



Breeding For Rare Fleece Colors

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If you've seen an unusually colored alpaca recently and thought "that's the one for me!", you are not alone. The popularity of animals with rare fleece colors and patterns has far outstripped their supply in recent years and led to an increase in both salability and prices. That has prompted more alpaca owners to think about breeding to produce them. But the rarity of these

animals has limited the amount of information available to help run this type of breeding effort, both from the standpoint of producing animals with the color or pattern of interest and with respect to running a business based on this production. In this discussion we provide a framework for thinking about some of these challenges and do a deeper dive into our understanding of three patterns of interest to many: the harlequin, leopard-spotted and appaloosa alpacas.

Learning About Rare Pattern Genotypes

To be successful, alpaca owners focused on producing animals with rare color patterns need both breeding and business plans that reflect the likely inheritance patterns of their colors of interest. For example, while breeding for dominant phenotypic patterns produced by a single gene is straightforward and can be successfully accomplished by a small breeding program, breeding for pattern produced by a single recessive gene is more difficult and will likely require greater scale to meet both breeding goals and sales needs. Breeding for a polygenic pattern is the most complex of all and requires a very thoughtful approach and a longer time frame. Obviously, then, it is important to understand the genetic characteristics of the patterns for which one is breeding. But how do you gain that understanding when there are no genetic tests available?

A study of inheritance patterns will provide useful information about the nature of the genotype that produces a fleece color pattern of interest, and this in turn helps determine other business requirements. We show some illustrative examples in Figures 1 through 3.

As Figure 1 reveals, breeding for a pattern produced by a single dominant gene is straightforward. All animals who display the pattern will carry at least one copy of the pattern gene variant and be able to produce similarly patterned offspring. Animals that carry two copies of the gene will always produce the pattern in their offspring even when bred to animals that do not carry the gene. Animals that carry a single copy of the gene will produce patterned offspring 50% of the time when bred to animals that do not carry the gene.

Homozygosity for a dominant pattern gene variant helps a breeder make advances in other fleece traits without reducing the number of animals born with patterns, which adds to the value of homozygous animals in the breeding program. It will take relatively few offspring from non-patterned animals to establish whether a male animal carrying the pattern carries one or two copies of the gene variant that produces it, making homozygous pattern males straightforward to identify. Because females have few offspring it will take longer on average to identify those that are highly likely to be homozygous, but tracking

the production results of females will help identify homozygotes in the next generation more quickly.

Breeding for a fleece pattern produced by a recessive variant of a single gene is also straightforward, though it requires research, planning and scale to both maintain genetic diversity and produce meaningful numbers of patterned animals when the pattern is a rare one. Figure 2 illustrates why this is the case. Because all animals displaying the pattern of interest will carry two copies of the recessive gene variation, they will always pass on a copy to their offspring. But animals carrying a single copy of the gene variation will not display the pattern even though they can produce patterned offspring. A generation-skipping pattern in a phenotypic trait can be a sign that the pattern a breeder is interested in may be produced by a recessive gene.

The good thing about breeding for a fleece pattern produced by a single recessive gene is that when two animals displaying the pattern are bred together the offspring will always have a homozygous genotype and display the pattern — at least, assuming other genes do not interfere with the pattern's expression. The bad thing is that carriers of just one copy cannot be identified as such by their phenotype. Absent a genetic test for the gene variant of interest, probable carriers will be found through careful sleuthing through animals' pedigrees and when available, production records, and most quickly confirmed via breeding to homozygotes.

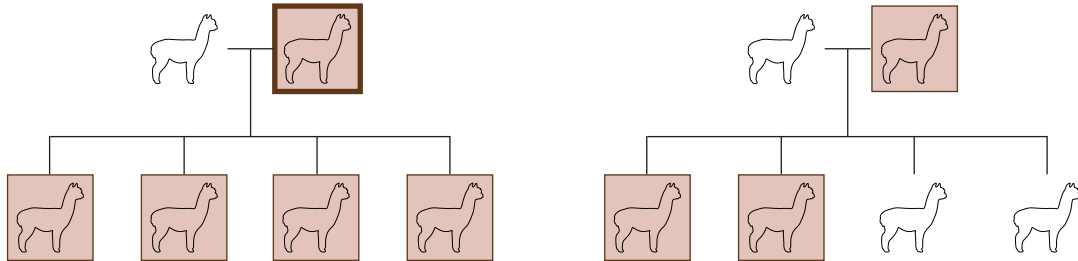
All else constant, the breeder focused on producing a recessive fleece pattern will produce fewer animals displaying that pattern than will the breeder selecting for a dominant fleece pattern, which creates a potential challenge balancing sales with herd-building. Maintaining genetic diversity and maximizing the number of animals displaying the desired phenotype will be competing goals. From a business perspective, a breeder will want to maximize the number of known pattern gene carriers in the herd so that some can be retained for the program and others sold. For recessive traits, sires that phenotypically display the trait and are therefore homozygous are especially valuable to maintaining both a breeding effort and sales based on that trait.

Figure 3 illustrates the incremental challenges associated with breeding for a phenotypic pattern produced by a combination of two genes. Patterns like this are not uncommon and alpaca breeders are used to breeding for some of them already. For instance, a tuxedo silver grey alpaca must have both a recessive black ASIP genotype (aa) and a single dominant tuxedo mutation in the KIT gene.

The example illustrated shows the results for breeding two animals which are both heterozygous for two dominant genes that work together to produce a desired pattern. These heterozygous parents can pass on a non-pattern version or pattern version of each of the two genes involved. Both these animals will display the pattern themselves, but only slightly over half of their offspring will. Of the ones that do not display the pattern, most will have at least one copy of one or the other of the gene variants required to produce the pattern. But unless that gene produces another effect that is independently visible in the phenotype it will be impossible to identify which of the gene variants they carry or whether they carry one at all.

Meanwhile, among the offspring of heterozygous parents that display the desired pattern, only about 1 in 10 will be homozygous for both pattern gene variants and always pass on the required combination to their own offspring.

Figure 1: Inheritance Of Fleece Pattern Produced By A Single Dominant Gene Variant



Phenotype production when the pattern gene is dominant in type and the animal is either homozygous (heavy-framed example above), heterozygous (light-framed), or does not carry (no frame) the gene of interest.


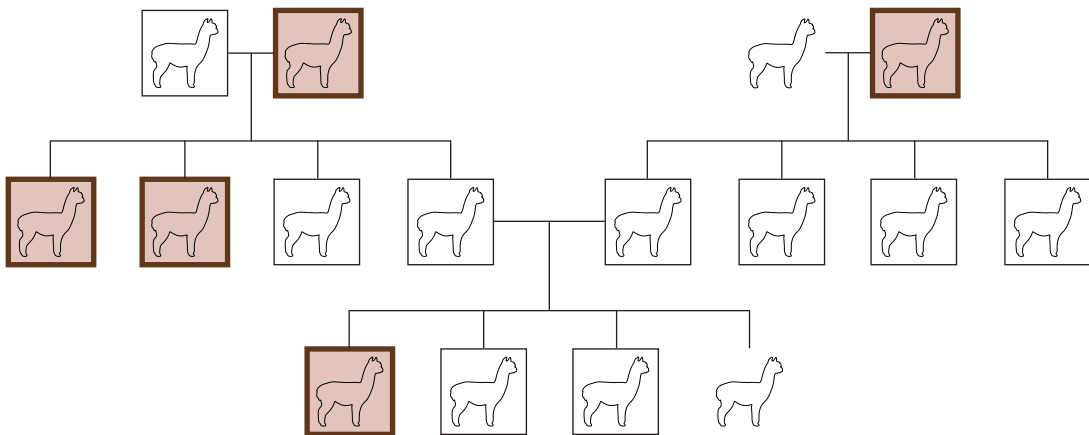
 Displays the fleece pattern

Figure 2: Inheritance Of Fleece Pattern Produced By A Single Recessive Gene Variant



Phenotype production when the pattern gene is recessive in type and the animal is either homozygous (dark-framed example above), heterozygous (light-framed), or does not carry (no frame) the gene of interest.


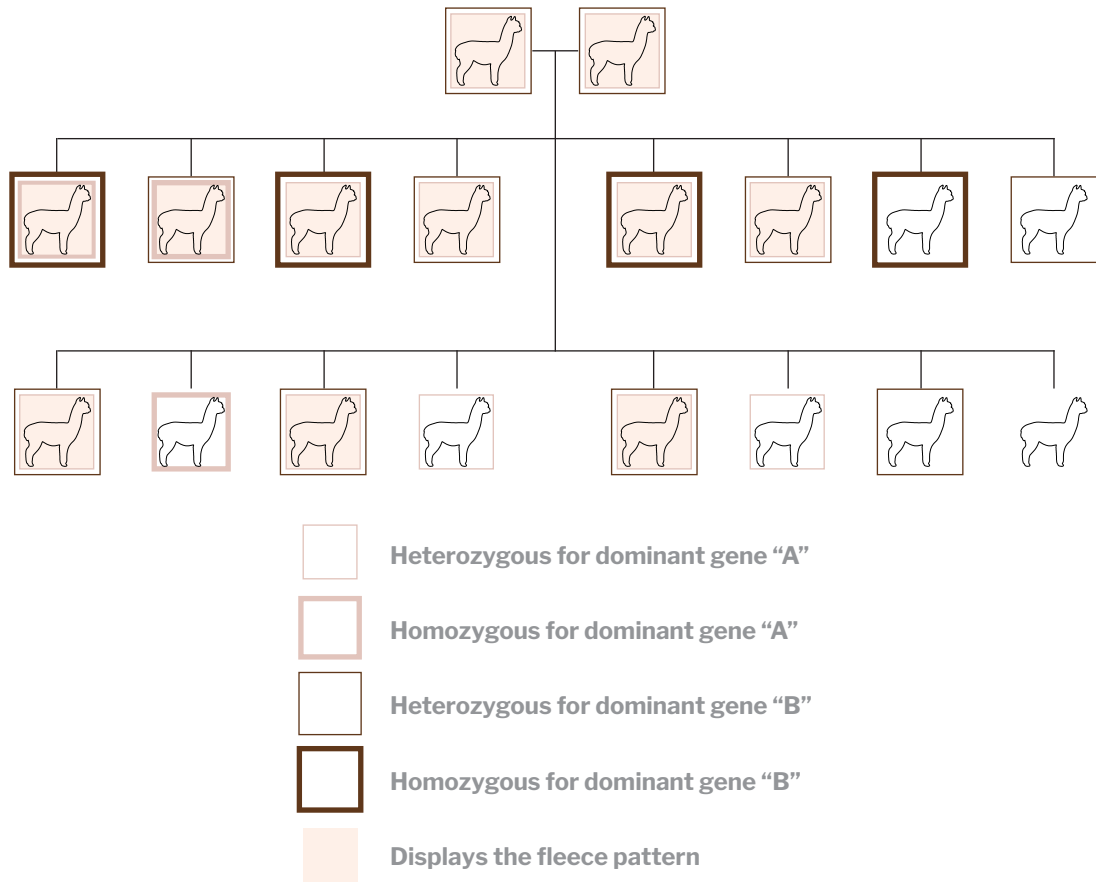
 Displays the fleece pattern

Figure 3: Inheritance Of Pattern When Two Dominant Gene Variants Are Required To Produce The Phenotype



Those will always produce crias displaying the pattern, and the rest will produce them less frequently (25% to 50% of the time, assuming they are bred to animals that lack the gene variants to produce the pattern.) This is a business challenge for a breeding program focused on producing this pattern because the selection focus they have to apply to multiple genes means they will make less progress advancing other fleece traits but, at the same time will have many non-patterned animals to sell that will be valued based on those other traits. These programs will need to pay particular attention to maintaining and advancing genotypes for fleece quality even as they strive to increase the number of animals with the genotypes for rare patterns they produce.

The popularity of animals with rare patterns has grown in recent years, and this has made it possible to infer more about the characteristics of the genotypes of the animals that carry these fleeces. Here we review what we've observed about some of the more popular rare pattern types: Harlequins and spotted alpacas.

Harlequin Alpacas

Alpaca breeders use the term harlequin to describe animals that evidence a particular type of ontogenetic color change.¹ The word “ontogenetic” means “during the life of the organism.” Harlequins are born with fleeces that darken in color as they mature. The color change in the blanket region is often quite precipitous and usually happens before age two. Harlequin animals tend to retain lighter-colored fleece on their faces, inner legs and bellies.

Most animals identified by breeders as harlequins are born with a light fawn fleece that turns grey or taupe by the time of its first shearing or soon thereafter. These animals almost always have black ASIP genotypes (aa) and one or two dilutive MC1R variants (Ee or ee) that would ordinarily cause them to produce light fawn, fawn, brown or black fleeces.² We've looked at the fleeces they produce at maturity and found that even when they appear a uniform smoky grey they actually have secondary fibers of two or even three colors present, suggesting a possible link to the roan genotype. But harlequins have something else going on too: The genotype that causes the harlequin color variation appears to result in additional dilution of the base coat color, the expression of which is highest at the time of the animal's birth and declines to some extent during its maturation but does not completely disappear.

Harlequin breeders often describe their animals' fleeces with color terms like platinum, pewter, taupe and smoky. This suggest to us that it is possible that this form of dilution doesn't just affect the total amount of pigment present but also affects the ratio of eumelanin (the black pigment) relative to pheomelanin (the brown.)

Many gene variants that produce coat dilution have been identified in other animals, including horses, sheep, dogs and cats. One such gene known as MLPH encodes the instructions for making a protein called melanophilin, which is found in the melanocytes which produce the pigment that appears in the hair and skin of an animal. Recessive mutations in this gene produce the dilute coat colors of Russian Blue cats, Weimaraner dogs, and so called

¹Breeders of other animals use the term differently, in particular to refer to animals with spots or patterns of grey appearing on a white base coat.

²We have found one harlequin animal with an Ee AA genotype.

“lilac” Jacob sheep among others. Several dilution genes have also been identified in horses. Among them, the cream dilution gene variant is an incomplete dominant version of the MATP gene, and responsible for colors like palomino, smoky black, and perlino. A rarer but dominant variant of the gene informally known as the Champagne gene produces similar colors. And another dominant gene variation of the TXB3 gene produces colors collectively described as dun. Closer to home, variants of the KITLG gene have been associated with variation in coat color intensity in multiple species, including alpacas.³ Variants of the KITLG gene are also associated with the production of roan fleeced alpacas, and the prevalence of roan animals in the pedigrees of harlequins and the variation in color of the individual fibers combining to produce the grey-appearing fleeces of harlequins may suggest another link. Long story short there are plenty of potential candidates to research in the search for the “harlequin gene” in alpacas.

The spectacularly patterned male Wahoo's Jackpot is owned by Pam Rose of Rockin Rose Ranch and produced by Rebecca Suryan of Alpacas From MaRS.
Photo credit: Ricki Dunlap.

Spotted Alpacas

Alpacas with lots of spots are usually referred to by their breeders as appaloosas (and we will do the same), but there is evidence to suggest that their spots are most commonly produced by something other than the white pattern that produces Appaloosa horses. We also observe variations in phenotypic spot patterns that suggest that an additional gene or genes may affect the distribution of spots across the animal.

Appaloosa horses carry a genotype for a white pattern with “holes” that reveal spots of color. The LP gene determines whether the horse will have this white pattern with dark spots and other genes, including the gene known as PATN1, determine whether the pattern is expressed across the whole body or limited to the blanket or even just the hindquarters. A horse that is heterozygous (that is, carries one copy) for the appaloosa LP allele usually has a lot of spots, where an animal that carries two copies of the appaloosa LP allele typically has an extensive white coat with very few spots in it, a result that may seem counterintuitive until you recall that the pattern is a white one expressed over a dark base coat.

Alpacas by contrast can have heavy spot patterns appearing in coat colors other than white, which rules out a white pattern as the source of the spotting in those cases. Instead, these animals have a genotype that produces true dark spots. Animals with these dark spots can produce animals that have dark spots in a white coat, and while this particular pattern could be produced by a hypothetical white pattern gene like that which produces Appaloosa horses, the fact that these animals descend from true dark-spotted animals suggests that they are not displaying an Appaloosa horse-type pattern, but rather something different and perhaps unique to alpacas.

Analysis of over 100 samples from six US farms by author Darcy Phillips revealed that all spotted alpacas had an Ee Aa base coat color genotype. It may be what differentiates the dark-spotted alpacas from harlequins is their ASIP genotype: Harlequins very often have visible spots, especially when they are young (these may “disappear” into a darkening blanket), produce what alpaca

³Shah Ishani, Gray Naomi, Groth David, Brooks Samantha, Munyard Kylie (2023) Identification of six genomic regions associated with pigment intensity in alpacas. *Animal Production Science* 63, 1052-1062.



breeders would describe as appaloosa offspring, and almost always have Ee aa base coat color genotypes.

As noted above the distribution of spots on heavily spotted alpacas varies in a way that suggests that another gene or genes may affect their distribution. “Classic” appaloosa alpacas have spots concentrated in the blanket area, while “leopard” appaloosa alpacas have spots on their faces, legs and tails as well. Breeders wishing to focus on producing a particular type of spot distribution should keep this potential in mind..

The Rare Trait Breeding Business

Even though we don’t yet have genetic testing available to determine which animals carry harlequin, leopard or appaloosa genotypes, let alone other even rarer patterns, base coat color genotyping is still quite valuable for a pattern breeding program. This is because some patterns may only be visible when an animal has a base coat color within a certain range or produced by a particular base coat genotype.

The fact that the great majority of patterned animals color genotyped to date carry at least one black ASIP allele suggests that pattern breeders adding non-patterned animals to their breeding program may wish to confirm that they cover black. Based on what we know now, these animals seem to have the best odds of being able to produce what we describe as the harlequin and leopard spotted phenotypes.

And as suggested above, because we haven’t yet found patterned animals with “EE” MC1R genotypes we suspect that these animals may have coats that are too dark to reveal dark spot or harlequin patterns even if they do carry them. This is something to consider both when assessing the probability of an animal having a spotting or harlequin genotype as well as when determining the probability that they will produce offspring expressing those patterns.

When making decisions about both selling from their breeding programs and adding to them, breeders of these unusually-colored animals will benefit from thinking carefully about the inheritance patterns they have observed and what those patterns imply for both the likely characteristics of the fleece pattern genotype — single-gene or multi-, dominant or recessive, etc. — and how they affect the development of the business plan for the breeding effort. This information won’t just support your own business, but help your clients build on your success. ◇

Rare Color Case Study: Rare Gem Alpacas

By Darcy Phillips

At Rare Gem Alpacas in Southern California, the primary focus of our breeding program is to produce elite-fleeced spotted and harlequin alpacas. My journey began eight years ago when I came across a picture of the most adorable spotted alpaca on Pinterest. As a knitter and fiber artist wannabe, I found the look of this alpaca completely captivating. I rearranged my life, bought a farm, quit my day job and jumped into the alpaca lifestyle with both feet.

There was relatively little information available at the time regarding these unique alpacas, but I was fortunate to find a mentor who had been breeding appaloosa alpacas in the USA-- Ed Kinser of Enchanted Hill Farms. Ed has since retired, but before his retirement, I was able to purchase my first harlequin stud male from Ed and glean valuable information. Ed was very open with his knowledge including what he believed to be the original key contributors to the U.S. herd of harlequin and appaloosa gene variants. Tracking the offspring of these gene carriers turned in to a multi-year endeavor for me. I did my best to obtain as many of these descendants as I could. I tested for color genotypes and studied the pedigrees to determine under which conditions these alpacas and their offspring would produce animals with spotted or harlequin fleeces.

At times, most of the walls of my home were covered with flipchart paper with alpaca family trees and pictures of alpacas. There was no color genotyping back then, and no DNA test for the patterns I breed even today. But my papered walls gave me clues. I found that when an appaloosa or harlequin was bred to a fawn over black or a vicuna patterned alpaca I'd get the desired result at a much higher rate. I was told a lot of things like "you cannot get an appy or harlequin from a white," and "brown is the appy gene killer" meaning they wouldn't let the phenotype express, or maybe the spots were there but the dark color covered them up. I tested them all. I bred to every color and pattern and logged the results.

Now that we have base coat color genotyping to overlay with these results, we can see that all the animals expressing the spotted trait that have been base coat genotyped so far have had "Ee" or "ee" MC1R genotypes. The so-called appaloosa alpacas we have tested to date all carried one black allele, and harlequins almost always carry two black alleles and an Ee MC1R genotype. While we are still studying the link between black alleles and pattern expression, what we have seen so far leads us to believe that, as is the case with grey alpacas, having animals with black alleles in a pattern breeding program will increase the rate at which breeders see these genotypes expressed in their animals' phenotypes.

In addition to the gene variant that produces dark spots, we believe there may be another gene or genes that controls the distribution of those spots because we see two types of spot distribution: The "classic" phenotype has spots primarily in the blanket area while the "leopard" type has spots from nose to tail and down the legs. It's important to note, too, that even solid-colored animals can have genotypes that allow them to produce harlequins and classic- or leopard-type appaloosas. We find these via our extensive pedigree research.

In just seven years Rare Gems has produced 88 harlequins, classic appaloosa and leopard alpacas. That's exciting. But while animals with unique colors and patterns are fun to breed, we always keep in mind that alpacas are ultimately fiber animals, and as such other fiber qualities also need to be emphasized in breeding decisions. One of the challenges we have faced is that animals expressing appaloosa or harlequin phenotypes have historically not been as advanced with respect to their other fleece attributes. By utilizing a breeding approach where we pair an animal with the desired pattern phenotype with another that does not reveal the pattern but has the right pedigree and color genotype along with elite fleece characteristics, we have been making substantial improvements in fiber quality in each succeeding generation while also producing plenty of "rare gems."