Proposed inheritance of coat colour in the German Longhair Pointer.

The study of genetics is a complicated business requiring its own language. In order to explain the inheritance of coat colour one has to use genetic terms. Therefore, I feel it wise to explain some of these terms before trying to explain how I think coat colour is inherited in the German Longhair Pointer.

The phenotype of an animal are the features or characteristics they inherit from their parents. These characteristics are carried by genes. Genes are located on chromosomes, the position of these genes are referred to as loci {locus - singular}. The basic unit of inheritance is a very large molecule called de-oxyribose nucleic acid, fortunately abbreviated to DNA, and chromosomes are essentially DNA molecules although they are wrapped in proteins for protection. DNA is a universal molecule, it consists of two backbones made from sugar and phosphoric acid molecules. Between the two backbones are combinations of four organic bases. It is the sequence of these bases which determine the characteristics of a gene. Therefore, a gene is a unit of DNA that codes {carries the message} for a particular characteristic. Genes mainly code for proteins which may be structural or for the production of enzymes, which are needed for chemical reactions e.g. the production of chemicals that may alter coat colour.

There can be many forms of the same gene, these are known as alleles. Alleles, therefore, have their own locus on a particular chromosome. Chromosomes occur in pairs called homologous pairs {homo meaning same}. Each locus on each chromosome carries one allele, therefore, a pair of alleles represents one gene. During cell division to manufacture sex cells called gametes {eggs or sperm}, the homologous chromosomes separate and thus alleles also become separated. This results in a gamete carrying one copy of each chromosome and, therefore, part of the genes {or alleles} carried on those chromosomes. During sexual reproduction a sperm carrying alleles from the sire, fuse {join with} and fertilise the egg which carries alleles from the dam. These alleles can now come together on the homologous chromosomes and the genes can be expressed.
e.g. A black dog may carry an allele for black colour {B} and an allele for brown colour {b}. During the production of gametes the homologous chromosomes separate thus half the sperm, if a male dog, will carry the black {B} allele and half the sperm will carry the brown {b} allele.

When a sperm fertilises an egg the chromosomes find their homologous partner and the alleles come together to be expressed as a gene. There are several ways in which these alleles can interact. By convention, a capital letter is used to signify that the allele is dominant and overrides the recessive allele, denoted by a small case letter. In its simplest form there are three possible combinations known as genotypes:

BB - homozygous dominant, black in colour
Bb - heterozygous, black in colour
bb - homozygous recessive, brown in colour

Thus if both the sire and the dam are heterozygous {Bb} there will be a 75% chance that there offspring will be black and a 25% chance of being brown. e.g.

	Sire	Dam
genotype	Bb	Bb
gametes	B or b	B or b

possible combinations:

	B	b
B	BB	Bb
b	Bb	bb

Genotypes of offspring: BB Bb Bb bb

Phenotypes of offspring black black black brown

Thus: 25% of the puppies will be black
50% will be black but carry the brown allele
25% will be brown

This type of dominant - recessive inheritance is common and is certainly believed to be involved in the inheritance of the brown colour in German Longhair Pointers {GLP's}. The brown colouration is due partly to the recessive inheritance of the gene found at the B locus. In contrast, a Large Munsterlander's black colouration is partly due the inheritance of the dominant B allele. Phenotypes can often be the same although the genotypes are different. In this case, it is often difficult to identify the true genotype, since the black colour could be the result of homozygous dominant {BB} or heterozygous {Bb}. This could present a problem when trying to breed out a recessive trait, since it is not uncommon for two black dogs to produce some puppies that are brown in colour.

Another type of inheritance which is relatively common is one known as incomplete dominance. Here, the dominant allele does not completely override the recessive allele. This leads to a different phenotype, often intermediate between the two homozygous phenotypes. In GLP's it is thought that genes at loci S for white spotting and T for ticking are inherited by incompletely dominant genes.

To further complicate matters, some genes may consist of multiple alleles. In this case a gene locus may have more than two alleles that influence the outcome of the phenotype. Since the offspring only inherits one allele from each parent for this particular locus there could be many possible combinations of alleles inherited. For example, the B locus has three possible recessive alleles bs , bc and bd. In GLP's the brown coat colour is the result of the homozygous recessive alleles bd bd, whereas in the Large Munsterlander the brown colouration is the result of a different mutation {change in the sequence of bases in the DNA} notably bs bs . The Newfoundland has a rarer mutation for brown colour bc bc. If the alleles appear in the heterozygous condition i.e. bd bs the dogs would still appear brown.

So far, we have only looked at inheritance by a single gene at the B locus. In reality more than one gene locus is involved in the inheritance of coat colour. A second locus, found on a different chromosome, the E locus, has to be present in its dominant form if any colour is to be expressed. This interaction between different loci on different chromosomes is known as epistasis. Therefore, a dog carrying the genotype EE or Ee for the E locus will be able to produce a colour pigment. This locus now interacts with the B locus i.e. black colour is inherited by the genotypes EEBB, EEBb, EeBB or EeBb. Brown colour in GLP's, is inherited by the genotypes EEbb or Eebb. If there is no dominant allele for the E locus i.e. ee then the colour will be red, as in the Irish setter, or yellow. This is an example of the E locus being epistatic to the B locus. When the E locus is recessive {ee} then the B locus cannot be expressed and a colour other than black or brown is produced.

We are now in a position to look more closely into the inheritance of coat colour in the GLP. Before looking at each gene in turn we need to know that mammals including dogs have two forms of melanin in their coats. Let us look at each of the genes separately, starting with the gene at the E locus. This gene is the Melanocyte Stimulating Hormone Receptor Gene and is responsible for the production of eumelanin pigment. An EE or Ee genotype produces a dark colour either black or brown in gundogs. The ee genotype can only manufacture the other form of pigment called phaeomelanin producing red or yellow colouration. Therefore, all GLP's must be EE, Ee is a possibility but this would lead to red or yellow coat colour for 25% of the offspring from two heterozygote parents.

The reason that the GLP is brown and the Large Munsterlander black is due to another gene found at the B locus. This gene codes for Tyrosinase Related Protein 1, an enzyme that breaks up the amino acid tyrosine which is the first step in the production of melanin. When present in its dominant form, BB or Bb, the coat colour is black as in the Large Munsterlander. When present in its homozygous recessive form, bb, brown instead of black eumelanin is produced. The nose leather and pads are also affected by this gene. GLP's must therefore have the genotype EEbb.

The gene coding for the length of hair is found at the K locus. K is dominant producing short hair, therefore, GLP's must be genotype kk. We have now considered three genes that code for hair length, pigment production and colour of pigment. This enables us to establish a genotype of kkEEbb for the GLP.

GLP's often display areas of white to a greater or lesser degree. This is due likely to the inheritance of alleles at the S locus. Solid colour is dominant over less colour but the gene is thought to be incompletely dominant. Thus, an SS genotype is solid in colour and can completely lack white, although, minor white markings are sometimes expressed e.g. white toes or paws especially forepaws, tail tip, or a streak on the chest. Heterozygotes, Ss, resemble the SS genotype but with typically less solid brown colour and more white. The recessive, ss genotype, has considerably greater white areas and gives rise to brown and white phenotypes. Therefore brown/white dogs are recessive and a mating between two brown/white dogs will always produce only brown/white puppies. The S locus is affected by modifying genes, the + {plus} modifiers increase the amount of pigment {decrease the amount of white} and the - {minus} modifiers decrease the amount of pigment {increase the amount of white}. This allows the white areas to show a vast range of variability.

The S locus interacts closely with the T locus for ticking. These are flecks of the solid colour {brown} in the areas left white by the S gene. Again alleles at the T locus are incompletely dominant. The TT genotype produces ticks of colour in any white areas on the dog, tt, produces no ticking and the genotype Tt produces less ticking than the TT genotype. However, a solid coloured dog of genotype SS may have no white areas but could still inherit the TT genotype for ticking. If there are no white areas then the ticking gene cannot be expressed. Therefore, this is another example of epistasis where the SS genotype and/or the ss genotype is epistatic to ticking.

Ticking is also very much affected by modifier genes that change the size, shape and density of ticking. Schimmel coats may very well be fine ticking, where there is gradual growth of pigmented hair in areas of white on the coat. There are three levels of brownschimmel notably dunkelschimmel {dark brown and dominant}, hellschimmel {light brown and recessive to dunkelschimmel} and forellenschimmel {trout schimmel probably the heterozygous genotype}. If two brownschimmel dogs are mated then most offspring will be brownschimmel, albeit in various degrees. However, brown/white pups are a possibility as long as the parents carry the alleles for brown/white in their genotypes. e.g. kkEEbbSsTT - the s allele for brown/white is overridden by the S allele for brown.

Possible matings:

1.	brown/white	x	brownschimmel
genotypes:	kkEEbbssTt		kkEEbbSsTT
possible gametes:	kEbsT or kEbst		kEbST or kEbsT

possible offspring:	kkEEbbSsTT	kkEEbbssTT	kkEEbbSsTt	kkEEbbssTt
	brownschimmel	brown/white	brownschimmel	brown/white

i.e there should be no solid brown offspring

2.	brown/white	x	brown/white
genotypes:	kkEEbbsstt		kkEEbbsstt
possible gametes:	kEbst		kEbst
possible offspring:	kkEEbbsstt		kkEEbbsstt
	brown/white		brown/white

i.e. All offspring will be brown/white. The amount of white could vary due to the modifying genes.

3.	brownschimmel	x	brownschimmel
genotypes:	kkEEbbSsTT		kkEEbbSsTT

gametes: kEbST kEbsT kEbST kEbsT

possible offspring:	kkEEbbSSTT	kkEEbbSsTT	kkEEbbSsTT	kkEEbbssTT
	brown	brownschimmel	brownschimmel	brown/white

i.e. Can have brown/white offspring since they carry the alleles for brown/white.

Brown crossed with brown will produce mainly brown offspring. However, it is possible to have 25% brown/white or schimmel offspring depending upon the genotypes of the brown parents. I envisage this possibility, if one or both of the brown parents carry the brown/white or schimmel alleles. A dog carrying the brown/white allele may look brown if the white spotting is heavily modified at the S locus to increase the amount of pigment.

To conclude, a dog close to my heart called Dasche is a German Longhair Pointer. She is solid brown in colour with a white chest streak and a white forepaw. The white areas show ticking. Her probable genotype for coat colour would therefore be: kkEEbbSsTt. She is mainly brown in colour due to the S locus being heavily modified for pigmentation.

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