, if semen from an outside buck were introduced into a closed herd, the age of that buck would have little bearing on the amount of time required to replace one generation with another. Why? Well, because that buck might be chronologically old, but if he is genetically superior, then in respect to the genetic level of the herd, he is relatively young. The range for generation interval for meat goats is 3 to 5 years.

The mathematical equation which incorporates all these elements into one function is as follows:

$$\textit{Rate of Genetic Change or Response to Selection per Unit of Time} = \frac{\text{(Accuracy of selection) + (Selection intensity) + (Genetic variation)}}{\text{(Generation interval)}}$$

This equation is conceptually simple. However it tends to become more complex when consideration is give to the fact that accuracy, selection intensity, and generation interval are often different for bucks versus does. In dairy goats where major production traits are associated with milk secretion, it will take additional time to obtain data from daughters to achieve the desired level of accuracy before final selection.

How to Select for Several Traits at the Same Time

In the real world it is highly unlikely that meat goat producers would select for a single production trait. It is more common for a number of traits to be involved in a selection plan. This is known as multiple-trait selection. The objective is to improve aggregate breeding value or net merit --- breeding value for a combination of traits, within a population. The definition of aggregate breeding value suggest determining which traits are worthy of selection, but also to assign some relative value to each one. To define aggregate breeding value or net merit is to define the "best" animal, to this environment.

In many cases multiple trait selection is as much an art as it is a science. There are no hard-and-fast rules. There may be an intuitive element to application. Animal breeding purists often suggest there are three distinct approaches:

- **Tandem selection**. This is simply selection for one trait at a time, and then another one of those identified as being important. A very simple approach, but not particularly efficient in terms of making genetic progress. Selection for one particular trait is applied for several years until a certain level of performance is achieved; then selection is focused on another trait for a number of years. In the presence of an unfavorable correlation between two traits, a breeder might loose most of the progress made in trait #1 while improving trait #2.

- **Independent culling levels or independent selection standards.** Under this approach breeders set minimum standards for traits involved in multiple-trait selection. Animals being reviewed for selection or culling (not selected) using this approach are culled or are not selected if they fail to meet any one standard regardless if they have outstanding merit in any one of the other standards. A relatively simple approach, but will often result in the loss of some otherwise pretty good potential parents. Setting these standards allows the goat breeder to select simultaneously for more than one trait by applying rather simple rules. They are most appropriate when there is a clear distinction between what is acceptable and what is not. Independent culling levels are also convenient when selection occurs at different stages of an animal's life. Kids whose weaning weights are too light are rejected at weaning. A second round of selection occurs at six to nine months of age, when decisions regarding replacement stock are being made. This approach allows the obvious choices to be made early in life and reduces the expense of maintenance. The practical use of independently culling levels takes an intuitive rather than a mathematical precise approach when setting levels or standards. If they are strictly applied, they may exclude some potentially useful animals. On the other hand, as one breeder stated, "I may loose some good ones along the way, but I will get all the bad ones".
- **Selection index.** The selection index incorporates each trait of some economic importance, and weights each one according to economic value. Essentially the same methodology is used here as was used in the genetic prediction application for a single trait. The index as used here is a prediction of aggregate breeding value. The equation for an index looks something like this:

$$\mathbf{I = b_1X_1 + b_2X_2 + \ldots.. + b_nX_n}$$

where: I = an index value or genetic prediction.

b_1 = an economic weighting factor based on the value of a unit change.

X_1 = a single item of information or evidence, e.g. average daily gain

n = the total number of items of information.

An example might be an index based on a weight of .75 for each unit of average daily gain (e.g., 0.10 pound), and a weight of .50 for each unit of estimated ribeye area (e.g., 0.1 square inch) above or below the contemporary group mean. In other words, one-tenth of a pound increase in average daily gain is worth somewhat more that a one-tenth square inch increase in ribeye area.

The practical benefit of selection indexes is that they help define breeding objectives rather precisely. The chief problem is that economic weights are difficult to determine. Economic weights require careful analysis of costs and returns and are not uniform from farm to farm. These weights must be determined locally and with the economic considerations that apply to each farm or ranch. They will also change from time to time. Selecting animals on the basis of a single index value seems appealingly simple. However getting to the point of the selection decision requires much effort and knowledge of breeding objectives.

There is no rule that suggests the breeder must use only one or the other of these selection methods. The methods can be combined as seen fit. Computer simulation models of the future may provide meat goat breeders an opportunity to test several selection scenarios, and then make the decision of which way to go.

Practical Mating Systems for Meat Goat Producers

There are two kinds of decisions that meat goat breeders must make. They must make decisions such as which individuals become parents, how many offspring they may produce, and how long they remain in the breeding population. Meat goat breeders must also decide which bucks to breed to which does. That is a mating decision. Mating decisions fall into two general categories, inbreeding and outbreeding. Inbreeding is most often practiced by purebred breeders who are producing the parent stock for commercial meat producers. Even linebreeding is a mild form of inbreeding.

The other category is outbreeding, which includes the often discussed practice of crossbreeding.

1. Crossbreeding can be used for upgrading, i.e. moving from breed to another, or "up" from common stock to pedigree stock. This is accomplished by backcrossing.
2. Crossbreeding can be used in a perpetual system to produce market stock and replacement females at the same time. There are some significant advantages seen in using this mating system for meat production. The advantages have been documented in other livestock, and there is a growing body of evidence that suggests the advantages apply for goats raised for meat too. A number of practical systems are available. Two major factors make systematic crossbreeding effective:
    a. Combining the attributes of two or more breeds. There is a practical limit to the number of breeds that can contribute positive aspects.
    b. Take advantage of hybrid vigor (heterosis), which in a sense provides a free boost in some traits.
3. Crossbreeding can be used to produce the foundation for new breeds, synthetics, or composites.

Appendix I provides many useful details of the mating systems available to meat goat breeders and producers.

Mating systems should be evaluated on several criteria. These include:

- Merit and availability (physical or financial) of the breeds to be used.
- Expected level of heterosis.
- Complementarity of the breeds available.
- Replacement stock considerations.
- Simplicity.

To assist the learner in visualizing the several system some specific crossbreeding examples are provided here.

Rotational crossbreeding systems

Rotational crossbreeding systems involve rotating sire breeds across the female population. Such systems produce replacement females internally, yet manage to maintain acceptable levels of the original heterosis. Either purebred sires or crossbred sires can be used. You can use the breeds of sires simultaneously by placing them in separate physical locations; or you can use the breeds sequentially over time. Any number of breeds can be involved but generally the system involves only 2 to 4 different breeds. Although adding more breeds will maintain heterosis at a higher level, it may be a challenge to identify more than four breeds that compliment one another.

Two-breed rotational system

A two-breed rotational system, also known as a crisscross system, represents the simplist system available. Suppose you have chosen to use the Kiko and the Spanish breeds to use in the rotation. The first step is to make the initial cross. Then backcross to one of those original breeds. The female offspring from that backcross will then be mated to the other breed; then back to the first breed. By following this system you will maintain about 67 percent of the original 100 percent level of heterosis. The actual result in terms of measurable differences and units will differ from trait to trait. This system is illustrated here using a rotation over time.

Two-breed Rotational System

Generation 1 -	Kiko x Spanish = (.5 Kiko + .5 Spanish)
Generation 2 -	(.5 Kiko + .5 Spanish) x Kiko = (0.75 Kiko + .25 Spanish)
Generation 3 -	(.75 Kiko + .25 Spanish) x Spanish = (.375 Kiko + .625 Spanish)
Generation 4 -	(.375 Kiko + .625 Spanish) x Kiko = (.6875 Kiko + .3125 Spanish)

After about the 3rd generation the relative percentages in breed composition will settle down to about 2/3 for the most-recently-used breed, and 1/3 for the breed next in rotation. These same crosses can be happening simultaneously if the system is applied on a spatial basis where different herds of goats are in different locations.

Three-breed rotational system

Three-breed rotational crossbreeding increases the level of complemtarity, and the level of hybrid vigor maintained after the first crosses. In this system, approximately 86 percent of the original level of heterosis will be maintained on average over time. In this next illustration, the Boer has been included as the third breed.

Three-breed Rotational System

Generation 1 -	Kiko x Spanish = (.5 Kiko + .5 Spanish)
Generation 2 -	(.5 Kiko + .5 Spanish) x Boer = (.5 Boer + .25 Kiko + .25 Spanish)
Generation 3 -	(.5 Boer + .25 Kiko + .25 Spanish) x Spanish = (.25 Boer + .125 Kiko + .625 Spanish)
Generation 4 -	(.25 Boer + .125 Kiko + .625 Spanish) x Kiko = (.125 Boer + .5625 Kiko + 3125 Spanish)
Generation 5 -	(.125 Boer + .5625 Kiko + 3125 Spanish) x Boer = (.5625 Boer + .28125 Kiko + .15625 Spanish)
Generation 6 -	(.5625 Boer + .28125 Kiko + .15625 Spanish) x Spanish = … and, so on.

After about the 5^{th} generation the relative percentages in breed composition will settle down to about 57% for the currently used sire breed, about 28% for the next most recently used breed, and 15% for the breed next in line for mating. The complementary effects will increase slightly and the level of retained heterosis will increase as compared to the two-breed rotational scheme. Crossbred replacement does will be produced internally from the mating plan.

Terminal sire systems

Terminal sire systems are systems applicable where breeds are unquestionably identified as maternal-breeds, which excel in maternal traits like conception rate, number born, milk yield, and that intangible term, mothering ability; or paternal-breeds, which excel in traits like growth rate and carcass yield.

In the meat goat sector, among the breeds available tend to be more balanced in terms of maternal and paternal features. One more extreme example is that if they were used, the Nubian breed would have to be considered a maternal breed. It would be more difficult to identify a similar breed on the paternal side because of the balance of traits. Terminally sired females are not kept as replacement, but are sold as meat animals because there will be other breeds which will do better on the maternal side. While these terminal systems produce ample amounts of hybrid vigor, their most important attribute is breed complementarity. There are two approaches to terminal systems; static terminal systems and rotational/terminal systems.

Static terminal-sire crossbreeding system

The static terminal-sire crossbreeding system is considered static because the proportional breed composition does not change over time as it does with rotational systems. The system does not provide for replacement females internally. Obtaining those replacement does is the most difficult aspect. A static terminal system that uses purchased does is very simple from a management standpoint. The system produces a lot of hybrid vigor. An example of this system is shown in the next box.

Static Terminal-Sire System

Generation 1 -	Spanish x Boer = (.5 Spanish + .5 Boer)
Generation 2 -	(.5 Spanish + .5 Boer) x Tennessee Meat Goat = (.5 Tennessee Meat Goat + .25 Spanish + .25 Boer)

The two-breed males are harvested. The females in Generation 1 are used as breeding females to produce Generation 2 market stock. All animals in the three-breed group will be harvested.

Rotational/terminal systems

Rotational/terminal systems are designed to solve the replacement problems associated with static terminal systems. They combine a maternal rotation for producing replacement females with terminal sires for producing market offspring. A portion of the goat herd is bred to "maternal sires" to produce the replacement does. The remaining does are bred to terminal sires to produce market offspring. Obviously the males from the maternal sires will be marketed too. The system is illustrated below:

Two-breed Spatial Rotational/Terminal System

Nubian x Boer = (.5 Nubian + .5 Boer)	x Boer = (.75 Boer + .25 Nubian) x Nubian = (.375 Boer + .625 Nubian) x Boer, and so on	for replacement does
	x Kiko = (.50 Kiko + .25 Boer + .25 Nubian)	all of which go to market for harvest

This system provides the breed complementarity that would be missing from purely rotational systems, and the crossbred replacement does missing from a purely terminal system. Approximately 25 percent of the two-breed does would stay in the system as replacements.

Naturally, certain individuals are nervous about the program and see it as an invasion of their privacy. The USDA has guaranteed that the only information the system will track is the location of the animal and any movements that occur during its life.

Rotational/terminal systems provide more hybrid vigor and breed complementarity than comparable rotational systems, but less than comparable static terminal systems. Whenever you combine two crossbreeding systems you can expect the combination to be more complex than its separate parts. In addition to the requirements of the rotation, an additional pasture is needed to accommodate terminal matings. Using a rotation in time would simplify the rotational component. Using artificial insemination on one of the groups would reduce the number of breeding locations required.

Composites

Composites are derived from crossbred foundations. They can be considered new breeds. Although developed initially through various crossbreeding systems, the intent of a composite base is to develop a new breed. The simplest way to use composite animals in commercial breeding is as one breed. Once the breed is closed (usually after about three generations of inter se matings (that is, among the crossbreds themselves), there is no longer any crossbreeding. A composite breed can be considered a breed made up of two or more component breeds and designed to benefit from hybrid vigor without crossing with other breeds. Development of new composites should be based on research information regarding the true need, and research on the optimal mix of breeds — that is, what the foundation breeds should be, and in what the proportion.

Pure composite systems can produce considerable hybrid vigor. When two F_1s are mated to produce F_2s, half of the F_1 heterosis is lost but half still remains in the F_2, F_3 and subsequent matings. This remaining 50% of the original level of heterosis is retained in what becomes a two-breed composite. A four-breed composite is expected to retain about 75% of the F_1 level of heterosis. This is on the assumption that inbreeding within the composite is kept at a minimum.

As a point of clarification, $\mathbf{F_2}$s are produced only through *inter se* matings of the $\mathbf{F_1}$ (first filial generation), and $\mathbf{F_3}$s are produced only through *inter se* matings among $\mathbf{F_2}$ individuals. These terms should not be used simply to designate generations. They convey information about what type of animals that went into them. Livestock people, including meat goat producers often make this error when speaking of various generations in crossbreeding.

The amount of vigor retained in a composite depends on the number and proportions of component breeds in the composite. This can be proven mathematically. Because the goats within a pure composite system are all of the same biological type, there is little opportunity for breed complementarity between the sire and dam.

Once the composite is formed, the management and operational aspects are similar to any other pure breed — relatively simple. Keeping several breeds around is no longer necessary, and the advantages of retained hybrid vigor can be used even in small herds. On the other hand, developing a new composite breed is not simple. Assembling the composite can be very complex, and should be based on scientific studies done in advance for justification. If it is done right, a predictable four-breed composite population can be created in seven generations.

The usual justification for composites is to fit in a specific environment where suitable alternative breeds do not exist. Whenever the environment poses special challenges there is an opportunity for an appropriately designed composite breed.

Following studies to determine which breeds should be involved and in what proportions, the following steps are required to create a composite:

1. Select the foundation animals - The foundation animals set the base on merit.
2. Make the initial crosses - Apply selection to replacement females.
3. Make subsequent crosses to reach the desired proportions
4. Mate within the population - Apply selection to replacement females
5. Mate within the population - Apply selection to replacement females
6. Mate within the population - Apply selection to replacement females
7. If the new composite is suitable, begin the controlled release of breeding stock for multiplication.

In developing a useful composite it is critical that those individual animals and families of animals within the foundation, that are not performing be rigorously and quickly culled. Nothing can kill the success of a new composite breed better than nonperformance of too many animals in those early generations. New meat goat producers may try a composite one time, but they will not stay with it if too many animals fail to reach expectations. Another key is to begin with a large population. This will help manage the rate of inbreeding. Unfortunately there is no single answer to the question, how large is large enough. Apply selection at each successive generation.

Summary of the Essentials in Meat Goat Breeding

As you have worked through this module there may have been times when you were nearly overwhelmed by the science and technical aspects involved. However, goat breeding, in the truest sense of the word, is more than the sum of its parts and details. Knowledge alone will not guarantee success in breeding goats for the food and clothing products they provide for humans. As Bourdon (2000) points out, success has more to do with the use of common sense in the application of all the theory and technology. He goes on to suggest that longevity in the livestock breeding business tends to be associated with six different characteristics or attributes, as follows:

Knowledgeable and understanding

An understanding of the several features of meat goat breeding is essential, particularly in regard to:

- Genotype by environment interactions and their importance in establishing breeding objectives.
- Randomness of inheritance and how it causes limitations and opportunities.
- Necessary differences in approach to breeding for simply-inherited traits, e.g. color, versus polygenic traits, e.g. growth.
- The elements of genetic change, and trade-offs among the elements.
- Importance and power of sire selection.
- Role of breeds and the power of between-breed selection
- Need to balance exploitation of heterosis and breeding values in crossbreeding.

Being knowledgeable also means understanding many things about meat goats in particular; which markets demand what characteristics, the impact of seasonality, impact of breeding for parasite tolerance, animal vitality, and the like. This can be learned by reading, by talking to other breeder you respect, and from personal experience. It is important to know the true genetic capabilities of your own animals and the limits to production imposed by your local environment (non-genetic factors). You should also be knowledgeable of your end-user needs and the kind of environment the your animals will be working for them.

The genetic theory applicable to meat goat breeding does not change rapidly. But animal breeding technology applicable to meat goats is changing rapidly. Research provides new information relative to genetic by environment interactions, genetic relationships, genetic impact on permanent change, and the like. Interact with those who know more about this than you.

Use good information

Good decisions are based on good information. If there is a major weakness in the meat goat sector is that the amount of good performance information is very limited. Steps are just now being taken to record performance data and to use it to create predictions in the form of expected progeny differences (EPDs) and estimated breeding values (EBV). Having good information means measuring meat goat performance and keeping good records. Performance information is not cheap — it takes time and labor to collect, store, retrieve, and synthesize into usable form. Keeping records and getting usable data remain a challenge. Procedural details, such as determining contemporary groups, need close attention. While commercial meat goat producers should probably limit their record keeping to the most basic items. Seedstock breeders are obligated to do as much as they can to document the performance of their meat goats because eventually the value of seedstock comes not only from the animals, but also from the information that goes with them.

Meat goat breeders also have the social responsibility of contributing their records to breed or genetic improvement associations for the greater good. You will improve the quality of genetic information to yourselves as well as to other breeders.

Slow down and take time to think

Take the time to think about what you do every day; especially in your breeding program. How is your best or optimum meat goat characterized? What are the fastest, easiest, most economical ways to obtain the next generation with those characteristics? Avoid coffee shop talk and avoid the pack mentality. Try to see the big picture and be analytical.

Be consistent

Those who call themselves meat goat breeders are too often influenced by fads that may seem important at the time but have little long-term justification. Lack of consistency dooms too many efforts to breed improved meat goats. Do not start and stop; go this direction and then that; or change the optimum from this to that. You must be able to see into the future and determine what kind of goat will be most useful over the longer term. Study, think, set goals and stick with them. Occasionally it may be necessary to modify or alter your breeding objectives, but do so only when markets change and there are legitimate reasons. The more consistent your goals, the more definable and more marketable your breeding stock will be

Simplicity; keep it simple

Successful breeding programs are usually simple. Simple programs do not avoid the use of advanced breeding technology. They are simple in concept. They have well-established goals and remain clear of complex rules or approaches for individual matings. No grand scheme will beat Mendelian probability over the long haul.

You can simplify your program by clearly defining the roles your meat goat breeding stock best fit. It may not be appropriate to try to make your breeding stock be all things to all people. Limit the traits under selection to those that are truly important. These are meat goats, albeit with good breeding values, so ignore those traits that have only aesthetic value. Complex breeding programs are difficult to maintain. Simplicity breeds consistency. We all appreciate a striking, attractive, good looking animal; but we can and do alter our notions of what constitutes a pretty animal and in time those notions tend to describe very functional types. As Bourdon (2000) suggests, perhaps it would be beneficial to be faster to adjust our aesthetic sense to the realities of meat goat production.

Have patience

The pace of genetic change in meat goats, relative to many other things in life, is relatively slow. Not as slow as some other species of livestock, but much slower than many of us would like. There is the tendency to jump to conclusions about animals on which there is very little known, other than the pedigree. Even if the animal is “an own son of Good Ole Boy”, if there is little performance information on “Good Ole Boy” then the relationship is meaningless. To be successful, patience is virtue.

Gene segregation and gamete selection are largely random processes. Therefore inheritance is necessarily unpredictable. The wisest breeders patiently play the averages. They understand that if they follow the rules, the next generation of animals will be better than the last. Once in a while nature steps in and both gene segregation and gamete selection get together to produce a truly outstanding meat animal. Seek those and exploit them. Be prepared; but don’t expect every herd sire to be that animal. Reject formula breeding. Have patience.

Ethics in Merchandizing Meat Goat Genetics

Livestock breeders, including those associated with the meat goat sector are generally respected for their understanding of genetic change in a particular species or breed. They are trusted. It is recognized that breeders take financial risks in order to test the breeding value of each new generation after selection of the parents has occurred. This trust and respect can evaporate quickly when unethical practices occur. What is just good salesmanship and where is the line which separates good marketing from unethical behavior?

As breeders know, it is rare if ever that nearly perfect animal comes along. So in most cases you are selling imperfect stock, and to suggest otherwise would not be honest. Several breed associations and organizations have taken the time to write a Code of Ethics which governs how members should behave and how the notion of truth in sales should be acted out. Even the Black and Tan Coon Dog association has a code.

"Honest and helpful" describes those people in the meat goat sector who can be considered truly successful and who are in business for the long haul. In all cases, honesty in regard to faults (especially to the novice), in regard to vaccinations, deworming history, previous health problems including caseous lymphadenitis, pedigree information, hereditary defects, and predictions of breeding value can pay off in the long run. The ethical breeder transfers registration papers at the time expected, and remains open to sharing information with new breeders.

Seek to do the most you can to determine the true breeding value of the breeding stock you are showing and selling. This can be done with individual, ancestors, and progeny performance information. Even on-farm evaluations, when appropriately designed, can be done well and raise the expectations by the owner. Pricing should reflect estimated breeding value, and until breed groups have amassed sufficient data, that will need to be by evidence from the farm itself. Obviously the conscientious breeder will keep their meat goats in healthy and well-fed, but not in a fat condition which impairs production.

Appendix A —	Available Genetic Resources: Breed Details.
Appendix B —	Fundamental Genetics for Understanding Gene Frequency and Breeding Stock Change.
Appendix C —	Understanding Breed Value and Expected Progeny Difference.
Appendix D —	Measures Describing Data Collected from Goat Herds.
Appendix E —	Basic Considerations in Heritability and Repeatability in Goat Breeding.
Appendix F —	Genetic Prediction and Evaluation of Meat Goats.
Appendix G —	Management Strategies and Mathematical Techniques for Improving Genetic Change.
Appendix H —	Trade-offs Among the Factors Affecting Rate of Progress from Selection.
Appendix I —	Details of Specific Mating Systems for the Breeder and Commercial Producer of Market Goats.
Appendix J —	Genetic implications of recent Biotechnologies.

Learning Objectives for the Breeding and Genetics Module

Breeding Objectives. Determining What Animal is "Best" for Your Production System and Climate.

Points to understand

- Factors which can cause distortion in breeding objectives.
- The difference between traits and phenotypes.
- How knowledge of interactions involving genotype helps us determine breeding objectives.
- How correctly defining end users and understanding the end user's system leads you to more appropriate breeding objectives.

Skills to Acquire

- Describe the system that is your farm or ranch by listing specific components of the system and categorizing them appropriately.
- Describe whom are the end users of your genetics or animal product, and justify your production system.

How Are Animal Populations Improved?

Points to understand

- The difference between selection and mating.
- How selecting parents with better breeding values improves future generations.
- How heritability influences the effectiveness of selection.
- How information on relatives increases the effectiveness of selection.
- The difference between simply-inherited and polygenic traits, and how selection differs for each.
- The difference between complementarity and hybrid vigor.
- How selection and mating can be interdependent.

Skills to Acquire

- List commonly measured traits that comprise performance testing programs in meat goats.

The Basics in the Biology of Genetics - Mendelian Inheritance; It Ain't All Dominance & Recessive

Points to understand

- How to distinguish among genes, alleles, and loci.
- Mendel's laws of segregation and independent assortment and their significance in determining breeding values.
- How linkage, crossing over, and recombination affect assortment of genes that are a part of the same chromosome.
- Various forms of dominance, and epistatis.

Skills to acquire

- Use Punnett squares to predict the possible outcomes of matings.
- Calculate the number of unique gametes a specified genotype can produce and the number of unique zygotes possible from the mating of two specified genotypes.
- Use a schematic diagram to illustrate the different forms of dominance.

Genes in a Population

Points to understand

- Understand the difference between gene and genotypic frequencies.
- Be able to explain how selection affects gene and genotypic frequencies.

Skills to acquire

- Calculate gene and genotypic frequencies in a population.
- Combine Punnett squares and gene frequencies to determine genotypic frequencies of offspring.

Simply-Inherited and Polygenic Traits

Points to understand

- The difference between simply-inherited and polygenic traits.
- The difference between quantitative (continuous) and qualitative (categorical) traits.
- The common characteristics of simply-inherited and polygenic traits.

Skills to acquire

- Define threshold traits in terms of simply-inherited/polygenic and quantitative/qualitative categories.
- Classify many commonly measured traits by simply-inherited/polygenic and quantitative/qualitative categories.

The Genetic Model for Quantitative Traits

Points to understand

- What a genetic model represents: the general factors affecting a single performance record.
- The relationship between progeny difference and breeding value.
- Why gene combination effects are not additive, nor transmittable from parent to offspring.

Skills to acquire

- Construct column charts to represent hypothetical examples of the various genetic models.
- Predict breeding value and performance of offspring from the breeding values of their parents.

Simple Statistics and Their Application to Quantitative Traits

Points to understand

- The difference between individual values and population measures.
- What the area under a segment of the curve of a normal distribution represents.
- Why polygenic, quantitative traits are typically normally distributed.
- Mean and variation.
- The importance of variation and uniformity in animal breeding.
- How most components of the genetic model has variation associated with it.
- The differences between the two measures of variation: variance and standard deviation.
- Covariation and its importance in animal breeding.
- Difference between positive, negative, and zero covariation.
- Three aspects of covariation and the differences among its three measures: covariance, correlation, and regression.
- The purpose of regression values.
- The elements of a simple prediction equation and how the equation works.

Skills to acquire

- Draw a normal distribution, label both axes, and indicate the mean and the distance represented by a standard deviation.
- Calculate a sample mean, variance, and standard deviation from a set of data.
- Calculate a covariance, correlation coefficient, and regression coefficient from a set of data.
- Calculate correlation and regression coefficients given appropriate variances and covariances.
- Label the components of a simple prediction equation and use it in an example.

The Concepts of Heritability and Repeatability

Points to understand

- The definition of heritability.
- Why the fact that a trait is genetically determined does not necessarily make it heritable.
- The relationship between heritability and accuracy of selection.
- The importance of heritability to genetic prediction.
- How knowledge of heritability can help a producer make management decisions.
- Define repeatability.
- How repeatability can be used to help make culling decisions.
- How environmental uniformity, accurate measurement, mathematically adjusting for known environmental effects, and contemporary groups can be used to improve heritability and repeatability.
- How the use of deviations from contemporary group means or how using trait ratios decreases environmental variation.

Skills to acquire

- Calculate heritability given appropriate variances, covariances, and(or) regressions.
- Construct column charts and scatter plots illustrating high and low repeatability.

Factors Affecting the Rate of Genetic Change

Points to understand

- Five elements of the key equation for genetic change: rate of genetic change, accuracy of selection, selection intensity, genetic variation, and generation interval.
- How it is possible to simultaneously have low accuracy and high intensity and vice versa.
- How "proportion saved" is related to selection intensity under truncation selection.
- Why selection intensity is often poor with phenotypic selection for a threshold trait, and why improvement in the trait leads to even worse selection intensity.
- Why the elements of the key equation change over time.
- The trade-offs among elements of the key equation: accuracy versus generation interval; accuracy versus intensity; intensity versus generation interval in each sex.
- Why male selection is so much more important than female selection, and why there are limitations to the rate of genetic change when sires are purchased.

Skills to acquire

- Use a particular formula of your choice to predict the rate of genetic change in a population.
- Make practical decisions about the design of a breeding program using the key equation for genetic change or its variants.

Genetic Prediction

Points to understand

- Why genetic prediction technologies are important.
- The several kinds of data commonly used in genetic prediction.
- The factors affecting accuracy of prediction.
- The relative importance of individual performance information versus relatives' information at different levels of heritability.
- Why pedigree information is important but often of limited value.
- Why progeny information is especially valuable.
- Why additional records are more informative when data are "scarce" than when data are abundant.
- The difference between direct, maternal, and paternal components of traits.
- The meaning of total maternal value.

Skills to acquire

- Calculate single-source predictions of breeding values, progeny differences, and producing abilities, when given appropriate formulas for regression coefficients and associated accuracies.
- Convert an accuracy value to a 68% confidence range.
- Given direct and maternal EBVs or EPDs and predictions of permanent environmental effects, calculate total maternal value and MPPA.

Genetic Evaluation

Key points to understand

- The rationale for genetic evaluation and methods for treating data.
- The merits of designed central tests versus analyses of field data.
- The differences among the various kinds of EPDs expected to exist for meat goats.
- Understanding that genetic predictions are tools for comparing animals.
- What a genetic prediction of zero from a genetic evaluation really means.
- How measures of accuracy can be used to determine both selection risk and the likelihood that differences in genetic predictions between animals are meaningful.
- That accuracy measures reveal nothing about uniformity of progeny.
- The kinds of problems that cause errors in genetic evaluation.

Correlated Responses to Selection

Points to understand

- The chief cause of correlated response to selection.
- That the (mathematical) sign of a correlation does not indicate whether the correlation is favorable or unfavorable.

- The factors affecting correlated response to selection.
- The conditions that favor indirect selection for an indicator trait over direct selection.
- How some genetic correlations can be helpful and others detrimental.

Skills to acquire

- Calculate correlation from appropriate variances and covariances.
- Given some required parameters, calculate response to selection.

Multiple-Trait Selection

Key points to understand

- Aggregate breeding value or net merit.
- The differences among and relative merits of the three methods of multiple-trait selection: tandem selection, use of independent culling levels, and use of economic selection indexes.
- The structure of a breeding objective.
- The criteria for determining traits in a breeding objective and traits in a corresponding index.
- Why selection intensity for and genetic change in individual traits is lower under multiple-trait selection than under single-trait selection for those traits.
- General guidelines for determining whether a trait merits efforts in selection.

Skills to acquire

- Use independent culling levels to choose a set of replacements given performance data or genetic predictions.
- Use an economic selection index to choose a set of replacements given performance data or genetic predictions.

Mating Systems for Simply-Inherited Traits

Key points to understand

- What information is needed to make mating decisions for simply-inherited traits.
- How to use repeated backcrossing or introgression to import an allele from another population.
- How repeated backcrossing to import an allele differs from grading up.

Skills to acquire

- Determine probabilities of parent genotypes from pedigree information and estimates of gene frequencies.
- Calculate probable proportions of offspring genotypes given probabilities of parent genotypes.

Mating Strategies Based on Pedigree Relationship: Assortative mating, Inbreeding, and Outbreeding

Points to understand

- How random, positive assortative, and negative assortative mating differ and for what purposes each should be used.
- The concept of complementarity.
- The value of crossing maternal and paternal breeds or lines.
- The effects of inbreeding on homozygosity, prepotency, expression of deleterious recessive genes, and inbreeding depression.
- The mechanism by which inbreeding causes inbreeding depression, and outbreeding causes hybrid vigor or heterosis.
- How inbreeding and relationship coefficients are defined.
- How linebreeding differs from inbreeding.
- The effects of inbreeding on uniformity in simply-inherited and polygenic traits.
- Why crosses of less related breeds and lines produce more hybrid vigor than crosses of more closely related breeds or lines.
- The major purposes of outbreeding: hybrid vigor and complementarity.
- Why inbreeding is practiced mostly by seedstock producers and outbreeding is practiced mostly by commercial producers.

Skills to acquire

- Use the genetic model for quantitative traits to explain why animals usually show little hybrid vigor for highly heritable traits and more hybrid vigor for lowly heritable traits.
- Calculate inbreeding and relationship coefficients using the path and tabular methods.

Hybrid Vigor or Heterosis

Key points to understand

- That hybrid vigor generated by crossing breeds or lines is simply a restoration of hybrid vigor lost in inbreeding.
- That superior crosses provide consistently more hybrid vigor and better performance than is possible with the original base population.
- How hybrid vigor or heterosis is measured.
- The trade-off between maximizing hybrid vigor and maintaining breeding value and performance.
- The differences among individual, maternal, and paternal hybrid vigor.
- Why hybrid vigor declines from the F1 to the F2 generation and then remains constant in more advanced generations of hybrids.
- How recombination loss can cause further decline in hybrid vigor beyond the F2 generation.
- Why hybrid vigor declines in each backcross generation.

Skills to acquire

- Calculate hybrid vigor and percent hybrid vigor from performance data for purebred parent populations and F1 crosses.
- Design a breeding program that takes advantage of individual, maternal, and paternal hybrid vigor.
- Calculate estimates of hybrid vigor.
- Predict phenotypic performance of crosses involving any combination of breeds.

Crossbreeding Systems

Key Points to Understand

- Why crossbreeding systems, based on good purebred stock, are needed in commercial production.
- How rotational crossbreeding systems work.
- How static terminal systems and rotational/terminal systems work.
- How a composite animal differs from a hybrid.
- Why composites can play both commercial and seedstock roles.
- How inbreeding can be avoided in developing composite populations.
- Strategies for increasing uniformity within a herd or flock. Why it is so difficult to decrease genetic variation in polygenic traits.
- Strategies for increasing uniformity within the meat goat sector.

Skills to Acquire

- List five criteria used to evaluate crossbreeding systems and explain the rationale for each.
- Calculate the percentage of F1 hybrid vigor retained in rotational systems using either purebred or crossbred sires.
- Calculate the percentage of F1 hybrid vigor retained in advanced generations of various composite breeds.

Biotechnology and Animal Breeding

Key points to understand

- Two general categories of biotechnologies.
- Factors determining the impact of a biotechnology.
- The advantages and disadvantages of the following reproductive technologies: artificial insemination, embryo transfer, in vitro fertilization, sex control, production of clones from embryonic tissue, production of clones from adult tissue, and same-sex mating.
- Why multiple cycles of cloning are required for continuous genetic change.
- The need for preservation of animal germ plasm.
- How reproductive technologies can be used to preserve germ plasm.

- The advantages and disadvantages of the following molecular technologies: DNA fingerprinting, marker assisted selection for simply-inherited traits, marker assisted selection for polygenic traits, and gene transfer.
- Why genetic markers must be closely linked to genes of interest.
- The usefulness of detailed gene maps.
- Why marker assisted selection may be more valuable for simply-inherited traits than for polygenic traits.
- Why marker assisted selection for polygenic traits may be more valuable for traits that have been subject to little selection pressure in the past.
- How information on genetic markers can be incorporated in genetic evaluation programs.

Summary Issues in Breeding Meat Goats

Key points to understand

- The attributes that successful meat goat breeders tend to have in common.
- How these attributes contribute to the success of breeding programs.

Ethics in Meat Goat Breeding and Merchandizing

Key points to appreciate

- Long term business success depends on treating people right and being honest in husbandry practices.
- Breeding for functional animals without major defects.
- Commercial meat goat needs should drive the selection program of purebred breeders.
- Get those registration papers transferred on time.

In developing this module I have been guided by and have included selected examples from the textbook I have used for several years in teaching the Animal Breeding and Small Ruminant Management courses at Fort Valley State University. That book, entitled "Understanding Animal Breeding," was written by Dr. Rick Bourden at Colorado State University. It is a recommended reference for goat breeders who have a serious interest be becoming a student of the discipline. Examples specific to goats in general and to meat goats in particular are cited when discussed. – Will Getz

*Information contained in this document is part of a web-based training and certification program for meat goat producers (*http://www2.luresext.edu/goats/training/qa.html*) that was developed with funding received by Langston University from USDA/FSIS/OPHS project #FSIS-C-10-2004 entitled "Development of a Web-based Training and Certification Program for Meat Goat Producers."*

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