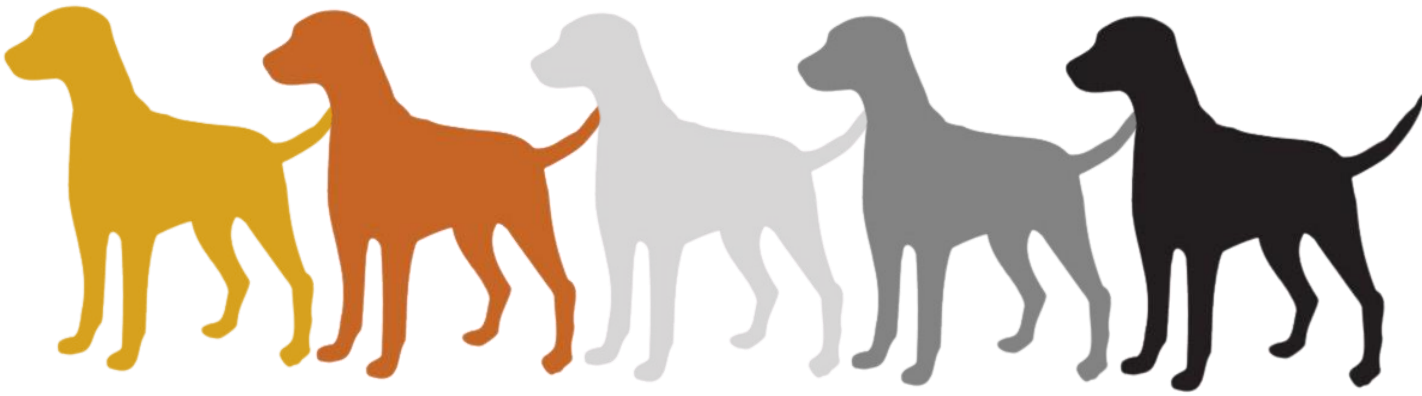
Coat Colour Inheritance Dogs

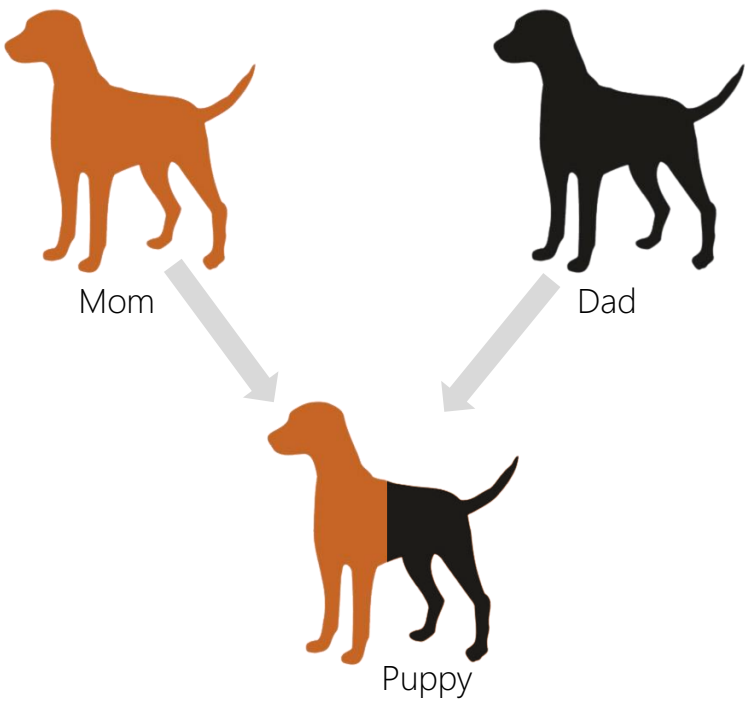


The fundamentals of genetics

Mendel's Laws of Inheritance

Genetic inheritance boils down to three simple rules:

1. **Segregation:** Chromosome pairs (and their copies of a gene) split into individual eggs or sperm. This means that **1 copy of a gene will come from the mother** and **1 copy of the gene will come from the father. Dogs will have 2 copies of a gene for every gene.**



2. **Dominance:** A **dominant allele completely masks the effects of a recessive allele**. A dominant allele produces the same phenotype regardless of whether the animal has 1 or 2 copies of the dominant allele.
3. **Independent assortment:** Alleles on different chromosomes are distributed randomly to individual eggs or sperm. A gene **does not affect** how other genes are inherited.

The fundamentals of genetics

Language of Genetics

Alleles: Alternative versions of a gene

DNA: The molecule that carries genetic information

Dominant: An allele or phenotype that **completely masks** a recessive allele or phenotype

Gene: The fundamental unit of heredity; a specific section of DNA within a chromosome that codes for a specific function

Genotype: The genetic makeup of an individual

Heterozygote: An individual with **two different** alleles of a given gene

Homozygote: An individual with **two identical** alleles of a given gene

Locus: A specific location on a chromosome

Phenotype: The **physical characteristics** of an individual

Recessive: An allele or phenotype that is masked by a dominant allele or phenotype; recessive traits are exhibited only when an individual has two recessive alleles at the same locus or gene

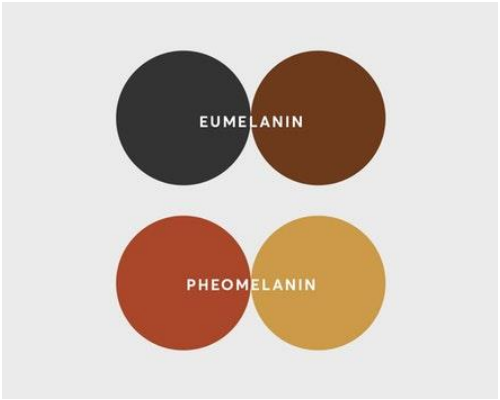
Coat Colour Inheritance Dogs

Pigment causing coat colour in dogs:
Melanin

Only 2 types of pigment

It starts with two different types of pigment…

- Pigment is the thing that gives each strand of hair its colour
- There are **two types of pigment** that creates coat colour in dogs.
- **All** coat colours and patterns are created by these two pigments
- Both are forms of **melanin**.
- Each of the pigments has a **"default"** colour, which can then be modified by various genes.



Eumelanin

- Eumelanin is, by default, black pigment.
- **All black areas** on a dog are due to cells producing **eumelanin**.
- **Black can however be altered by other genes:**
    - b/b (B locus) will change **black** into **brown**.
    - d/d (D locus) will change **black** into **blue**.
    - The combination b/b and d/d will change **black** into **isabella**.
- The black colour is altered because the genes affect the strength at which the black pigment is expressed.

Genes affecting the expression of black coats:

B locus altering black

Genotype:
K^B/
b/b

D locus altering black

Genotype:
K^B/
d/d

B & D locus altering black

Genotype:
K^B/
b/b
d/d

Unknown locus altering black

Genotype:
Unknown

Phaeomelanin

- Some dogs have **no eumelanin (black)**.
- The skin cells only produce the 2nd type of pigment: **phaeomelanin.**
- This is **red** pigment.
- The term "red" covers everything from deep red to light cream, encompassing gold, yellow and orange.
- **Phaeomelanin** should be seen as a colour range rather than individual colours. It can be thought of as letting a tea bag seep. The more pigment that seeps into the water, the darker it becomes, it is the same with the build-up of red pigment in the follicles.
- Whenever we talk of **red**, unless we're talking particularly about Setters, we mean the **whole range of colours**.
- Phaeomelanin is produced only in the coat.
- **Red** will only express if a dog is homozygous recessive: **e/e**

Distribution of Pigment:

- The colour genes in dogs do two things:
  - they first **determine** whether **black**, **red** or **both** will be expressed in the coat and secondly
  - they **control** the **distribution** of the two pigments.
  - Exactly which cells are told to produce what pigment is determined by the exact set of genes that the dog carries.
  - Coat colour should **never been looked at on a gene by gene basis** as all genes interact on the functioning of the other genes.
  - All **coat colour genes** should be **viewed simultaneously** to get the full picture of how colours will present phenotypically.

The Dominant Black Gene:

- Black is the **"default" eumelanin colour** for dogs.
- A dog that isn't homozygous for **brown** (bb) or homozygous for **dilution** (dd), will have **black** eumelanin.
- This means that it will have a **black nose** and, usually, **brown eyes.**
- The entire coat will be **solid black**.

The Dominant Black Gene:

- Whether a dog has a **solid eumelanin** (black) coat or a **coat with red**/tan markings (caused by phaeomelanin) depends almost entirely on the **K locus**.
- The K locus has three variants (alleles):

  - **K^B** - **dominant black** (**solid black**, no red). Sometimes referred to as simply **K**.
  - **k^{br}** - **brindle** (it acts as a **k** allele, but just adds brindle on top of any red markings).
    k^y - **recessive non-black** (will still have black nose pigment and may have black markings but the coat will not be solid black). It allows for the expression of other colours/patterns. Sometimes referred to as simply **N**.

- Because **black is dominant**, a dog with even just **one copy of the K^B gene** will be **solid black**.
- A dog with two **k^y** genes (i.e. k^y/k^y) will not be solid black and will be able to show other colours.
- A genotype of **k^yk^y** allows a dog to show whatever it has on the **A** locus.
- A **k^yk^y** dog may have some black in its coat, but it **won't usually be solid black**.
- A **$K^{br}k^y$** or **K^BK^B** dog may be genetically tan-pointed or sable on the A locus, **but won't be able to show those markings** because of its dominant black allele/s.

Did you know?
Different laboratories use different Nomenclatures for the same genes!
For the K locus, some laboratories use the nomenclature:
K^B, **k^{br}** and **k^y**
While others will use the nomenclature:
K, br and **N**
Both types are completely acceptable, but cannot be used interchangeably.

The Brown/Liver Gene: B series

- The brown gene occurs on the **B** locus, and causes a brownish colour.
- It's **recessive**, so **b/b** will produce a brown coat and **B/B** or **B/b** will produce non-brown dogs.
- This means that a **brown puppy** can be born from **black parents** if **both are carriers** of the brown allele (i.e. if both are B/b, then every puppy has a 25% chance of being brown).
- The brown gene affects **eumelanin** (black pigment) only.
- **All of the black in the coat will be turned to brown (liver)** when a dog is b/b on the B locus.
- It is **genetically impossible** for a brown dog to have black or grey hair in its coat, or for a black or blue dog to have brown in its coat.
- **Bronzing** and **seal** may **look like brown**.
- A brown dog may have "red" (phaeomelanin) hairs depending on the K and A locus alleles present.
- You may sometimes hear of brown dogs being described as "dilutes".
- Brown is not technically dilution, but just a **different colour of eumelanin**.
- Dilution in dogs is controlled by a separate locus and causes blue and isabella/lilac.

Cocoa

- Similar gene to brown has recently been discovered in **French bulldogs.**
- The gene is on a different locus. This has been named as **cocoa** and assigned the locus "Co".
- Cocoa is also **recessive**, so a visibly cocoa dog would be **co/co**.
- It's not yet known how cocoa interacts with true brown, but a dog heterozygous for each would unlikely show any brown or cocoa colouration.
- It can also be assumed that dilution acts on cocoa in the same way as on brown, although the resulting colour may look slightly different from usual isabella.

The Dilution Gene: D series

- The dilution gene occurs on the **D** locus and is **recessive**.
- Coats will be diluted with a **d/d** genotype.
- Non-diluted coats will either be **D/D** or **D/d**.
- The dilution gene generally affects **eumelanin** (black and brown), but can also lighten **phaeomelanin** (reds).
- A **black** dog with two copies of the **d** allele will be diluted to **blue**.
- A **brown** dog with two copies of the d allele will be diluted to **isabella**.
- Dilutes can have any coat pattern, but whatever they have, any **black** or **brown** in the coat will be turned to **blue** or **isabella**.
- It is genetically impossible for a **blue** dog to have any **black** in its coat, or for an **isabella** to have **brown**.
- The dilution gene also causes the eyes to lighten to **amber**. The colour is likely to be paler than the amber eyes seen on brown dogs.
- Dilution can occur in almost any breed, and may remain hidden for many generations.
- Within most breeds however, the **blue** gene is fairly uncommon.
- The dilute gene is however, notably common in Italian greyhounds, whippets, Tibetan mastiffs, greyhounds, Staffordshire bull terriers, and Neapolitan mastiffs and is an established mutation for the Weimaraner and Slovakian pointer breeds.
- It is likely that the dilution mutation occurred very early in the domestication of the dog, and seems to occur in most (if not all) breed types.
- There are a few genes that can cause a dog to display a greyish colour when in fact they're not **blue**-pigmented or **isabella**, but standard **black** or **brown**.
- Merle gives a **bluish base coat**, and the **greying** gene can also turn a dog grey.

The Agouti Gene: A series

- The agouti series is currently known to consist of **four** variants:
    - **A^y** : sable (fawn) – most dominant variant
    - **A^w** : wolf (agouti)
    - **A^t** : tan points
    - **a** : recessive black – least dominant variant
- The agouti series controls **which** cells produce eumelanin (black pigment) and **when**.
- Genes in the Agouti series can **only** be expressed if the **dog does not carry the dominant black** allele.
- A **dominant black** dog may **genetically** be a sable (fawn), wolf (agouti) or tan-point, but it **will not be able to display it**, except as "ghost" tan or seal.
- All sable (fawn), wolf(agouti) and tan-pointed dogs that aren't brindled must be **k^yk^y** on the K locus.
- It's generally accepted that many breeds display **incomplete dominance** on the A locus, with the appearance of the dog being **affected** by its more **recessive alleles** as well as the **more dominant one**.
- Sable (A^y) is the **most dominant** in the agouti series, with dogs only requiring **1 copy** of the sable (fawn) allele to phenotypically express it.
- There are at least **three types of pattern** that can be caused by this gene, but it's not certain what causes each one to appear.
- The three common patterns are:
    - **clear sable**,
    - **tipped sable** and
    - **shaded sable**.
- The Wolf (agouti) is typified by strands of fur that are **banded**.
- As the fur is growing, the cells first produce one type of pigment (for example eumelanin) and then they switch to another type (phaeomelanin) and back again.
- In its normal form, wolf (agouti) can be very similar to **shaded sable**.

The Agouti Gene: A series

- The range of markings on a tan pointed dog are very restricted.
- Red (tan) appears as:
    - **pips above the eyes**,
    - on the **sides of the muzzle** extending to the cheeks, as **pips on the cheeks**,
    - on the front of the **neck** just below the head, as two **triangular patches on the front of the chest**,
    - on the **lower legs and feet** (and inside of the legs), and as a **patch underneath the tail** (and sometimes along the bottom edge of the tail too).

- Although most **solid black coats** have the **dominant black g**ene, there is also another, less common type of **black** called **recessive black**.
- Most of the breeds that carry recessive black are herding/pastoral types.
- Recessive black is **not** on the **K locus**, but on the **A locus**.
- It is denoted by **a** and is **recessive** to ALL other A locus variants.
- This means that if a dog has just one **a** allele, it will **not be solid black**, as it needs **two a** alleles for the recessive gene to work.
- **Recessive black is, aesthetically, no different to dominant black.**
- The only difference is in the **breeding**.
    - a **solid black puppy** could be born from two parents who are **non-solid black** if they both carry (without expressing) one copy of the recessive black gene
    - a **dominant black pup** could only be born if **one or both of its parents** are also **dominant blacks**
- This makes it the **only way that a dog can still be solid black if it is $k^y k^y$ (non-solid black) on the K locus**.
- **Recessive black looks identical** to **dominant black**, and can come in all the same patterns and shade variations as the dominant blacks, including brown, merle etc.

Recessive black will not show seal.

The Extension Gene: E series

- The E series is responsible for almost all non-agouti (A series) related eumelanin/phaeomelanin patterning in dogs.
- This gene helps to determine **which areas** of the coat can produce eumelanin (**black**/ blue/ **brown**/ isabella) and which can produce phaeomelanin (red).

- The dominance hierarchy of the E:
    - **E^m** - masked (the mask appears over the top of the A locus pattern)
    - **E** - "normal extension"
    - **e** - recessive red
- **Eumelaninistic masks** are caused by the **E^m** allele.
- It is the **most dominant** of the E series, which means that the dog only needs **1 copy** of the E^m allele to have a mask, regardless of which other E locus allele it carries.
- Masks can appear on any dogs that are genetically sable (fawn), tan-pointed, saddled or wolf (agouti).
- The expression of a mask on a dog with the mask gene depends on the **A** and **K** series.
- In order to display a **mask**, a dog cannot be dominant black (**K^BK^B**, **K^BK^{br}**, **K^Bk^y**) on the K locus, because **dominant black stops the A series** from **being expressed**, and obviously, a black mask on a black dog is not going to be visible.
- If a dog is brindle or non-black on the K locus, they can express the A locus.
- R**ecessive black** coats may genetically have the genes for a black mask, but won't express the mask phenotypically.
- Masks consist of **eumelanin** pigment, so they can be affected by any gene that changes the **colour or intensity of eumelanin**.
- This means a mask will follow the main pigment of the dog and can be **brown**, blue or isabella, and can also show the merle pattern.
- **Masks can vary greatly, covering anything from just the end of the muzzle to the whole of the muzzle, eyebrows and ears.**

The Extension Gene: E series

- The E allele simply allows a dog to express its other genes normally.
- It has no effect on the dog.
- A dog that has 2 copies of recessive red (**e/e**), will be **completely red (remember that the term read refers to the range of colours, from cream to red, and not just the colour red)**.
- Its nose will remain **black** (or **brown**, blue or isabella, whatever its eumelanin pigment colour is), and so will its eye rims and lips.
- It is **impossible** for a **recessive red** dog to have **any black** (or **brown**, blue or isabella) in its coat.
- **Recessive red**, although **recessive in its own gene** series, is essentially **dominant** over almost **all other loci**.
- **Dominant black**, **sable (fawn)**, **wolf (agouti)**, **tan points**, **merle**, and any other pattern with **black** in it will be turned to **solid red** by the **recessive red gene**.
- **Brown (b/b)** recessive red dogs show **more significant pigment loss** than **black** (K^BK^B, K^BK^{br}, K^Bk^y) recessive red dogs.

The White Spotting Series

- Most white spotting on dogs is determined by the genes on the **S locus**.
- "White spotting" refers to white **areas** on the dog, not actual white spots.
- **White spotting can occur on any colour**, and will cover up both eumelanin (**black**) and Phaeomelanin (**red**).
- In technical terms this is known as **epistasis**.
- Any dog can have white markings, whether they're **black**, blue, **brown**, isabella, **brindle**, **sable (fawn)**, **tan-pointed**, **merle**, etc.
- White hair occurs when the skin cells are **unable to produce any pigment**.
- The white spotting gene impairs the ability of cells on particular parts of the skin to make pigment, so the skin becomes pink and the fur white.
- To date, only two white alleles have been identified on the S locus:
    - **S** - no or very minor white
    - **s^p** - piebald (white patches)
- A third allele may exist for "extreme white" (s^w), however this has not been proven.
- The white spotting alleles are thought to be examples of **incomplete dominance**.
- This means that a heterozygous dog will express its most dominant gene, but may also be affected by the more recessive one to a lesser extent.
- An **S/S^p** dog may have some white spotting, but not as fully as a **S^p/S^p** dog.
- The relationship between the alleles is complicated and can vary between breeds.
- It has been shown that some dogs with white spotting do not have an S^p allele. These are mostly dogs with **Irish spotting**.

Incomplete alterations of the black coat:

- A **brownish cast** on an otherwise **black coat** may be due to **bronzing**.
- This can look a bit like red, but bronzing is when **sunlight lightens** the **black hairs** on a dog over time, and it can also be caused by dietary factors.
- **Bronzing** is generally most noticeable on long-haired and curly-coated breeds.
- **Bronzing** is not present at birth.

It doesn't usually indicate that the dog is anything other than a normal solid black, but if it's particularly extensive and **present while the dog is still growing**, it **can be** due to **seal**.

This Border Collie is a dominant black with **Irish spotting**. Note the bronzing on the tail and ears, where the coat is longest.

Incomplete alterations of the black coat: Seal

- **Seal** is currently a mystery.
- Seal colouration makes **black coats** appear **brownish** (with the nose remaining black), varying from a slight brown cast to a shade almost as light as brown.
- There is often a **black stripe** down the back, and the legs and tail generally remain darker than the main part of the coat.
- **Seal** dogs are **born brownish whereas bronzing develops with age**.
- A black seal will always have a black nose regardless of how light and brownish its coat is.
- **No genetic research has so far been conducted into seal, so it is unknown how it is caused or which locus is responsible for it.**

Incomplete alterations of the black coat: Seal

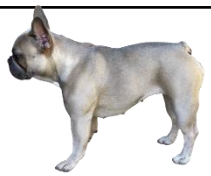
- Seal dogs generally test as **K^bk^y** (black) on the **K locus**, and are usually **A^yA^y** (fawn) on the **A locus**.
- This **does not mean** that all dogs who are **K^bk^y; A^yA^y** will be **seal**.
- It only means that if a dog is phenotypically seal, they will have a greater chance of also carrying the **K^bk^y; A^yA^y** genes.
- It is a possibility that the seal colouration could be caused by the A locus "leaking through" the black coat. This **theory however needs to be confirmed with research**.
- However, the **exact mechanism** for seal is **unknown**.
- **Seal** seems to be an **alteration of eumelanin** (black), without the presence of phaeomelanin (red), which means that the dog most likely has to initially carry the genes for black in order for them to be altered to seal.

Laboratories will be able to determine whether the dog carries a copy for the dominant Black (K locus) gene, but cannot provide any other information as the mutation is completely unknown. No laboratory can genetically test for seal.

Colour Inheritance Tables – Dominant black allele PRESENT:

Genotype:	Phenotype:
K^B/K^B or K^BK^y or K^yK^y $A^y/A^w/A^t$ E/E B/B or B/b D/D or D/d	 Solid black
K^B/K^B or K^BK^y or K^yK^y $A^y/A^w/A^t$ E/E B/B or B/b **d/d**	 Solid blue
K^B/K^B or K^BK^y or K^yK^y $A^y/A^w/A^t$ E/E **b/b** D/D or D/d	 Solid brown
K^B/K^B or K^BK^y or K^yK^y $A^y/A^w/A^t$ E/E **b/b** **d/d**	 Solid isabella
K^B/K^B or K^BK^y or K^yK^y $A^y/A^w/A^t$ **e/e** B/B or B/b D/D or D/d	Solid Cream to red range 

Colour Inheritance Tables – Dominant black allele NOT PRESENT:

Genotype (Sable/Fawn genes):	Phenotype:
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a Em/Em or Em/E or Em/e B/B or B/b D/D or D/d	 Sable (fawn) with mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a Em/Em or Em/E or Em/e B/B or B/b d/d	 Blue Sable (fawn) with mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a Em/Em or Em/E or Em/e b/b D/D or D/d	 Brown Sable (fawn) with mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a Em/Em or Em/E or Em/e b/b d/d	 Isabella Sable (fawn) with mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a E/E or E/e B/B or B/b D/D or D/d	 Sable (fawn) with NO mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a E/E or E/e B/B or B/b d/d	 Blue Sable (fawn) with NO mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a E/E or E/e b/b D/D or D/d	 Brown Sable (fawn) with NO mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a E/E or E/e b/b d/d	 Isabella Sable (fawn) with NO mask
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a e/e B/B or B/b D/D or D/d	 Tan
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a e/e B/B or B/b d/d	 Champagne

Colour Inheritance Tables – Dominant black allele NOT PRESENT:

Genotype (Agouti/wolf genes):	Phenotype:
K^y/K^y A^y/A^y or A^y/A^w or A^y/A^t or A^y/a Em/Em or Em/E or Em/e B/B or B/b D/D or D/d	 Agouti (Wolf) with mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a Em/Em or Em/E or Em/e B/B or B/b d/d	 Blue Agouti (Wolf) with mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a Em/Em or Em/E or Em/e b/b D/D or D/d	 Brown Agouti (Wolf) with mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a Em/Em or Em/E or Em/e b/b d/d	 Isabella Agouti (Wolf) with mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a E/E or E/e B/B or B/b D/D or D/d	 Agouti (Wolf) with NO mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a E/E or E/e B/B or B/b d/d	 Blue Agouti (Wolf) with NO mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a E/E or E/e b/b D/D or D/d	 Brown Agouti (Wolf) with NO mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a E/E or E/e b/b d/d	 Isabella Agouti (Wolf) with NO mask
K^y/K^y A^w/A^w or A^w/A^t or A^w/a e/e B/B or B/b D/D or D/d	 Tan
K^y/K^y A^w/A^w or A^w/A^t or A^w/a e/e B/B or B/b d/d	 Champagne

Colour Inheritance Tables – Dominant black allele NOT PRESENT:

Genotype (Black and tan genes):	Phenotype:
K^y/K^y **A^t/A^t or A^t/a** **Em/Em or Em/E or Em/e** B/B or B/b D/D or D/d	 Black and tan with mask
K^y/K^y **A^t/A^t or A^t/a** **Em/Em or Em/E or Em/e** B/B or B/b **d/d**	 Blue and tan with mask
K^y/K^y **A^t/A^t or A^t/a** **Em/Em or Em/E or Em/e** **b/b** D/D or D/d	 Brown and tan with mask
K^y/K^y **A^t/A^t or A^t/a** **Em/Em or Em/E or Em/e** **b/b** **d/d**	 Isabella and tan with mask
K^y/K^y **A^t/A^t or A^t/a** E/E or E/e B/B or B/b D/D or D/d	 Black and tan with NO mask
K^y/K^y **A^t/A^t or A^t/a** E/E or E/e B/B or B/b **d/d**	 Blue and tan with NO mask
K^y/K^y **A^t/A^t or A^t/a** E/E or E/e **b/b** D/D or D/d	 Brown and tan with NO mask
K^y/K^y **A^t/A^t or A^t/a** E/E or E/e **b/b** **d/d**	 Isabella and tan with NO mask
K^y/K^y **A^t/A^t or A^t/a** **e/e** B/B or B/b D/D or D/d	 Tan
K^y/K^y **A^t/A^t or A^t/a** **e/e** B/B or B/b **d/d**	 Champagne

Colour Inheritance Tables – Recessive black allele PRESENT:

Genotype:	Phenotype:
K^y/K^y **a/a** E/E B/B or B/b D/D or D/d	 Solid black
K^y/K^y **a/a** E/E B/B or B/b **d/d**	 Solid blue
K^y/K^y **a/a** E/E **b/b** D/D or D/d	 Solid brown
K^y/K^y **a/a** E/E **b/b** **d/d**	 Solid isabella
K^y/K^y **a/a** **e/e** B/B or B/b or b/b D/D or D/d or d/d	 Some breeds will be white

Contact us for more information about genetics testing available:

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