# Chapter 1
# An overview of animal breeding programs

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INTRODUCTION .......... 1
IMPORTANT FACTORS IN BREEDING PROGRAMS .......... 2
BREEDING STRATEGIES .......... 3
STRUCTURE OF BREEDING PROGRAMS .......... 5
INTRODUCTION TO MARKER ASSISTED SELECTION .......... 5

## Introduction

The face of animal breeding has changed significantly over the past decades. Animal breeding used to be in the hands of a few distinguished 'breeders', individuals who seems to have specific arts and skills to 'breed good livestock'. Nowadays, animal breeding is much dominated by science and technology. In some livestock species, animal breeding is in the hands of large companies, and the role of individual breeders seems to have decreased. There are several reasons for this change. Firstly, the breeding industry has taken up scientific principles. Looking was replaced by measuring, and an intuition was partly replaced by calculations and scientific prediction. Other major developments were caused by the introduction of biotechnology. These are roughly the reproductive technologies, and the molecular genetic technology. Not all of this is new. Artificial insemination was introduced in the fifties in cattle. No doubt that the technology had a major impact on rates on genetic improvement in dairy cattle, and just as important, on the structure of animal breeding programs. Nowadays, technologies like ovum pick up, in vitro fertilization, embryo transfer, cloning of individuals, cloning of genes, and selection with the use of DNA markers are all on the ground. Some of the technologies are already applied, others are further developed, or waiting for application. Finally, the rapid development of computer and information technology has greatly influenced data collection and genetic evaluation procedures in livestock populations, now allowing comparison of breeding values across herds, breeds or countries.

The introduction of breeding methods typically needs to find the right balance between what is possible from a technological point of view and what is accepted by the decision makers and users within the socio-economic context of a production system. Ultimately it is the consumer who decides which technology is desirable or not. In most western societies, consumers are increasingly aware of health, environmental and animal welfare issues. Food safety and methods food production are part of their buying behavior. However, price and production efficiency remain to be major contributors to sustainability of a livestock industry. Successful animal breeding programs need to find the right dose of technology that helps them to be competitive.

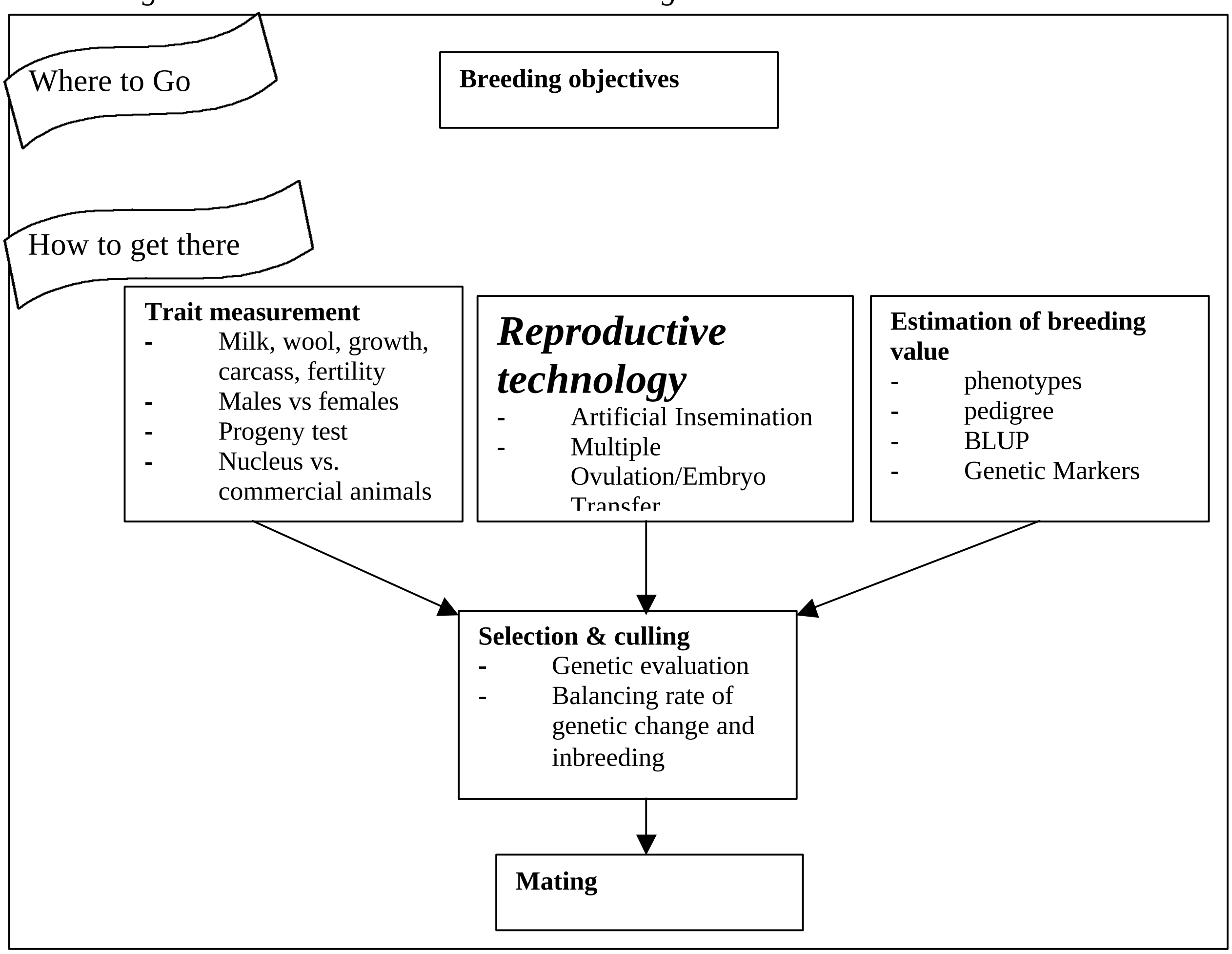
## Important factors in breeding programs

Which decisions need to be made?

In essence, the two key questions in animal breeding are: *Where to go?* and *How to get there?* Running an animal breeding program involves the answer to these questions, which can be worked out in a bit more detail as:

1. What is the breeding objective: which traits need to be improved and how important are different traits in relation to each other.
2. What and who do we measure? Which traits, which animals?
3. Do we need to use any reproductive technology (Artificial Insemination, Embryo Transfer) if possible.
4. How many and which animals do we need to select as parents for the next generation
5. How to mate the selected males and females

*Figure 1. Decision issues in animal breeding*




The definition of the *breeding objective* is the first and probably most important step to be taken. Improving the wrong traits could be equivalent or even worse than no improvement at all! If many breeding animals males will be considered for reasons *irrelevant to* the breeding objective, than the selected group will not be as good with regard to the breeding objective as was expected. It is important in the selection process that the selection criterion is clear, and whether the selection is efficient in relation to the breeding objective.

## Breeding Strategies

Reproductive rate of breeding animals and uncertainty about true genetic merit of breeding animals make up the most important limiting factors in a breeding program. How many and which animals should be selected is determined by these factors. Investments in breeding programs are therefore often related to trait measurement and genetic evaluation, and to technology to increase reproductive rates.

*Measurement Effort and Genetic Evaluation*

The benefit of abundant and good measurement is that we may better be able to identify the genetically superior animals. This leads to more accurate selection and more genetic improvement.

Phenotypic measurements are turned into *Estimated Breeding value's (EBV's)*. Estimation of breeding value based on an animal's phenotype alone can already be quite accurate for high heritable traits. However, animals need to be compared across herds, and genetic and environmental influences have to be disentangled. To achieve this, more sophisticated statistical methods are used, leading to *Best Linear Unbiased Prediction* (BLUP) of breeding values. Besides allowing across herd comparisons, BLUP also uses all available information about an animals' breeding value, including data on related animals. Selection accuracy is strongly dependent on the degree of data recording, which requires a range of considerations related to cost and infrastructure. In data recording, individual performances need to be related to animal identification. If BLUP is used to generate EBV's also an animal's pedigree needs to be known (in principle, for each animal only sire and dam). If pedigree is not recorded, breeding value can be assessed on own performance only, and is limited to sexes, which express the traits of interest.

BLUP relies good structure of data (use of breeding animals across herds) and proper pedigree recording. If these prerequisites are in place, investment in BLUP methodology is usually highly cost efficient.

Molecular genetic technology has rapidly developed in the past 2 decades. Genes have been found coding for factorial traits (such as many diseases). Many production traits are *quantitative traits* and a likely genetic model is here that genetic differences between animals are due to many genes. However, DNA technology has also provided genetic markers. Certain genetic markers can improve estimation of an animal's genetic potential as they are associated with regions that account for genetic variation. Genotyping animals for marker genotypes is therefore an investment with the aim to better assess true genetic merit of animals.

*Reproductive technology*

Most of the main factors that determine genetic gain are directly influenced by the reproductive rate of the breeding animals. A higher reproductive rate leads to the need for a decreased number of breeding animals, therefore increasing the intensity of selection of these animals. If reproductive technology is possible, for example AI, the benefit could be expressed in terms of increased genetic rate of improvement, which in turn has a dollar component attached to it. More offspring per breeding animal allow also more accurate estimation of breeding value.

Reproductive technology allows the intensive use of superior breeding stock. An obvious consequence is possibly that the most popular breeding animals are overused, and the population could encounter inbreeding problems. Typically, as new technologies in animal breeding allow faster genetic change, long term issues such as inbreeding and maintenance of genetic variation become important. For that reason, selection tools in animals breeding have become somewhat more sophisticated in recent years. The impact of reproductive technologies on rates of genetic improvement and inbreeding will be discussed.

Besides a direct effect on rate of genetic improvement, another important consequence from increasing reproductive rates is to disseminate superior genetic stock quickly. The influence of a superior breeding animal would be much higher if thousands of offspring could be born, rather than if the superiority is passed on through the production of sons via natural mating. Another example is that of cloning. Cloning is not extremely important for increasing rate of genetic progress, but it could have a large impact by allowing many copies of the best individual to perform in commercial herds. As reproductive rates are basically multiplying factors in a breeding structure, any improvement in reproduction will justify higher investment in improvement of the best breeding stock

*Selection and Mating*

The decision about which animals should be selected as parents for the next generation is mainly based on *assessment of breeding value* of individual animals. *Genetic evaluation* is central to animal improvement schemes. Selecting animals based on estimated breeding value maximizes the response to selection that can be achieved. However, there is one other criterion that is relevant when deciding which animals should have offspring. This criteria is *common ancestry* of all selected parents. The coancestry of selected parents should stay below certain limits, since it is directly related to the build up of inbreeding. Coancestry among selected parents is determined by the average relationship among the selected parents as well as the number of parents selected. In this course we will more explicitly discuss selection strategies that maintain low levels of inbreeding.

Decisions about which animals need to be mated are often seen in relation to dominance effects. Utilizing dominance variation is often not of primary importance for improvement of purebreds, but it can have more impact if breeding animals are selected from different breeds or lines, as heterotic effects between breeds can be utilized. When multiple traits are involved in the breeding objective, assortative mating could be useful, matching qualities in different parents for different

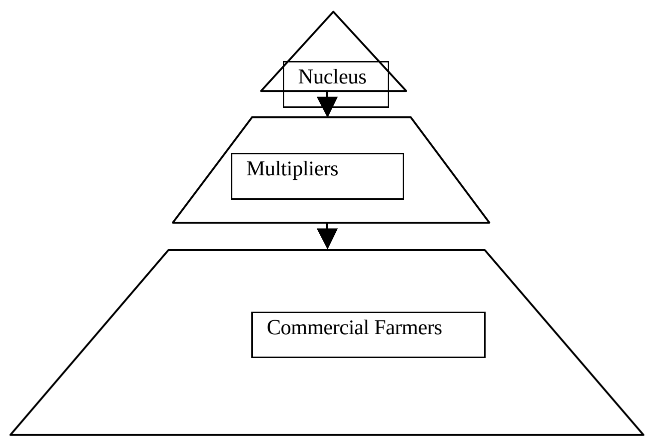
There is a good possibility that in the near future, planned mating will gain in importance, when effects of specific genotypes will be better understood. One could envisage certain genotypes with high growing potential to be combined with specific genes that have major effect on meat quality. Another argument for planned matings is to avoid inbreeding in direct offspring as well as the rate of inbreeding in the population. However, the rate of inbreeding depends mainly on population size and number of parents selected. Methodology to optimize selection and mating decisions related to inbreeding will be discussed.

## Structure of breeding programs

Most of the key decision factors mentioned earlier are related to the rate of genetic change that can be made. However, this could be genetic change in a small fraction of the national population (in nucleus or 'elite breeders'). Genetic superiority should be transferred as soon as possible to most of the commercial farms.

The structure of a breeding program is therefore relevant for two aspects of an improvement scheme:

1) The genetic improvement aspect: how do we determine the genetically superior animals.
2) The dissemination aspect: how do we manage that those superior animals disseminate their genes quickly though the whole population of production animals




We often talk about the 'design of a breeding program', suggesting that breeding programs can be characterized by some kind of structure. The traditional model here is the pyramid with a small group of breeding animals that are actually improved (the 'elite breeders' in the nucleus) and underlying levels of (possibly) a multiplier and a commercial. The later groups may not be involved in selection, but merely, they receive genes from the nucleus and are therefore improved over time. The genetic mean of lower tiers is somewhat lower than that of the nucleus, but the rate of improvement is in principle equal.

## Introduction to marker assisted selection

Over the last two decades most livestock industries have successfully developed EBV's to allow identification of the best breeding animals. EBV's are best calculated using BLUP, meaning that they are based on pedigree and performance information of several traits from the individual animal and its relatives. BLUP EBV's are the most accurate criteria to identify genetically superior animals based on phenotypic performance recording.

Although the idea of genetic selection is to improve the genes in our breeding animals, we actually never really observe those genes. Selection is based on the final effect of all genes working together, resulting in the performance traits that we observe on production animals. This strategy makes sense, since we select based on what we actually want to improve. However, animal performance is not only affected by genes, but also by other factors that we do not control. Selection for the best genes based on animal performance alone, can never reach perfect 100% accuracy. A large progeny test comes close such a figure of perfect selection, but this is expensive for some traits (e.g. for traits related to meat quality), and we have to wait several years before the benefits from a progeny test have an effect. Efficient breeding programs are characterised by selecting animals at a young age, leading to a short generation intervals and faster genetic improvement per year. For selecting at younger ages, knowledge about the existence of potentially very good genes could be very helpful.

Quantitative genetics uses phenotypic information to help identify animals with good genes. *Extension to use information from molecular* genetics techniques aim to locate and exploit gene loci which have a major effect on quantitative traits (hence QTL - Quantitative Trait Loci).

The idea behind marker assisted selection is that there may be genes with significant effects that may be targeted specifically in selection. Most traits of economic importance are quantitative traits that most likely are controlled by a fairly large number of genes. However, some of these genes might have a larger effect. Such genes can be called major genes located at QTL.

In practice, we rarely know the genotype at actual QTL, as the exact gene location (mutation) is often unknown. Currently there are few examples where QTL effects can be directly determined, but knowledge in this area is rapidly developing. Most QTL known today can only be targeted by *genetic markers*. Genetic markers are “landmarks’ at the genome that can be chosen for their proximity to QTL. We cannot actually observe inheritance at the QTL itself, but we observe inheritance at the marker, which is close to the QTL. When making selection decisions based on marker genotypes, it is important to know what information can be inferred from the marker genotypes. Figure 3 shows the principle of inheritance of a marker and a linked QTL. We can identify the marker genotype (Mm) but not the QTL genotype (Qq). The last is really what we want to know because of its effect on economically important traits.

Let the Q allele have a positive effect, therefore being the preferred allele. In the example, the M marker allele is linked to the Q in the sire. Progeny that receive the M allele from the sire, have a high chance of having also received the Q allele, and are therefore the preferred candidates in selection.

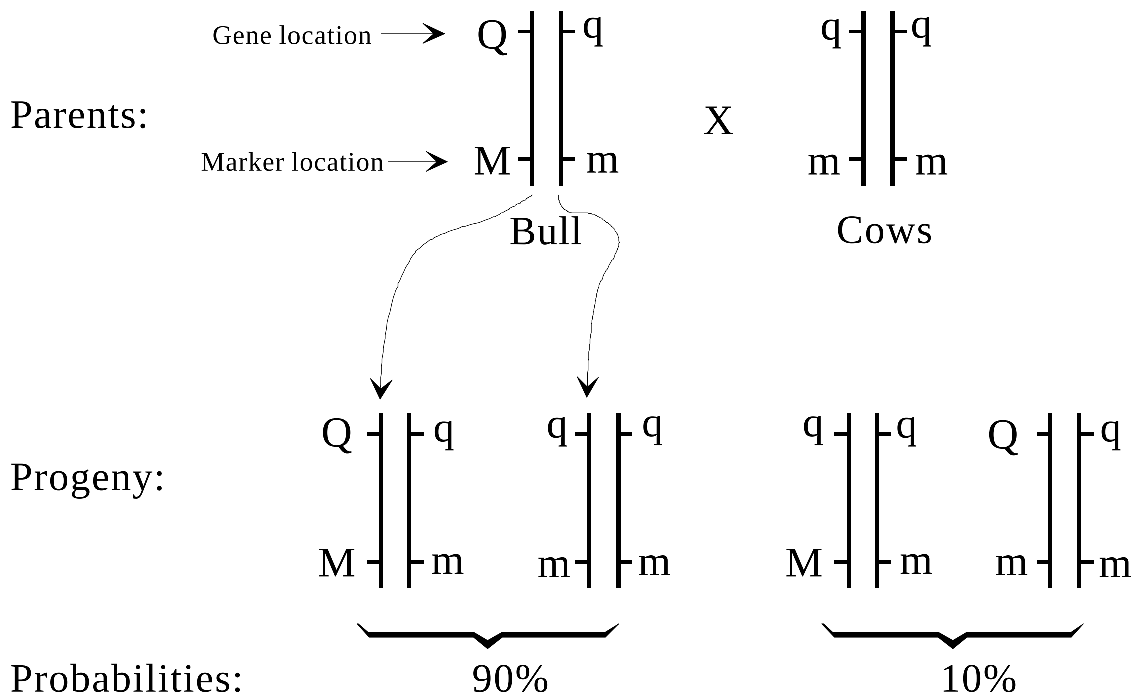



*Figure 3: Following the inheritance of a major genotype affecting a quantitative trait (Q locus) with a genetic marker (M locus) closely linked to the Q locus. The sire is heterozygous for either locus and the dam is homozygous. For this example, we can determine for each progeny whether they received M or m allele from their sire. The recombination rate (10%) determines how often Q alleles join M alleles.*