Alpaca Color Genetics: The Genetics of White Markings

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To make predictions about coat color, or almost any other trait, in cria from specific breedings you need to understand some basic rules of genetics. Coat color is determined by genetics. When people say something is genetically determined, what they are really talking about is DNA. DNA is what codes for all of the proteins (things like hemoglobin, albumin, melanin, insulin, keratin tissues, hormones all the stuff that make up an alpaca), and for the instructions on how, when and where to make these proteins within the alpaca. Segments of DNA that code for proteins are called genes. Humans have 30,000-40,000 genes and a total of 3 billion base pairs of DNA. In humans, only about 5% of those 3 billion base pairs are protein coding genes, most of the rest is called "junk DNA" or contains instructions on how, when, and where to express the proteins inside the body. No one knows yet how many genes an alpaca has, or how many base pairs of DNA they have. We do know that like other living creatures, each alpaca has its own unique DNA sequence that determines many of its physical characteristics, including its sex and its coat color. Genes are organized into chromosomes. Alpaca have 37 pairs of chromosomes (autosomes numbered one to thirty-six plus the sex chromosomes X and Y). Every alpaca is created by merging 37 chromosomes from its dam's egg, with 37 chromosomes from the sire's sperm during fertilization after a successful mating. Mutations in the DNA can lead to changes in the proteins that are made, which may make the proteins work differently or be expressed differently. DNA also codes for proteins involved in skin, coat and eye color, fiber shapes and patterns, and aspects of conformation. DNA codes for virtually every aspect of an animal

Genes interact with the environment in many cases to produce the phenotype that we observe in both people and alpaca. Genes, however, may behave differently in different environments. Prior to 50 years ago, very few U.S. Native Americans suffered from diabetes. Now, after switching to a high-fat Western diet, over 80% of their adult Native Americans in some tribes (like the Pima) eventually get diabetes. They have the same genes as their ancestors, but the environment has changed since then (their diet being part of their environment). Some people believe the Native Americans were perfectly adapted to a very low fat, low carbohydrate diet (their traditional diet), and having versions of genes that cause diabetes on high fat diets, actually help you survive better on starvation or low fat diets (called the Thrifty Gene Hypothesis). Many people are aware that alpacas fiber is influenced by diet. Fiber gets much finer on a near starvation diet (which is certainly more like their natural diet in the Andes mountains, think how many animals actually starve to death every year!). So genes are a big part of the picture, but so is environment for many traits.

Each alpaca gets two copies of every gene (called alleles), one from the dam and one from the sire, but we only see one phenotype. A phenotype is what we can observe in the individual (the expression of the genes), like coat color. This means that both parents' genes play important roles in the coat color of the offspring. Alleles are two different versions of the same gene that differ by one or more mutations in the DNA. To complicate things, there are probably at least three genes involved in coat color, and possibly additional genes which can have minor affects on coat color as well. Genes do not pull or push each other around, as you sometimes hear breeders say. However some are dominant and some are recessive. Dominance means that one allele masks the expression of another allele. For a recessive gene to be expressed you need to this same gene from both dam and sire. From the ARI registy data, it seems like black and brown are recessive to white. Fawning may be an independent gene although it also would appear to be recessive to white. It would be wonderful if this was the entire picture, but sadly other genes are very obviously involved that can really complicate things. There is one gene which appears to be dominant that influences coat color and pattern. This gene which goes by many names, we will refer to it as a “white spot” gene (Sponenberg, 2001). The white-spot gene may have many alleles which place white fibers on an animal of any color. The alleles of the white spot gene probably include the patterns “white face”, “tuxedo”, a white spot anywhere on the body, “all white”, “blue-eyed-white with and without deafness”, and possibly some others. Some people suspect multis or patterns are also part of the white-spot gene. There is just not enough convincing evidence at this point for or against this idea since there are relatively few multis around. Here is an example of how the white spot gene appears to work. If the dam passes on her white spot allele to her cria, the cria will have a white spot even if she got the “solid” allele from her sire. So a white spot allele will mask or override the solid phenotype. What is really important to know about the white spot gene is that sometimes two alleles add together to create a new phenotype. For the white-spot gene, if a cria gets the white spot gene from the dam and the white-spot gene from the sire, the cria will be born a blue-eyed white (usually deaf). It is not known what all the different possible combinations (like white face and tuxedo, tuxedo and white spot, white spot and roaning) will produce, but it appears that a number of them can combine to make blue-eyed whites. Much more research needs to be done to verify all the possible crosses and their outcomes.

Another important question concerns grays and the white spot gene. Many (but not all) gray animals have white faces and often other white markings with “roaning. Roaning in this case means that dark and white fibers are mixed together on the same animal ” (what we call silver grey or rose grey in the alpaca industry). Since this roaning allele appears to be dominant, having just one copy of any of these alleles leads to a particular phenotype (ie.you only need to get the roaning allele from one parent for the offspring to be gray). We will add one more wrinkle to the white-spot gene story. It is possible that the roaning gene is not an allele of the white-spot gene, but is a different gene located very close to the white-spot gene. So close that alleles of the white spot gene are almost always transmitted together with specific alleles of a roaning gene since they reside on the same chromosome. We suspect this might be so because there are less commonly greys that have no white face or white markings. It is possible that these greys with no white markings (just grey fibers distributed throughout the coat alternating with the natural colored fibers) may not lead to blue-eyed whites. We are just beginning to collect data on this, and these greys with no white are often mis-categorized as solids. If you have one of these greys with no white markings, and have done breedings with solid and white marked animals, we would love to hear the outcomes, so please email us about them. Same for multis. if you have bred animals with three or more colors that are not greys, we would love to hear about the breeding outcomes. You can contact us at andym@binghamton.edu.

Some Example Breeding Outcomes:
To figure out what colors an animal can throw (what alleles an animal possesses), you need to look at the animal's dam and sire, and often the granddams and grandsires and the cria they have thrown from all of their matings. Let's start with a simple example of two solid animals that don't have white spots. We also know what colors their parents were and so can determine what recessive genes might be hiding. We have Vanilla a beautiful white dam whose mother was white but whose father was black. We also have Blackie a lovely true black herdsire out of a true black dam and true black herdsire. Vanilla's gene's would be represented Wb (the dominant white gene from her mother and the recessive black gene from her father). Blackie's genes would be bb having received both recessive genes from both parents. Some breeders might be afraid that breeding Blackie to Vanilla might make a black and white pinto. This is extremely unlikely with two truly solid colored animals (athough white animals can have white spot alleles, but you cannot see white on white to detect the pattern). To make predictions you should construct a Punnet square that shows all the possible alleles each parent could throw (meaning what alleles could end up in each sperm or each egg.

Vanilla		**W**	**b**
Blackie	**b**	Wb	bb
	b	Wb	bb

What this would suggest is about half the time you would get white animals (who would if bred to black throw black about half the time) and about half the time you would get black animals. Data on these breedings from the Australian Registry actually shows a higher percentage of darker colors than would be expected. What this likely means is that there are more influencing genes involved (like the white spot gene) or diluting genes.

Let's look at an example involving the white spot gene we won't worry about coat color yet.

Example with three alleles from two parents, S=solid no-white markings, W=white face, R=roaning:
Dam is SW (a white faced animal)
Sire is SR (a grey animal)
Each egg and each sperm only contains one of the two alleles at random from the parent. So for the sire, half the sperm have the S allele and half have the R allele. For the dam, half the eggs have the S allele and half have the W allele.

	Dam		
Sire		**S**	**W**
	S	SS=solid	SW = White faced
	R	SR= Roaned (silver)	RW = Blue-eyed white (often deaf)

So if you did this cross hundreds of times, it would even out to 25% normal (solid) animals, 25% white faced animals, 25% roaned (silver) animals, and 25% Blue-eyed white animals that may be deaf. When you look at data from the registries you actually seem to get fewer blue-eyed whites that you would expect. Some have speculated that some combinations of alleles may be lethal (Paul, 2003) and that pregnancies don't progress to term or are lost almost immediately after conception. This may explain the deviations from the expected frequencies in some of the registries.

Let's look at a more complicated example involving both coat color and the white spot gene. This time a black dam with a white spot named Spotty is bred to a beautiful silver gray white faced male named Silverstar. Since Spotty is black and we know black is recessive, we know her alleles are bb, and since she has a white face we know she has SW so her four alleles (from two genes) are Wsbb . Silverstar's mother was a silver gray and his father was black. Since silver grays are really blacks with a roaning gene. Silverstar's alleles are Rsbb.

	Dam Wsbb				
Sire RSbb	**Alleles**	**Wb**	**Wb**	**sb**	**sb**
	Rb	RWbb (BlueEyedWhite)	RWbb (BlueEyedWhite)	RSbb (Silver Grey)	RSbb (Silver Grey)
	Rb	RWbb (BlueEyedWhite)	RWbb (BlueEyedWhite)	RSbb (Silver Grey)	RSbb (Silver Grey)
	sb	SWbb (WhiteSpotBlack)	SWbb (WhiteSpotBlack)	SSbb (Solid Black)	SSbb (Solid Black)
	sb	SWbb (WhiteSpotBlack)	SWbb (WhiteSpotBlack)	SSbb (Solid Black)	SSbb (Solid Black)

Of the 16 out comes, 1/4 were blue-eyed whites, 1/4 were blacks with a white spot, 1/4 were silver grey, and 1/4 were solid black. Records are not as well kept for the white spot alleles and many breeders are not certain why they are getting blue eyed whites. Currently greys are very popular with US breeders, so that is the one category we have a fair amount of data to work with.

The biggest difficulty in color genetics research and cria color prediction is in correctly identifying the phenotype. Color is still quite arbitrary, and huge numbers of animals are re-classified at shows by color judges during admission. Coat color changes during the lifespan as well. Lastly, the white spot alleles may manifest themselves as tiny dots of white on the lip, in-between the toes, or other hard to spot places, and many animals are mis-classified as solids. For the registries, many people do not bother to fill out the pattern portion when sending in their registration certificates. Also, as dark animals are often viewed as more valuable, people tend to err on calling their animal the darker color (as even ARI guidelines suggest). These mis-classifications make figuring out inheritance much more difficult.

In general, be cautious about breeding animals with white spot genes together. Certain combinations certainly seem to produce blue-eyed whites. Sadly at this point there is simply not enough data to make predictions from all the different combinations. For more information about color genetics, you can also read Merriwether and Merriwther (2003). We are always interested in genetic insights and questions so please feel free to contact us.

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