Breeding Basics - Genetics

As a breeder you will be responsible for selecting animals for breeding based on a whole host of traits and aptitudes that you value and wish to pass on to the next generation. You also want to minimise disease and undesirable traits in the litters you produce.

Your goal will always be to breed for improvement – each litter or generation healthier than the last, each litter moving closer to the breed standard ideal.

To do this well, you need to have a basic understanding of genetics and inheritance. In fact, the better you understand how traits are passed from generation to generation, the easier it will be to make informed breeding choices. Having a good understanding of inheritance can also help when unexpected problems crop up and you need to develop a hypothesis of how they may have been transmitted through the gene pool.

Many breeders find the science of genetics very complicated and quite daunting to learn, but without it, you are unlikely to be able to move ahead in your breeding program. There are a lot of good references for breeders – some more technical than others – that can help you understand how traits are passed from generation to generation and how the study of genetics can be used to help your breeding program.

This overview aims to give you a basic understanding of the important concepts, but as a breeder, you should always be looking to expand your knowledge further. You are taking a role as the guardian of your breed, so you want to make sure you never stop learning, questioning and striving for improvement.

First Principles

Genetics is the study of how traits are passed on from one generation to the next.

The individual units of inheritance are called ‘genes’ with each gene specifically relating to a single trait or function. Our genes determine everything from what colour hair and eyes we have, to how tall we are and how our body functions and behaves.

At the heart of the science of genetics is a special substance called DNA – Deoxyribonucleic Acid. The DNA exists inside each cell as long strands of ‘genetic code’ – like a recipe book for growing and maintaining a working body. A single strand of DNA can contain thousands of individual genes all coding for different things.

Because the strands of DNA can be very, very long, they are coiled up tightly to save space. These coiled up strands are called ‘*chromosomes*’.

Chromasomes come in pairs, meaning that there are two copies of every gene. We inherit one copy from our father, and one copy from our mother.

Every animal has a set number of chromosomes. Cats have 19 chromosome pairs and humans have 23 pairs. Dogs have 39 pairs. Of this 39 pairs, 38 of them are perfectly matched pairs called ‘autosomal pairs’ and the remaining pair may be unmatched and are called the ‘sex chromosomes’.

Sex chromosomes are labelled ‘X’ and ‘Y’. If an animal has two ‘X’ chromosomes (XX), they develop into a female, and if they have an ‘X’ and a ‘Y (XY)’, they develop into a male animal.

During the production of sperm cells and egg cells, a special process occurs that divides the chromosome pairs found in normal cells so that only one copy of each chromosome (and therefore only one copy of each gene) is carried by each sperm or egg.

During this division process, there is a somewhat random assortment of genes – no two eggs, and no two sperm are exactly the same because there are thousands of genes and therefore millions of possible combinations.

When fertilization occurs, these single chromosomes, carried by the sperm and the egg, join together to produce a single cell with a full set of paired chromosomes. From here, the cell will grow and divide, becoming a new animal.

You can see that even within a litter there will be quite a bit of genetic variation because of all of the possible egg-sperm combinations. This goes some of the way to explaining why no two puppies are identical, even if they are from the same litter.

Breeding Basics - Genetics

Note:

Identical twins in dogs are extraordinarily rare. Identical twins occur when a single fertilised egg divides and becomes two embryos.

The genetic coding that each individual receives from their parents is called their 'genetic potential' – what we would see if nothing went wrong, and everything was perfect from the time of fertilisation until the animal died. However, in reality, there are a lot of external factors that can influence what actually happens during an animal's lifetime – factors such as diet, disease, injury and environment can all impact the eventual outcomes.

Scientist have now 'mapped' the entire dog genome – meaning they have identified the location of all of the genes on each of the chromosomes. This information is used when looking for markers for a disease, or developing DNA tests for a particular trait.

Important!

As a breeder, you need to remember that all animals carry both 'good' or 'healthy' genes and 'bad' or 'unhealthy' genes.

Therefore, no matter how successful or amazing an animal is – they will still produce some offspring that are 'less good' and have more of the undesirable traits.

So how do genes work?

The body of every animal is made up of billions of individual cells. The cells vary in shape and size, and they do different 'jobs' within the body – some are skin cells, some are liver cells, some are responsible for fighting infection, others produce the enzymes needed to digest food.

The 'instructions' for growing all of these cells and maintaining a functioning body are coded for in the genes. Each gene can be 'read' and the instructions will lead to the production of a single protein. It is the protein that goes off into the cell or into the body to actually cause the 'effect'.

These proteins are involved in every imaginable cell, tissue and body function. From building bones and muscles, to replacing and repairing cells, to triggering the changes that make one cell grow into a nerve cell and another into a cell that secretes a specific hormone. It is truly amazing how it all works!

Some traits that we see are the result of a single gene and a single protein, whereas other traits are the result of a combination of many genes (and many proteins) acting together.

Some important terminology

Genetics has a language all of its own. Unfortunately as a breeder, you will need to learn at least some of this terminology if you want to understand some basic genetic concepts. So here are some of the most commonly used terms:

Genes – these are the 'units' of inheritance, a small section of DNA . Remember: every animal has two copies of every gene

Allele – alleles are the various different forms of a single gene. You could consider then the 'possible options' for that particular gene. For example, a gene that codes for coat type may have the possible options of 'wavy' or 'straight' – the 'wavy allele' and the 'straight allele'.

Homozygous – refers to an individual whose two copies of the gene are the same.

Heterozygous – refers to an individual whose two copies of the gene are different.
Genotype – refers to the actual genes the animal carries – the combination of alleles it has.

Phenotype – refers to what we can see – the expression of the genes. Because there are two copies of every gene, there is a variety of possible interactions and outcomes. Phenotype is the visible result of these interactions.

Heritability – A statistical representation of how much of a trait is likely to be due to genetics and how much is due to environment.

Breeding Basics - Genetics

Traits with very high heritability have very little environmental influence, and are usually much easier to select for or against when choosing breeding animals. Traits with very low heritability are heavily impacted by environmental factors, and are therefore much harder to selectively breed for or against.

Modes of inheritance

There are many different modes of inheritance. This refers to the way the genes and the different alleles interact.

There are simple dominant-recessive interactions, sex-linked and polygenic modes of inheritance, and then there are variations of these such as incomplete dominance, incomplete penetrance, and the effects of epigenetics. Sound complicated? Well it is!

Simple dominant – recessive inheritance

As a breeder, probably the most important mode of inheritance that you need to understand is the simple dominant-recessive interaction that is seen when a single gene controls a single trait. This form of inheritance is important to understand because many serious diseases are inherited in this way.

Example:

We have identified a single gene that determines the colour of a particular breed's coat. In this breed, there are only two possible coat colours – black and cream (these are the two possible *alleles*).

We know that every individual has two copies of the coat colour gene, one from their mother and one from their father. So they can either have two copies of the gene for the same colour – black/black or cream/cream (*homozygous*) or they can have one copy of each - black/cream (*heterozygous*).

Because we can see the coat colour we have a visual display of how the genes interact (*phenotype*) If the animal only has the genes for the black coat colour – they will have a black coat, if they only have the genes for the cream coat colour, they will have a cream coat.

If they have one copy of each gene – the coat colour we see will tell us how the two genes interact. In this case, the coat is black, so the black coat gene is said to be 'dominant', and the cream coat gene is said to be 'recessive'.

When geneticists write this, they use the capital letter to indicate the dominant gene and the lower case of the same letter to indicate the recessive gene. So, in this case they may use 'B' for black and, 'b' for cream in genetics shorthand.

So the possible combinations would be written like this:

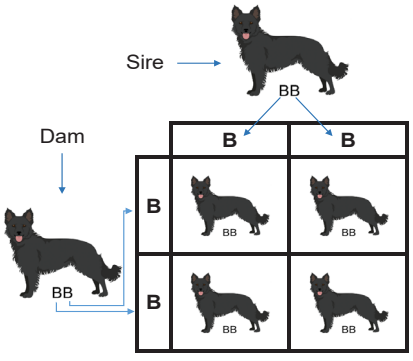
- BB – Only carries black, also called *homozygous black*
- bb – Only carries cream, also called *homozygous cream*
- Bb – *heterozygous* black, but said to 'carry' the cream gene

BB Bb bb

Because we know that when a breeding occurs – the offspring receive one copy of the gene from each parent we can now predict what the possible combinations, and hence coat colours, would result from any of the possible combinations.

Geneticists use a tool called a 'Punnet Square' to show the possible combinations. The genotype of the mother is put on one side of the square and the genotype of the father is put on the adjacent side, and the possible combinations are then plotted.

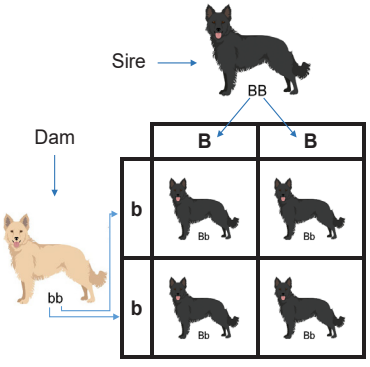
Breeding Basics - Genetics



Combination 1 - BB x BB (Black to Black)

Each parent can only contribute the Black gene, as this is all that they have.

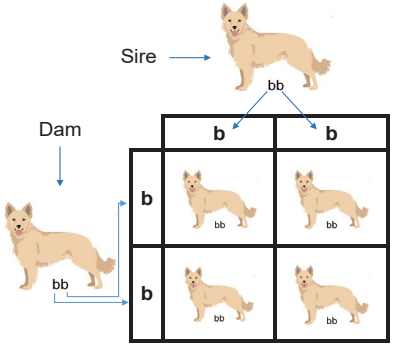
All offspring will be Black



Combination 3 - BB x bb (Black to Cream)

In this case one parent will contribute the Black gene and the other will contribute the Cream gene

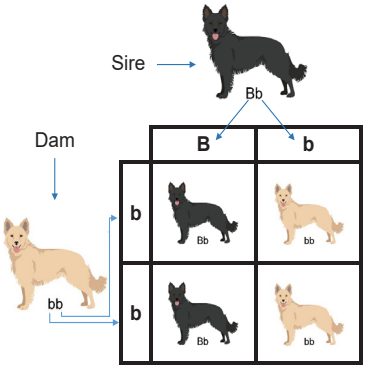
All offspring will be ‘Bb’ genetically and their coats will be BLACK……but they will all ‘carry the cream gene’



Combination 2 - bb x bb (Cream to Cream)

Each Parent can only contribute the Cream gene, as this is all that they have

All offspring will be Cream

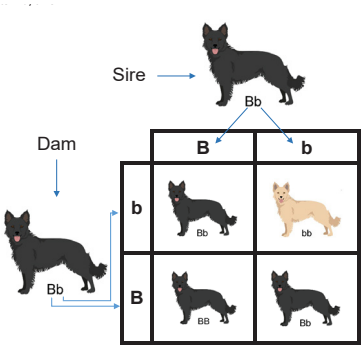


Combination 4 - Bb x bb (Heterozygous Black to Cream)

In this case the cream parent can only contribute the cream gene, but the Black parent can either contribute the Black gene OR the Cream gene.

The result will be 50% Bb and 50% bb – half of the offspring will be Cream and the other half will be Black but all of the Black offspring will carry the cream gene.

Breeding Basics - Genetics



Combination 5 - Bb x Bb (Both parents heterozygous black)

In this case both parents may either contribute the Black or the Cream gene.

The result will be 25% BB, 25%Bb, 25% bB and 25% bb. Bb and bB are the same – both will have black coats but carry for cream.

So on average one in four of the offspring will be cream, and of the Black coated off spring, 2 out of 3 will carry the cream gene.

Remember:

For combinations 3, 4, and 5 above, the outcome percentages listed are only an average if there were an infinite number of matings. The actual result in any single litter will vary.

How might this relate to health?

Imagine if the trait we were looking at caused something more serious – a disease or fault that was transmitted in the same way.

You can see if the fault or health defect was 'dominant' and if it caused the affected animals to die or not be able to reproduce, the disease would be quickly removed from the population.

Imagine if the black coat gene *(the dominant allele in the above example)* was paired with a heart defect that caused pups to die at quite a young age.

You can see that the black coated pups would not get to reproduce, and the black coated pups that carried the healthier cream genes would also not pass their genetics on – so it would not take long for the entire population to have cream coats and normal hearts.

Of course, every now and then a mutation can occur leading to a dominant trait emerging, but it soon gets 'bred out' of the population by natural selection.

Very few diseases are caused by dominant genetic traits for this reason. Instead, most of the problematic diseases and defects are the result of a recessive trait. Often the carriers are not obvious and cannot be tested for. The first time you know one of your animals is a carrier is when you accidentally mate it to another carrier – so an affected individual appears from a breeding of two apparently normal parents.

Although this sounds very bad, having carriers in the population is not a problem if there is a genetic test available that can identify them. If you are aware of an animal's genetic status as a carrier, you can then select a breeding partner who is clear of the problem, and prevent producing puppies that carry two copies of the problem gene, and who are affected by the disease.

Sex-linked traits

When animals get their genes from their parents, there is one special pair of chromosomes that are not like the others – the sex chromosomes.

As we discussed earlier, a female will result when two copies of the X chromosome are inherited, and males where there is an X and a Y chromosome.

Of course, the X- and Y-chromosomes also carry genes for other traits along their length, with the Y chromosome being much shorter and having fewer genes. Because there are quite a few genes on the X chromosome, and males can only have one copy, it means they are at a much higher risk of being affected by recessive traits or diseases coded for on the X chromosome.

Breeding Basics - Genetics

Where can I learn more about genetics and inheritance?

Dogs Victoria recommends that you continue to learn all you can about genetics and how it affects dogs and dog breeders. There are plenty of online sources for genetic information, but here are a few places to get started.

An important document for you to read is the Victorian Government's mandatory '*Code of Practice for the Responsible Breeding of Animals with Heritable Defects that Cause Disease*' that applies to all Victorian breeders.

It gives an outline of the inheritance patterns for many of the common serious hereditary diseases and sets rules for the breeding of animals with these.

If you are breeding dogs in Victoria, you MUST adhere to these guidelines.

Some other resources include:

The UK Kennel Club's Website has some excellent information about understanding canine genetics.

The American Kennel Club Website also has some excellent information on genetics for dog breeders.

There is also an easy to understand US-based video, however it does contain footage of dogs with cropped ears (which is a *prohibited procedure* here in Australia)

Finally a Ted Ed animated video on Mendelian Genetics is available on Youtube.