MEAT YIELD AND QUALITY: THE GENETICS BEHIND COAT COLOR IN COMMERCIAL BREEDS OF SWINE

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Introduction.

Coat color and more importantly hair follicle color is of interest to the pork production because of the problem known as 'seedy bacon'. Seedy bacon can devalue a pork carcass due to colored hair follicles giving a speckled appearance to the processed skin. The spots or seeds of color can be mistaken for dirt and question the during processing and also damage the retail of the bacon at the grocery store. The colored hair follicles stain deep into the skin and cannot be scalding or scraping the skin surface. This concern of quality, albeit cosmetic, has lead to processors imposing penalties on swine with black hair follicles. Of the four main commercial breeds of swine, Yorkshire, Landrace, Duroc and Hampshire, only the Yorkshire is considered to be traditionally free of hair color. Although the Landrace is generally considered a large white breed, spots or patches of color are known to segregate in the pure population. Duroc and Hampshire are known as colored breeds but this is due to only one gene difference from the large white breeds, the *Dominant White* allele of the *c-Kit-receptor* gene also known as the ***I*** locus.

Hair color development.

*c-Kit receptor gene {**I** locus}*

Classic genetic studies using mice models have now implicated at least 20 different genes that can influence hair and skin color. Essentially however, hair color development can be grouped into three genetic levels. First is the embryonic development of the color producing melanocytes. Next are the responses of melanocytes to endocrine signals mainly through the *melanocortin receptor 1* (*MC1R*) and finally, the expression of genes involved in the actual production of pigment inside the melanocyte's melanosomes. Melanocytes are cells that give color pigment to the skin and hair and cause tanning when skin is exposed to UV light. UV light can cause DNA damage leading to cancer therefore the pigment is made to block or absorb UV radiation before it can reach the DNA. The color pigments known as melanins are made from the amino acid tyrosine by a key enzyme known as tyrosinase oxidase. In the white pig breeds, melanocytes are absent; therefore they are essentially albino and cannot protect themselves from high UV exposure. In most white pigs, the lack of melanocytes is due to a mutation of the *c-Kit receptor* gene known as the dominant white allele. The dominant white allele is the result of a gene duplication, which disrupts normal melanocyte development in the embryo. Without melanocytes the animals skin cannot produce any color pigments. The mutated *c-kit receptor* normally responds to the *c-Kit* ligand also known as the *Stem Cell Factor* (*SCF*) which is secreted by stromal cells throughout the animal. *SCF* and *c-Kit receptor* activation is also involved in hematopoiesis (blood cell development) and as a result the pigs carrying the *dominant white* allele also have reduced plasma concentration of white blood cells. Complete disruption of the *c-Kit receptor* gene is probably lethal; as observed when horses are homozygous for the Roan coat color gene. Aside for the Dominant white version of the porcine *c-Kit receptor* gene, there are other mutants known as *Patch* (I^P) and *Belt*

Patch which is found mainly in Landrace, is a also a gene duplication but with a new point mutation in exon 17 of one of the duplicated genes that only occasionally blocks the over expression of the *c-Kit receptor* protein. This allows patches of normal melanocyte development resulting in patches of color. In mice, patches of color have also been linked to deletions in their *c-Kit receptor* promoter region. It has also been shown in mice, that normal *c-Kit receptor* activity can be rescued by other cell receptors with tyrosine kinase signally activity. Therefore some lines of pigs with patches of color might be due to over expression of tyrosine kinase activity from some other type of cell surface hormone receptor.

Belt describes pigs that are black with a white belt of absent color. This pattern is typically observed in the Hampshire breed of pig. The actual genetic mutation has not been isolated yet but mapping studies have linked it to the *c-Kit receptor* {I locus}. The Belt allele is not duplicated like the Dominant White or Patch alleles but is believed to have its mutation in the promoter (on/off signal) region of an otherwise normal *c-*

Kit receptor gene. In mice, there are versions of the *c-Kit receptor* gene that give the belt pattern in the heterozygous condition but a spotted or patch appearance in the homozygous genotype (Kluppel et al. 1997).4

*Melanocortin receptor 1 (MC1R) {Extension, **E** locus}*

If the melanocytes do develop normally in the embryo, the next major controlling genetic factor is the MC1R gene, which resides on the cell surface of the melanocytes. Typically, the MC1R is activated by the 13 amino acid long pituitary peptide, α-melanocyte stimulating hormone (α-MSH). Activation of the MC1R stimulates the production of the melanocyte gene tyrosinase (Trp). Increased tyrosinase activity in the melanosome then promotes the production of more eumelanin (brown/black) pigment over phaomelanin (yellow/red) pigment from tyrosine. Many color density variations in mammals from black to brown to red to yellow have been linked to mutations in the MC1R gene. Red Angus and Holstein cattle breeds have a deletion in their MC1R gene, which is otherwise normal in the Black Angus breed. In swine, polymorphisms (non-lethal genetic mutations) in the MC1R gene at codon 161 (Ala → Val) and 240 (Ala → Thr) have been linked to red hair in Duroc pigs and at codon 92 (Val → Met) and 99 (Leu → Pro) to black hair in Meishan and Large Black pig breeds. Wild boars are considered to have the normal MC1R gene. Over expression of MC1R activity has also been linked with obesity and can be activated by the stress hormone ACTH.

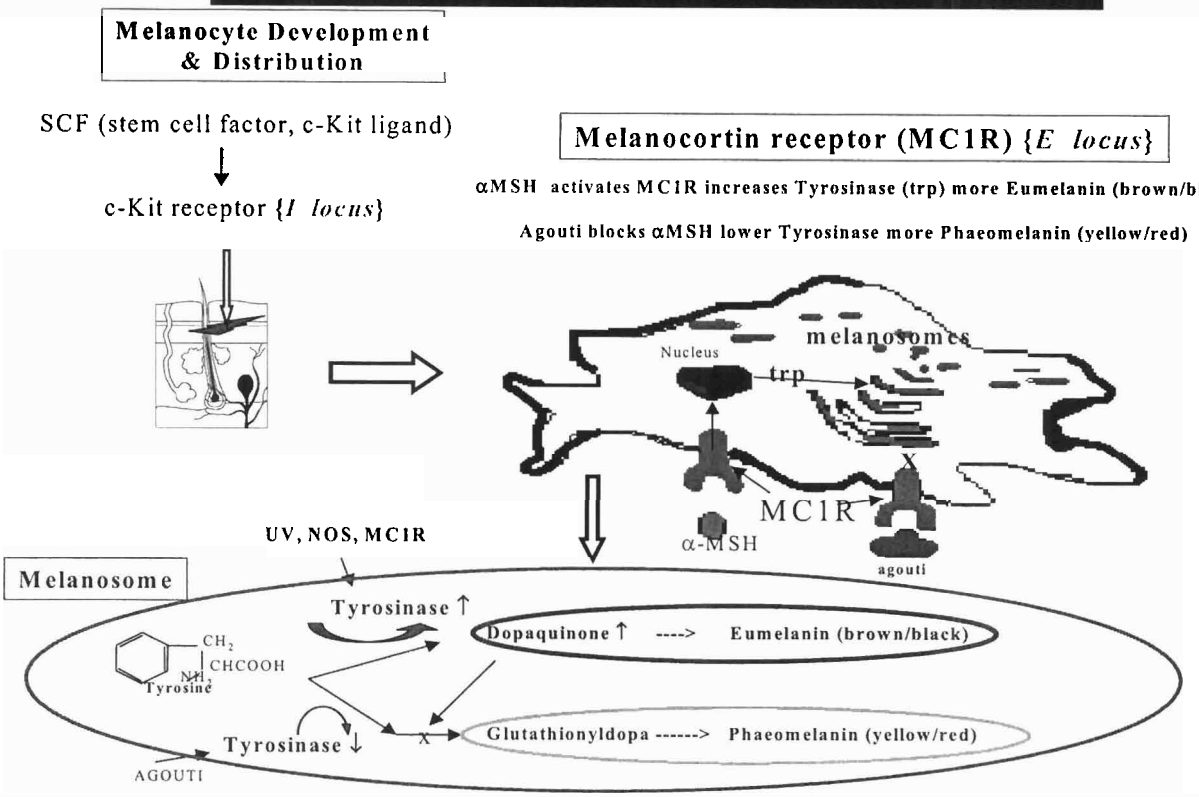
Although not yet described in pigs, the genetic control of color also depends on the expression of a competitive 131-aa peptide factor known as Agouti. Agouti promotes the expression of the yellowish red phaomelanin by blocking αMSH from binding to the MC1R. Over expression of agouti is the cause of the lethal yellow phenotype in mice.

Pigment production and the tyrosinase gene.

As mentioned at the beginning of this review over 30 genes in mice studies have been linked to the more subtle variations of color. Some of these genes effect the expression of the *c-Kit receptor* such as the microphthalmia-associated transcription factor (MITF) or the block the activation of the melanocortin receptor like the agouti protein. However, many of these genes are involved in the modification of enzymes in the melanosomes. The key enzyme involved in color development tyrosinase (TRP) appears to be too essential for normal cellular activity and most mutations are lethal, genetic alterations are more tolerated in the genes that code for associated proteins and transcriptional factors that modify melanin synthesis in the melanosomes. These associated genes include the Tyrosinase related proteins 1 and 2 (Trp-1 also known as dopachrome tautomerase and Trp-2), attractin (Mg), the Pink gene which affects melanosome pH, and even Nitric oxide synthase (NOS). Diet can also affect color. Supplements with vitamin E or polyunsaturated fatty acids (PUFAs) such as linoleic acid can lighten melanin pigments by reducing the effect of UV and alternatively, the antidepressant drug *imipramine* can form a complex with melanin to darken the melanocytes.

Conclusion.

To the commercial pig breeder, the best marker to select for to get color free pigs is the dominant white allele of the *c-Kit receptor* which prevents the formation of melanocytes. A patented gene test is available that identifies the Dominant white allele by its extra copy of the normal *c-Kit receptor* sequence (Andersson et al. 2001). However, a variation of the Dominant white allele appears to exist in the commercial white pig population known as Patch. A gene test can identify some of the Patch mutations but if missed the next best scenario would have the breeder select animals that would have lighter red to yellowish hair. Lighter hair can be selected for using genetic markers for the mutations in the MC1R gene such as the Duroc red hair MC1R allele or avoid the Meishan black hair MC1R allele. Finally there is also the option of introducing genetics from the hairless (hypotrichosis) breeds such as the Mexican hairless last reported back in 1930, although a few are believed to exist in modern Iberian pig populations.



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