Brief Introduction to Plant and Animal Breeding

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These lecture notes contributes to "Compendium Plant and Animal Breeding and Genetics" (CPABG). The aim of the notes is to give a brief introduction to breeding in animals and plants and to support the associated lectures.

The notes consist of the following chapters:

The material provided in these notes is in part from the following sources (CC-BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0/): https://en.wikipedia.org/wiki/Selective_breeding https://charlotte-ngs.github.io/lbgfs2021/cn/01_intro_lbg.pdf

1 Brief Introduction to Breeding in Animals and Plants

Selective breeding (also called artificial selection) is the process by which humans use animal breeding and plant breeding techniques to selectively develop particular phenotypic traits (characteristics) by choosing which parents will sexually reproduce and make offspring. Domesticated animals are known as breeds, normally bred by a professional breeder. Domesticated plants are known as varieties, cultigens, cultivars, or breeds. Two purebred animals of different breeds produce a crossbreed, and crossbred plants are called hybrids. Flowers, vegetables and fruit trees may be bred by amateurs or professional breeders: major crops are usually produced by professional breeders, in academia or industry.

In both animal and plant breeding, crossing techniques such as inbreeding, linebreeding, and outcrossing are utilized. Charles Darwin (https://en.wikipedia.org/wiki/Charles_Darwin) discussed how selective breeding had been successful in producing change over time in his 1859 book, On the Origin of Species. Its first chapter discusses selective breeding and domestication of animals like pigeons, cats, cattle, and dogs. Darwin used artificial selection as a springboard to introduce and support the theory of natural selection.

The deliberate exploitation of selective breeding to produce desired results has become very common in agriculture and experimental biology.

Selective breeding can be unintentional. In plants, it may result from the process of human cultivation, and may produce unintended – desirable or undesirable – results. For example, in some grains, an increase in seed size may have resulted from certain ploughing practices rather than from the intentional selection of larger seeds. Most likely, there has been an interdependence between natural and artificial factors that have resulted in plant domestication.

1.1 Fundamental Questions in Selective Breeding

Natural selection and selective breeding can both cause changes in animals and plants. The difference between the two is that natural selection happens naturally, but selective breeding only occurs when humans intervene. For this reason, selective breeding is sometimes called artificial selection. Selective breeding takes place over many generations. These are the main steps involved:

- Which traits should we breed for?
- How do we select the *best* breeding individuals?
- What can breeders do to obtain the *best* breeding individuals?

The term `best` is relative, because there is no `best` breeding for all situations and all environments. Breeding individuals that show high performance in one environment, may not perform as well in a different environment. For example, Holstein cows in Europe or North America, are able to produce a lot of milk, but they have difficulties surviving in Africa. Knowing that the environment plays an important role for animals and plants, we usually assume that breeding populations are more or less adapted to their environment.

Breeding individuals are usually described or characterized in terms of appearance and/or performance. In any case, we will be talking about **traits** where any trait is an observable or measurable characteristic of an breeding individual. Examples of *observable* traits are:

Type of traits	Animals	Plants
Observable	Coat color Size Muscling Leg set Udder conformation	Grain/flower/leaf color Branching pattern Disease
Measurable	Body weight Milk yield Protein and fat yield Carcass weight	Plant height Grain yield Biomass yield Nutritional content

Note, it is important to distinguish between the observed or measured values of a trait which might be `red` coat color or 343 kg of body weight and the traits themselves which are just coat color or body weight. The observed or measured values of a trait are also called **phenotypes**.

1.2 Genotypes and Phenotypes

In selective breeding we are mainly concerned with changing the populations at the genetic level. The reason why we are interested in changing a population genetically is because parents do not pass their phenotypes per se to their offspring. Instead, they pass a random sample of their genes to their offspring. For each offspring every parent does transmit a different sample of their genes. From a genetic point of view, we want to know not only the most desirable phenotype, but also the most desirable genotypes. From the central dogma of molecular biology (https://en.wikipedia.org/wiki/Central_dogma_of_molecular_biology), it follows that an animal's genotype provides the genetic basis for phenotypes. The relationship between phenotypes (P) and genotypes (G) can be summarized by the following equation:

$$P = G + E \tag{1}$$

where E represents the **environmental effects**. These may include external effects like climate and soil composition (abiotic factors) and exposure to beneficial or pathogenic microbes (biotic factors). They may also include developmental effects like maternal effects, or simply measurement errors (random fluctuations in measurement of phenotypes). Because we want to change our populations at the genetic level, we are interested in the effect of genotypes (G). In most cases, we are not able to directly observe or measure G. But we will see later on how we can estimate G based on measurements and observations of P and based on estimates of E. In particular, we will see how **breeding values** , the part of G that is transmitted over generation, are estimated and used by breeders to perform crosses and improve populations. Those tools are being described in the following section.

1.3 Improvement of Breeding Populations

The purpose of selective breeding is to improve the traits selected for, in a breeding population. Once a breeding individual is conceived, its genotype is fixed and cannot be improved anymore. Breeders can improve populations at the genetic level using the following two tools:

- **evaluation** of individuals in the current generation
- **selection** of the 'best' individuals (for phenotypes of interest)
- **mating** of selected individuals to generate the next (improved) generation

1.3.1 Evaluation

Breeding value estimation is a fundamental component of breeding programmes,in which the breeding value of each individual is predicted to inform subsequent selection decisions. The breeding value for an individual is the effect its genes will have in the population. Breeding values are used for 1) comparing individuals in the breeding population and to select parents for the next generation, 2) predicting the consequences of selection decisions, and 3) describing genetic differences over time (result of previous selection).

1.3.2 Selection

Selection is the process of choosing individuals in the current generation, as parents for the next generation. The application of selection in a certain population over a certain time changes the breeding individuals in that population at the genetic level. The most familiar form of selection is natural selection which occurs in natural and wildlife populations. Natural selection is one of the great forces of evolution and it also affects domestic animal and plant populations. All animal or plants with lethal genetic defects are naturally selected against, i.e., they do not survive before the breeder gets to evaluate them.

Although natural selection cannot be ignored for agricultural animal and plant species, for the focus of animal and plant breeders is **artificial selection**. The idea behind artificial selection is simple. For a given trait all individuals in a breeding population are ranked according to their estimated breeding value. From this list, the top-ranking breeding individual are used as parents for the next generation. In most breeding populations, breeders are interested in proving more than one trait. When considering more than one trait, the question is how to come up with the ranking for the individuals to be selected as potential parents. There are several strategies to produce such a ranking based on a number of traits. It has been shown that using a weighted mean of the breeding values of all traits, which is called an **aggregate genotype** , to rank all animals is an optimal procedure to be used as selection criterion.

1.3.3 Mating

The second tool we have available as animal or plant breeders is **mating**. In a mating scheme, we must decide which of the selected males and females are mated with each other. There are a number of different rules that can be followed. The application of a given set of rules is summarized as a mating system. There are three reasons for using a specific mating system.

1. producing offspring with extreme breeding values. When parents with extreme breeding values (high or low) are mated, offspring with extreme phenotypes can be expected. This is mostly used when a given trait is to be changed in one direction
2. making use of complementarity in parental traits. When neither of the parents is optimal, a mix of traits can be desirable. In such a case parental genotypes can be quite different. . When parents of different breeds are mated, then this is called **crossbreeding**.
3. obtain positive effects due to heterosis. Hybrid vigor or heterosis in crossbreeding occurs when offspring performance exceeds the performance of the pure-breds.

There might also be other aspects that influence a mating system, e.g. to restrict the level of inbreeding or to consider optimum genetic contribution theory.