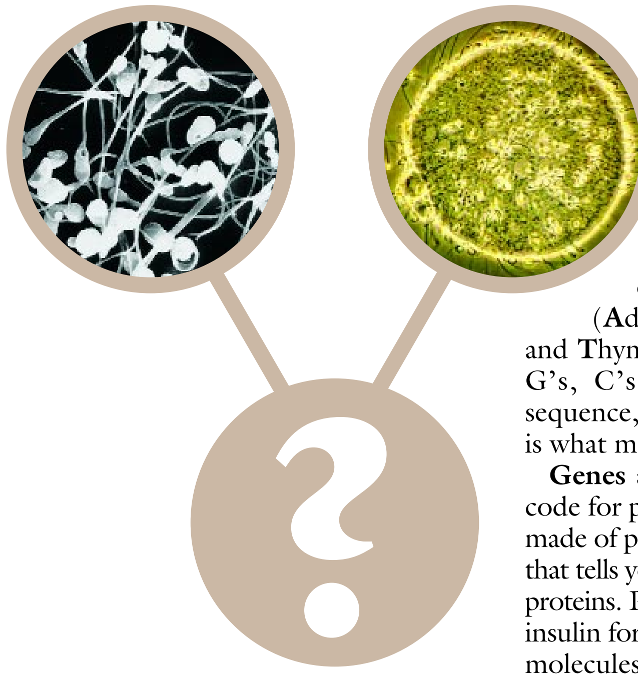
Alpaca Color Genetics

Andy Merriwether, Ph.D. and Ann Merriwether, Ph.D.



Photos © Helen Dishaw, Frieda Goodrich and Tom Pinter

Few topics generate as much interest among alpaca breeders as the subject of color genetics. No wonder, considering the multiplicity of colors that our animals produce. So in the interest of providing a wide array of facts and opinions on this intriguing subject, Alpacas Magazine *presents another viewpoint, this time from Drs. Ann and Andy Merriwether, from the University of Michigan. – Ed.*

Basic Concepts

DNA (deoxyribonucleic acid) is the chemical that makes up genes. DNA is composed of long strands comprised of four nucleotides (**A**denine, **G**uanine, **C**ytocine, and **T**hymine). The order of the A's, G's, C's, and T's arranged in a sequence, or order of the nucleotides, is what makes each gene unique.

Genes are sequences of DNA that code for proteins. All living things are made of proteins. DNA is the template that tells your cells how to make specific proteins. Proteins include enzymes (like insulin for processing sugar) and other molecules (like hemoglobin that carries oxygen and CO_2 in your blood). Eumelanin and phaemelanin are proteins that cause pigmentation in cells of other animals (and probably alpacas). Slight changes in the DNA pattern of the genes that encode eumelanin and phaemelanin can lead to different color cells. In humans, hair color and eye color are specified by several genes. Sex is specified by genes as well. Some physical traits are completely controlled by genes (eye color, coat color) and some traits are influenced by both genes and environment (height and weight in humans and alpacas, for example, can be influenced by genes, but diet can also have a significant effect). Humans have about 30,000 genes. The alpaca genome project will help determine how many genes camelids have.

Chromosomes are long strands of DNA wrapped around proteins called Histones. Most of the DNA in chromosomes is useless (junk DNA that does not code for proteins) but about 5% of the chromosomal DNA sequences code for proteins. The parts of chromosomes that code for proteins are called genes. Humans have 46 chromosomes (23 pairs). Each person receives 23 chromosomes from the mother (from the egg) and 23 chromosomes from the father (via the sperm that fertilizes the egg). In humans, they are numbered 1 through 22 (called the autosomes) and the 23rd chromosome is called the sex chromosome (either an X or a Y chromosome). So each person gets a chromosome "1" from his mother and a chromosome "1" from his father. A chromosome "2" from his mother and a chromosome "2" from his father, etc… Twenty-three pairs in all. Males get a Y from their father and an X from their mother. Females get an X from each parent. All camelids (including alpacas) have 74 chromosomes, 37 from the mother and 37 from the father. This means half of any individual's genetic variation, and hence half of its appearance, is contributed by each parent.

Dominance: Some genetic traits are dominant. Dominant traits are not blocked or hidden by other traits. Since you get two copies of every gene (one from each parent), dominance is important. The two versions of a gene are called **"alleles."** In humans, curly hair is dominant over straight (curly allele and straight allele). In alpacas, the color white is dominant over black (white allele and black allele). This means that if a cria gets a white allele from its mother via the egg, and gets a black allele from the father via the sperm, the cria will be white. This is because white is dominant over black. It masks or hides the non-dominant (recessive) alleles.

Recessive: Some genetic traits are recessive. If an animal inherits a version of a gene (allele) that codes for a recessive trait it will only be expressed in the presence of another recessive version of that same gene. In the presence of a dominant gene, this gene will not be expressed, it will be masked. This is how two white alpacas could have a black offspring (if each white parent were masking a black allele).

Homozygous means you have two alleles that are the same (one from the mother and one from the father). For example, a black animal has two black alleles and is described as homozygous for black. Another example, a white animal could have two copies of the white allele and would then be described as homozygous for white.

Heterozygous means you have two different versions of a gene. For example, a white animal could be heterozygous and have one white allele and one black allele. The animal would still be white (the recessive black allele would be masked).

Some examples of these concepts:

Question: How come when I repeatedly bred my white alpaca to a black alpaca all I ever got were white offspring?
Answer: One possibility is that both animals were homozygous.

In this example:

b=gene for black (and is recessive)
W=gene for white (and is dominant)

Remember that even though each animal has two copies of every gene (two alleles), they can only pass one on through the sperm (if it is a male) or egg (if it is a female). This is because sperm and eggs only have one set of 37 chromosomes, not two sets. So the male passes on one of his two alleles for each gene in the sperm, and the female passes on one of her two alleles for each gene in the egg. Which of the two alleles ends up in each sperm and each egg is purely random chance (like a coin flip).

Black animal: a herd sire named "Blackie," whose genes are bb (homozygous).

White animal: a potential mother named Wilma, whose genes are WW (homozygous).

Their babies will all be white (but heterozygous):

	b	**b**
W	Wb	Wb
W	Wb	Wb

But each baby carries a recessive gene for black and has a 50% chance of passing that gene on!

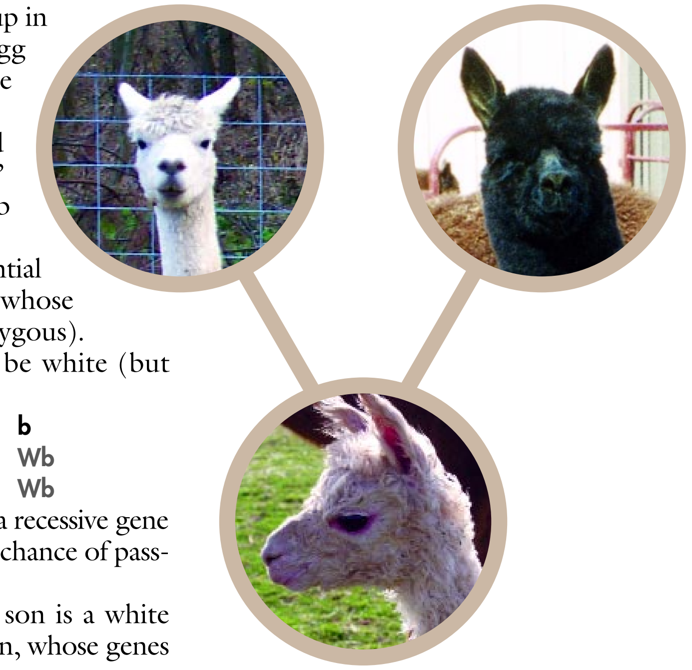
Blackie and Wilma's son is a white herd sire named Winston, whose genes are Wb (heterozygous).

Winston is mated to a black dam named Betty who has bb (homozygous).

	W	**b**
b	Wb	bb
b	Wb	bb

Potentially half of their offspring will be white but cover black, and half of their offspring will be black. (But of course it is always a gamble, and Lady Luck has no memory, so each breeding has a 50/50 shot of either a white or black offspring).

Sadly, most traits that are observed in people (and alpacas) are not the results of one gene location on one chromo-

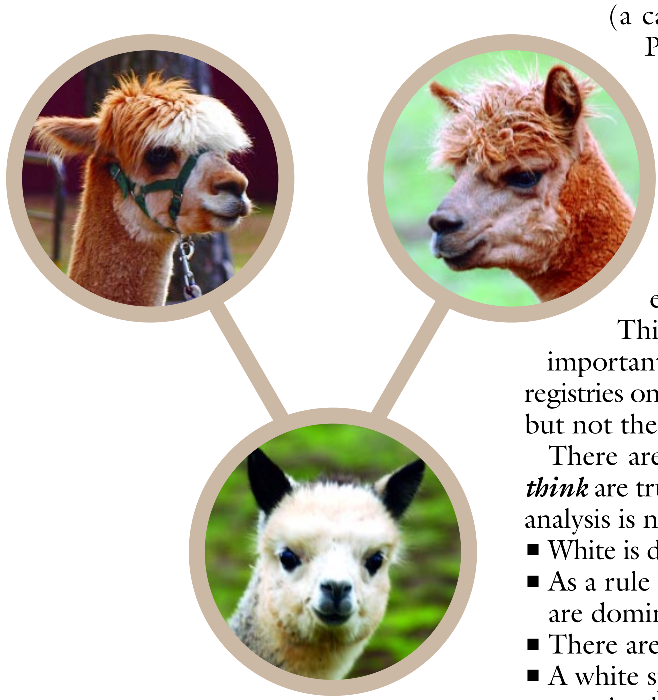


Myth #1: There are strong genes.

For example, you might hear an alpaca owner say "My black herd sire has strong black genes." Implying that somehow this animal's strong black genes are wrestling it out with white genes and winning! This is a myth. Genes may be either dominant or recessive. Black is recessive. A black herd sire throws one of his recessive black genes. Basic coat color depends on what the mother throws. It also depends on if there are other genes modifying or influencing that basic coat color gene. Certainly there are black herd sires that, when bred to whites, throw black. This means the white dam covered black. The dam had the one dominant white gene and one recessive (masked) black gene (the dam was heterozygous).

Myth #2: The herd sire's genes are more important (or stronger) than the dam's.

This is a myth (probably linked to the strong gene myth). Each parent contributes 50% of the genes. Never underestimate either parent's contribution. Certainly, very few males get to be herd sires and those that do are usually spectacular choices. Certainly, some traits are dominant (but very little is known about traits that influence head shape, top knot, fiber characteristics). Certainly you can get improvement by breeding a "not-so-great" female to an amazing male. It would work the other way as well ("not-so-great male" with an amazing female).



some. Most traits are polygenic, meaning multiple genes in multiple places on chromosomes (even multiple chromosomes) are involved. In people, even eye color is influenced by more that one gene, (that is how we get hazel, green, etc). In alpacas, coat color is influenced by more than one gene at more than one location in the genome (locus). This makes color prediction complicated.

Not much is known. There have been no genetic studies that actually look at what genes might control this (a candidate gene approach). People have attempted to look at existing data sets, but colors are often reported incorrectly. (For example: Is a cria really dark fawn, or is it brown? Did an animal have any white markings, even a small dot on the lip?). This makes answers to many important questions difficult. Some registries only provide info on the sires, but not the dams for each individual.

There are certain concepts that we *think* are true, but much more genetic analysis is needed to confirm:

- White is dominant, black is recessive.
- As a rule of thumb, lighter colors are dominant over darker colors.
- There are multiple genes involved.
- A white spot gene adds white color to animals of any color.

Question: Why did I get a blue-eyed white from breeding a gray to a black animal?
Answer: There is a "white spot" gene.

It is not the same gene that makes an animal's basic coat color (white, brown, black, etc). Combinations of alleles of this gene lead to animals with a white face, white spots, tuxedo, pintos, white feet, silver grey and rose grey (roaning), blue-eyed white animals, and some non-blue-eyed whites. Most alleles of this gene seem to be dominant. If you get two copies of this gene you get a blue-eyed white animal. Sometimes two copies of a dominant gene cause a different effect than one copy alone. This seems to be the case with the "white spot" gene.

In general, you should not breed any two animals with white spot alleles together (i.e., do not cross a grey with a white faced black, or a pinto with an animal with white feet, etc.) or you have a ¼ chance of ending up with a blue-eyed white cria. You can breed the dams back to solid sires that do not have any white spot alleles. Remember, white animals may have these white spots on them, but you cannot see white on white. So breeding white spot animals to white animals could result in blue-eyed white offspring.

Example of how this gene might work (not including basic coat color):

S represents the dominant "white spot" allele

s represents the recessive "no white spot" allele

"Spotty," a black animal with a white face, Ss (heterozygous), is

bred to "Blackie," a solid black animal with no white markings, ss (homozygous).

	S	s
s	Ss	ss
s	Ss	ss

Approximately half of their offspring will have a white spot somewhere. Again, 50/50 shot, again Lady Luck has no memory and you could wind up with all white spot-bearing animals or all solid animals. You should not get a blue-eyed white out of a breeding with a truly solid animal.

Now for a new example. One of their white spotted offspring is bred to an animal that also has a white spot:

"Spotson," a black animal with white spot (Ss), breeds to "Whiteface," a black animal with white face (also Ss).

	S	s
S	SS	Ss
s	Ss	Ss

Theoretically, the animals that get two copies of the gene are blue-eyed whites (SS). The animals that get one copy (Ss) have a white spot somewhere and are fine. The animals that get no copies (ss) are solid colored.

This can happen with any color! We used a black as an example, but basic coat color is independent of the white spot gene. It happens more with grays (because we have lots of gray herd sires). It is relatively rare to have colored herd sires with white spots.

So if you wanted to speculate on probabilities of offspring with and without this gene and include the gene for basic coat color, it becomes a bit more complicated. The following examples include two genes:

"Blackie" (a solid black male), bbss, bred to "Spotsdaughter" (a solid black female with a white spot), bb Ss.

	bs	bs
bS	bbSs	bbSs
bs	bbss	bbss

This would yield ½ black offspring with white spots and ½ solid black cria.

Now try Spotsdaughter (bbSs) with Greyboy (bbGs)

	bG	bs
bS	bbGS	bbSs
bs	bbGs	bbss

Repeated breedings would yield, on average, ¼ blue-eyed whites (bbGS), ¼ Silver Greys (bbGs), ¼ White spot blacks, and ¼ solid blacks.

Last example. This time, let's have WhitefaceWilma (WbSs) mate to Greyboy (bbGs).

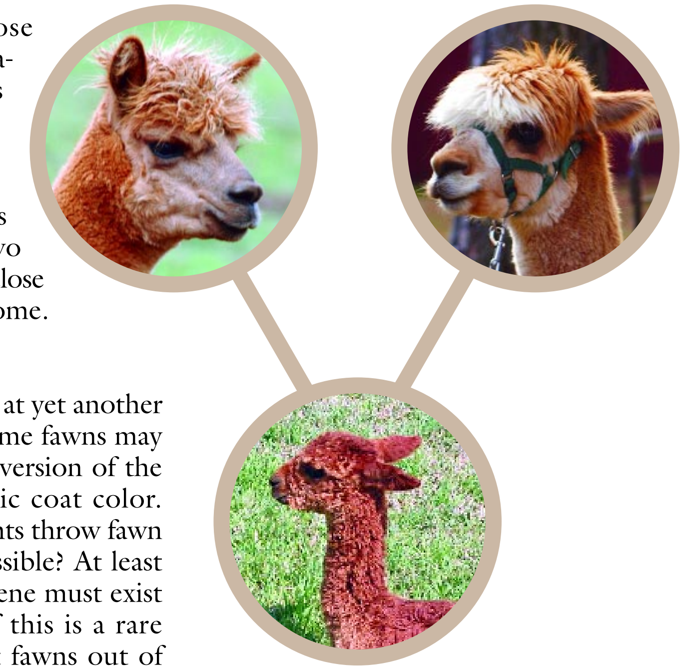
	bG	bs
bS	bbGS	bbSs
bs	bbGs	bbss
WS	WbGS	WvSs
Ws	WbGs	Wbss

This would yield ¼ blue-eyed whites; ⅛ white faced blacks; ⅛ silver grey; ⅜ non-blue-eyed white (⅛ with white spot, ⅛ with roan, and ⅛ true solid); and ⅛ solid black.

Now imagine how complicated it gets if there are three or more genes involved.

Some speculation

The roaning allele could be a version of the white spot gene OR it could be an allele of a different gene that lies very close on the same chromosome. Most grays seem to have white markings (but a few do not). This means that grays with white markings are going to pass the white spot gene on. If there are actually two genes close together, this means occasionally a gray could pass on either white spot or roaning (but not always both). It just depends on whether this is two alleles of the same gene or two different genes that are close together on a chromosome.



Other genes

There is a fawning gene at yet another location. Most/many/some fawns may be the result of a fawn version of the gene that controls basic coat color. Occasionally black parents throw fawn babies. How is that possible? At least one version of a fawn gene must exist in another location. If this is a rare recessive, it means that fawns out of blacks will throw lots of blacks.

Multicolor animals could represent an allele of the white spot gene or it could be a gene that allows any coat color gene to be expressed. For example, a white animal that has recessive black becomes a multi-colored animal because this gene allows expression of underlying recessive genes. The inheritance patterns for multi's is poorly understood, partly because they are uncommon. There are not enough breedings in the registry to sort out the inheritance patterns yet.

Additive genes

Many traits are due to the effects of many genes simultaneously. We believe many fiber qualities may fall into this category. For additive genes, we can illustrate with an imaginary example:

Myth #3: An animal "pulls color" out of other animals or "lets the dam's color come through."

This is related to Myths 1 and 2. The basic coat color genes don't pull and push each other around. This basically means that the herd sire has recessive alleles that are masked by the dam's alleles. Any animal that has a black allele will "let the dams color come through" since black is recessive to everything.

Myth #4: Some animals throw a higher percent of female offspring than others (and will keep doing this).

Animals with two "X" chromosomes are female and animals with an "X" and a "Y" chromosome are male. Fathers determine the sex of the offspring. Mothers have two "X's" to pass but fathers contribute either an "X" or a "Y". Sex is actually determined by the presence or absence of particular genes on the "Y" chromosome. The ratio of male to female births in most species is approximately 50%. Again Lady Luck has no memory, so each birth has a 50% chance of being male or female. However, we probably all know of a family that has five sons or five daughters, and certainly we have heard about a breeder that has had nine male births in a row. Any of these events is statistically unlikely, but possible. On a positive note, you've had nine boys in a row, you still have a 50:50 shot at a girl cria the next time.

there may be three genes that control fineness, each has four alleles numbered 1 to 4 with 1 being the finest in each and 4 being the coarsest. The finest animal possible (the pre-Columbian vicuña population) would get eight "1" alleles (two from each parent from four loci): 1/1, 1/1, 1/1, 1/1. The coarsest animal possible (a guanaco crossed with a porcupine) would get 8 "4" alleles: 4/4, 4/4, 4/4, 4/4. When two animals mate, each donates one of its two alleles at each of the four loci (loci are locations on the chromosome, and loci is the plural form of locus, a single location). The lower the total number, the finer the animal, the higher the total number, the coarser the animal.

Here's another example. Consider flowers. Sometimes petal colors are additive. For example, W=white, w=red. WW = white petals, ww= red petals, but Ww = *pink* petals. The heterozygote Ww is half-way between white and red in color.

In alpacas, coat color is influenced by more than one gene at more than one location… This makes color prediction complicated. People have attempted to look at existing data sets, but colors are often reported incorrectly.

Intermediate colors

So what is the difference between beige and light fawn; between medium brown and dark fawn; and between dark brown and bay black? By now, virtually everyone has heard of animals that were assigned a color when they registered with the ARI, and then a color judge placed them in a different category when they were taken to a show. Animals change hue throughout the course of their lifetimes, greying as they age, but also darkening sometimes between birth and adulthood. Diet may play some role in color as well. If humans eat a lot (and we mean a lot) of carrots, their skin takes on an orange hue. Diet certainly plays a role in fiber fineness, with skinny animals having noticeably lower micron counts than obese animals. Regardless of all this, the evidence is weaker for dominance of color in between white and brown/black. We are not yet convinced that dark fawn is recessive to light fawn or to beige. Maybe these intermediate colors are due to a combination of additive and dominant/recessive genes. It may be, but the color assignments are not rigorous, so it is hard to trust the data to do the tests.

If you have questions about genetics, feel free to e-mail Andy Merriwether at andym@umich.edu. Andy is currently an Assistant Professor of anthropology and of ecology and evolutionary biology at the University of Michigan. Andy is a member of the Center for Statistical Genetics and the Center for the Molecular and Clinical Epidemiology of Infectious Disease at the University of Michigan. Ann is a lecturer in Human Development and Psychology at the UofM. Andy and Ann will be moving to their new farm in Vestal, New York, in July 2003, and will be joining the facul-

Myth #5: A solid non-gray animal carries gray genes from a parent.

For example, you have a beautiful black daughter out of a beautiful gray herd sire. Can she have a gray baby? A better question is does she have a "gray gene"? The answer to this second question is "no". If the roaning gene is dominant, she didn't get it and we know that because she is not gray herself. If she had gotten it, she would be gray. Can she have a gray baby? Yes! If she is bred to a gray herd sire, then he would have a 50/50 shot of throwing his roaning gene to his offspring.

Since the roaning gene is either a version of the "white spot" gene or another gene really close to it, animals that clearly also have the white spot gene should not be bred to grays. Theoretically, you would have a 25% chance of getting a blue-eyed white. Unless blue-eyed whites are OK with you – and for many breeders, they are.

Myth #6: The only way to get a blue-eyed white is from gray parents [or stated another way: grays throw more blue-eyed whites than other colors].

The first part is definitely a myth. The second part is perhaps statistically true, but only because you don't tend to see herd sires other than grays with lots of white markings. Since there are more gray herd sires, (with white markings as a result of the white spot gene) it seems like grays are most responsible for this.

If blue-eyed whites are the result of two copies of a dominant "white spot" gene, then you could get it from any mating between two animals that both have one copy of it. For example, non-blue-eyed but white-coated animals can hide one copy of this gene. How could you tell if a white animal has a white spot? Any colored animal with a white spot could be paired with another animal and would produce a blue-eyed white. Keep in mind that each time this happens, there is a 25% chance for a blue-eyed white, but a 75% chance for a non-blue-eyed white.