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Breeding Guppies: Genetic Pitfalls and Successes[1]

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Most fish keepers view guppies as children's fish. However, if ever there was a fish to study livestock breeding and genetics, it is the guppy *Poecilia reticulata*. Scientists have been studying guppy inheritance since the 1920s [1].

Learning more about the underlying genetics of guppies makes keeping them more interesting. Also, saves time and frustration. Thirty years ago there was not much genetic information available to hobbyists. Now, there is plenty [2, 3, 4].

Fig 1 Homebred Blue Guppies c. 1988

My Experiences

I have kept guppies off and on since childhood. In 1988, I created my own blue delta strain [**Fig 1**] by crossing a store-bought male with vibrant, iridescent sky-blue colors with a female from a blue "show strain" where the males had better finnage but suffered from much duller coloration. The resulting progeny (F1) combined the best of both parents. During the two years that I kept these guppies, there were no planned matings, just "colony breeding." I simply kept all the breeder guppies together in one tank and occasionally culled unwanted individuals (e.g., orange-colored males).

In 2017 I returned to keeping guppies with a sharper focus and a more serious breeding program. After successfully tackling disease problems in newly purchased guppies, I then found myself inadvertently stumbling into several genetic pitfalls.

First jolt came with the Swallowtail strain that I ordered on-line. The breeder sent me 5 juveniles. The males turned out nice, but afterwards the breeder explained that the strain carried a gene that made it impossible for some of the males to breed. Males with the characteristic ribbon-like finnage [**Fig 2a**] had a long gonopodium fin that was useless for insemination. Apparently, breeders used males without the abnormal fin gene to keep the strain going.[2]

Fig 2a Male Sterility

The abnormally long gonopodium (bottom fin) on this Swallow-tail male prevents him from impregnating females.
{Internet Photo}

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[1] Complementary articles on guppy breeding ('Small-Scale Guppy Breeding' and 'Guppy Longevity') are also available on my website.

[2] Guppy strains with ribbon fins contain one or more fin elongation genes (*Kal*, #171; *Sup*, #170; and *Rib*, #163). (Numbers here and throughout this article correspond to their listing in a comprehensive gene reference table [4].)

Fig 2b Handicapped Male
Genes for fin elongation were incorporated into this particular BG (Blue Grass) strain. {Internet Photo}

Thus, breeding this strain was complicated. I would have to choose males for a functioning male organ as well as color, vigor, size, etc. And if I bred Swallowtail females to another strain, would I have the same problem? The owner chided me to read up more before I bought fish. Good point, but alas, I never suspected that anyone would breed guppies where some males could not impregnate females.

Sadly, I concluded that the Swallowtails were a dead end for me and stopped working with them. Later, I learned that it was not just Swallowtails that carried fin elongation genes [**Fig 2b**].

Gradually, the BG (Blue Grass) became my favorite strain. It was beautiful, prolific, and relatively disease-resistant. Females were attractive and had big dorsals.

However, once again I ran into a genetic problem. Only about 30% of the BG male progeny actually had the BG phenotype [**Fig 3a**]. The rest were either Red Grass [**Fig 3b**] or unattractive males with small black tails [**Fig 3c**].

The Red Grass is the foundation genotype for the BG strain and beautiful in its own right. Notice that it has the characteristic spotted 'grass' pattern on both dorsal and caudal. In contrast, the BT (Black-tailed) has a small, uniformly dull grey/black dorsal and tail. BT males are also small and weak.

Apparently, the appearance of 3 different phenotypes in an offspring batch is typical of many other blue-colored strains (e.g., Blue Moscows, Blue Galaxy, etc). The root cause is the *Ab* (Asian Blau) gene.[3] Guppy breeders use this gene to produce beautiful iridescent blue colors and to suppress red and yellow colors. The genes for red pigments are still there, but *Ab* prevents their expression. The same is true of yellow colors, but to a lesser degree.

Three Blue Grass Phenotypes

Fig 3a Blue Grass

Fig 3b Red Grass

Fig 3c….Black-tail (BT)

[3] *Ab* (#69) is just one of several genes coding for male blue color. Two others [European Blau (#68) and Hellblau (#70)] also suppress red and/or yellow color [4].

Crossing males of the Metalhead strain with BG females did not improve matters [**Fig 4**]. Apparently, both my Metalhead and BG strains contained the *Ab* gene, so crossing them did not help. I got only 2 decent males out of twenty. Granted, the males were gorgeous, but the rest were just plain ugly. Breeding these fish was almost impossible. How could I select breeder females from a batch where the majority of males were unacceptable?

Fig 4 This Breeding Group of blue/green Metalhead males with BG females was supposed to produce beautiful babies. Unfortunately, most (~95%) of the F1 were small and unattractive BTs (Black-tails).

Asian Blau Gene

The Asian Blau gene (*Ab*) is present on the autosomes (i.e., non-sex chromosomes) of both males and females. The female counterpart to Black-tail males was easy for me to distinguish from other females; a BT female [**Fig 5**] has the same black/grey caudal as BT males.

Depending on how *Ab* sorts out during meiosis, the progeny of a BG mating will be a mixture of BG, Red Grass and BTs (Fig 3). The Punnett Square in **Fig 6** shows how the underlying *Ab* gene sorts out to produce the 3 different phenotypes. In the example with my BG guppies, the heterozygote genotype ($A\ A^{Ab}$) is the only progeny that will display the desired BG phenotype.

Fig 5 Female BT (Black-tail) is homozygous for the *Ab* gene and easily recognized by her small, uniformly black/grey caudal and the absence of the grass pattern.

Blue Grass female \ Blue Grass male	A	A^{Ab}
A^{Ab}	$A\ A^{Ab}$	$A^{Ab}\ A^{Ab}$
A	A A	$A\ A^{Ab}$

Fig 6 Fate of *Ab* in a BG Mating

Ab is classified as an autosomal partially dominant gene. The Punnett Square above shows the sorting out of *Ab* during meiosis to produce 3 different phenotypes in a BG batch of fry. If *Ab* is absent from the autosome (‘A A’ in bottom left box), the individual will be a Red Grass. If heterozygous (‘$A\ A^{AB}$’), the individual will be a BG. If homozygous for *Ab* (‘$A^{Ab}\ A^{Ab}$’), the individual will be a BT (Black-tail). [Like humans, the guppy (*Poecilia reticulata*) has 23 pairs of chromosomes. One of those 23 pairs contain the sex chromosomes X and Y; the other 22 pairs are autosomes (A).

Pet Shop Guppies

Breeding fancy guppies was getting complicated, so I turned to guppies from the pet shops. For I assumed that commercial guppy breeders in Southeast Asia were not going to keep strains that produced only 5-30% saleable fish.

Imported guppies also have more iridescent colors than many fancier "show guppies" from the American market. Typically, the males pass these bright colors onto their sons. (Most genes for male color are carried solely on the male's Y chromosome.)

I tried working with HB-Blues (Half-black Blues), a popular commercial strain, sometimes called Neon Blues. While the body and caudal are a dull blue-black, this strain has a characteristic iridescent white/blue top that stands out when viewed from above, making it a popular fish for ponds. My BG strain had better finnage and more iridescence. Perhaps crossing HB-Blue males with BG females would improve the strain while keeping its unique iridescent blue top?

Fig 7 HB-Blue X BG Mating

Progeny (F1) of HB-Blue X BG show very little influence from their BG dam. They all looked alike and had dull colors.

I was disappointed with the HB Blue X BG cross. I got wholesale uniformity [**Fig 7**]. Plus, not one of the F1s showed the pretty grass pattern tail of my BG. Apparently, HB-Blues carry dominant genes that over-ride those of the BG strain.[4] The HB coloration showed up on all fry at birth—males and females. I have never been a fan of Half-black guppies, and this experience cemented my prejudice. I like male bodies that have colorful spots and patterns.

The F2 generation was no better. The colors were even more faded. Plus, color uniformity was boring. I might just as well have been breeding Zebrafish where the progeny all look alike and just like the parents. I decided that the shiny blue top of the HB-Blue did not compensate for its solid dull color elsewhere and its small dorsal fin.

As to the female guppies offered in stores, one can only guess at their genetic makeup. Their quality is nowhere near that of the males in pet stores. The few times that I have bred them, their progeny was disappointing.

[4] The basic genotype of the HB-Blue strain is Asian Neon (#63) featuring the co-expression of genes NiII and Leucophore White. Black caudal peduncle (*Bcp*, #65), a dominant gene carried on both X and Y chromosomes, codes for the Half-black trait. Asian Blau (*Ab*, #69) is sometimes added to suppress orange pigment [4].

Fig 8 BG Male X Gold Female

The sire was a pure BG.

The dam was an ordinary female from a pet store. Her gold color comes from the homozygous expression of *b*, a recessive gene. (*See* Footnote #5)

The F1 batch contained two males with a snakeskin body and tail pattern.

However, I did cross a gold female[5] from a pet store [**Fig 8**] with one of my BG males. Most of the fry were rather ordinary except for two pretty snakeskin males.[6]

Mating one of the snakeskin males (F1) to his sibling [**Fig 9a**] produced an F2 containing only solid colored males such as shown in **Fig 9b**. Not one of the F2 had the desired body and tail pattern of their snakeskin sire. Rather, they represented the homozygous expression of recessive genes[7] from their pet shop granddam. While the F2 had their own charm, I decided not to pursue breeding them.

Fig 9a F2 Reveals Genetic Makeup
These are F1 siblings from the BG X Gold outcross shown in Fig 8.

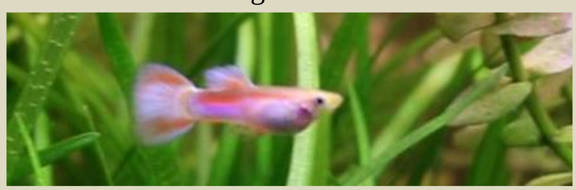

Fig 9b The F2 contained mostly yellow and pink males with white bellies. This is the pink-white version.

[5] Ordinary "gold" guppies like this female contain the mutant blond gene (*b*), an autosomal recessive gene. This mutation (#66) reduces the *size* of the fish's melanophore pigments. In contrast, another mutant gene (*g*, #84), reduces the *number* of melanophores, producing "bronze" guppies. "Cream" guppies (*bb gg*) are double mutants (#77). The natural body color of guppies is grey [4].

[6] The snakeskin phenotype is due to two dominant genes, *Sst* (#140) for the tail and *Ssb* (#119) for the body [4]. Both genes can be on either the X or the Y chromosome [4].

[7] Most progeny had white bellies, an expression of the Micariff White gene (*Mcw*, #99) [4].

Outcrosses with Swordtail Guppies

In 2017 and on a whim, I purchased two swordtail males from a pet store. They were double swords, advertised simply as lyretails. However, I recognized the iridescent blue body color of the JB (Japan Blue). Wild JB guppies were first discovered in the late 1980s in a Japanese river. They have a beautiful, iridescent blue peduncle. My purchased males had a white/purple double sword, but the fins of JBs can be any color or shape.

When I crossed the JB males with one of my BG females, the resulting progeny (F1s) were uniformly fast-growing, vigorous, and absolutely lovely [**Fig 10**]. All the males had the iridescent blue body color of their sire plus the big dorsal and grass pattern of their BG dam.

The blue color is due to a *Ca* gene[8] carried on the male's Y-chromosome, so it is only passed from father to sons. It differs from *Ab* in being fully dominant and carried on a sex chromosome rather than an autosome. **Fig 11** shows that it is inherited by all sons and no daughters. (Many guppy color genes are similarly carried on the male's Y chromosome.)

Japan Blue male

Blue Grass female		X	Y^{Ca}
	X	X X	X Y^{Ca}
	X	X X	X Y^{Ca}

Fig 11 ***Ca* Gene for the Japan Blue** color is passed only to male progeny via the sire's Y sex chromosome. The genetic makeup of the dam does not matter.

Fig 10 JB Male X BG Female

The sire, a JB (Japan Blue) with a double sword carries the *Ca* gene for his unique blue body color. (Unfortunately, the lighting that I used for this photo turned his blue body color purple.)

BG dam used for the outcross. Note the big, high dorsal that characterizes many BG females.

The F1 had the JB body color of their sire and the delta/grass tails of their BG dam. [These males were still immature (~2-months-old) when photographed.]

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[8] The Caeruleus gene (*Ca*, #74) is expressed as a heavy density of blue iridescent cells (iridophores) on the male's body [4].

All male F1 progeny had delta tails. Genes for the delta tail from the BG dam dominated the *Ds* gene for the double swordtail.[9] As juveniles, some males had a "caudal gap," suggesting that they might turn into double swords like their sire. However, by adulthood they filled in this gap and developed delta tails.

To see if the F1s were carrying the recessive swordtail gene, I mated F1 siblings. About half of the F2 males [**Fig 12**] had double swords like their JB grandsire. The F2 swordtails were due to the pairing of recessive *Ds* genes from both F1 parents. This homozygous expression of recessive genes in the F2 is standard Mendelian inheritance.

Initially, I was concerned that I would have problems breeding out the swordtail gene, but that turned out not to be a problem. To reinforce the delta tail, I backcrossed an F1 male [**Fig 13**] to a pure BG female. From that mating, I never obtained any progeny with swordtails. All progeny—and their descendants—had delta tails.

Fig 12 F2 from Mating F1 (JB X BG) Siblings show the predicted mix of double swords and delta tails.

Fig 13 An F1 (JB X BG) male at 8 mos. (Here, I photographed used a light source that brought out the beautiful iridescent blue body color that characterizes Japan Blues.)

The results with the Japan Blue swordtails were so stunning that I repeated it with another strain of swordtail guppies (Ls or Lower swords) purchased from an authoritative and long-time breeder [5]. The Ls guppies carried genes for iridescent colors that I was interested in. Moreover, swordtails have a reputation for greater longevity and fitness than delta tail guppies.

[9] Gene for the double sword (*Ds*, #147) can be on either the X or the Y chromosome. Delta tails (#146) represent a complex genotype resulting from a combination of Pigmentierte Caudalis (*Cp*, #138) and the double sword gene (*Ds*, #147) [4]. Females carrying the *Cp* gene will have dark tails; females without the gene will have clear tails. Thus, in breeding for delta tails, I select F1 females with dark tails.

One Ls male [**Fig 14**] turned out to be an outstanding sire when crossed with BG females.[10] All the F1 males were absolutely stunning [**Figs 15** and **16**]. They inherited brilliant iridescent colors from their sire and the grass/delta tails from their BG dam.

Fig 14 This Ls Male Guppy carried a boatload of iridescent color genes, many masked here by the blue color from the Stoerzbach gene.

In contrast, progeny from a reverse cross (mating a BG male to an Ls female) produced swordtails and less colorful offspring. I did not pursue the outcrossing of Ls swordtail females for several reasons. I did not want to lose color and pattern genes carried on the Ls male's Y chromosome. Also, females of the BG strain carried genes for the grass pattern and a high dorsal.[11] I did not want to lose genes for the beautiful phenotype of my BG females.

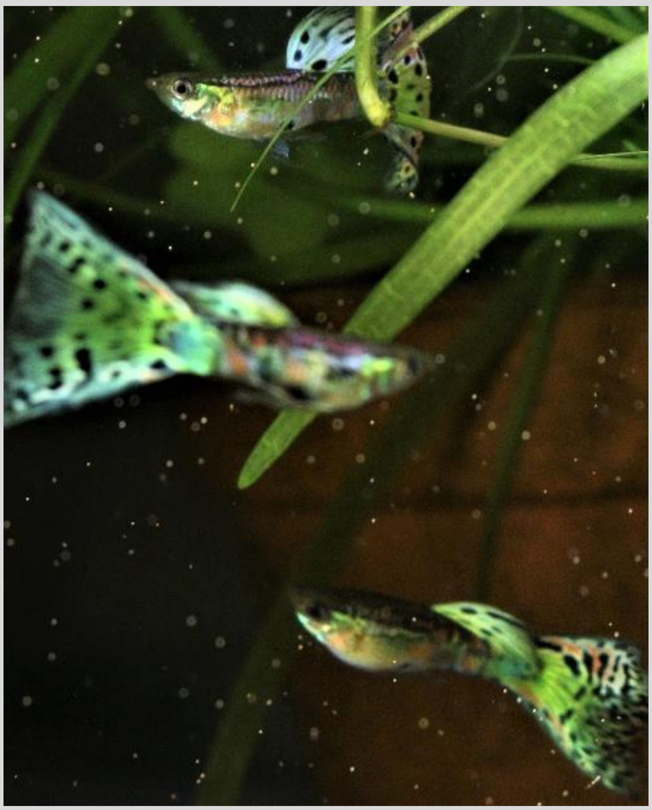

Fig 15 F1 (Ls X BG) Males were not uniform in color and pattern, but in my opinion, they were spectacular.

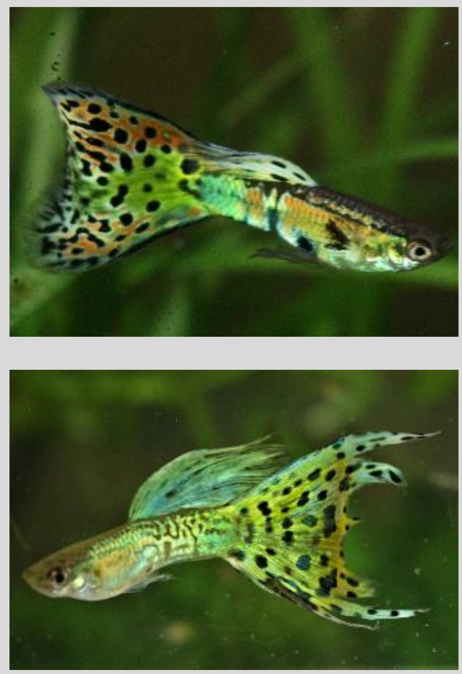

Fig 16 F1 (Ls X BG) that I used for breeding were a reddish male (top photo) and a yellow male (bottom photo). The distinctive green patch at caudal base is from their Ls sire's Emerald Green Iridescent (*EGI*) gene.

[10] My Bias Ls male carried genes for yellow color [Metal Gold (*Mg*), #96]; blue color [Stoerzbach (*me*), #97]; blue color [Asian Blau (*Ab*), #69)]; green color [Vienna Emerald Green (*VEG*), #124]; green color [Emerald Green Iridescent (*EGI*), #78]; and vertical stripes [Zebrinus (*Ze*), #249]. Genes for the Lower swordtail (*Ls*, #145) are on both X and Y chromosomes [4].

[11] An unknown autosomal gene(s) ("Hi-Fin Dorsal, #158) produces big, semi-circular dorsals [4]. This phenotype—often abbreviated as HTD—is one that I rigorously select for in my female guppies (*See* Fig 10).

As with the Japan Blues, I backcrossed select F1 males (Fig 16) to pure BG females to reinforce the delta tail genes and prevent the loss of precious color genes carried on the Ls male's Y chromosome. I mated the reddish F1 (Ls X BG) male to a BG female and saved as many progeny as possible. From 4 batches, she produced 3 beautiful male phenotypes— Blue Grass [**Fig 17**], Red Grass [**Fig 18**], and multi-color "Christmas Guppies" [**Fig 19**].

I did not get any yellow phenotypes from the backcross. I did get yellows, though, by mating a yellow F1 male (Ls X BG) to a female sibling that had yellow-colored fins. From a large batch of F2s, I obtained a yellow snakeskin male [**Fig 20**].[12]

From the backcross, I unexpectedly obtained 6 males with the BG phenotype shown in Fig 17. (It was absent in the F1.) These new BG must have gotten their blue color from some other gene than *Ab*, for they did not produce any Black-tails.

Fig 18 F2 Red Grass

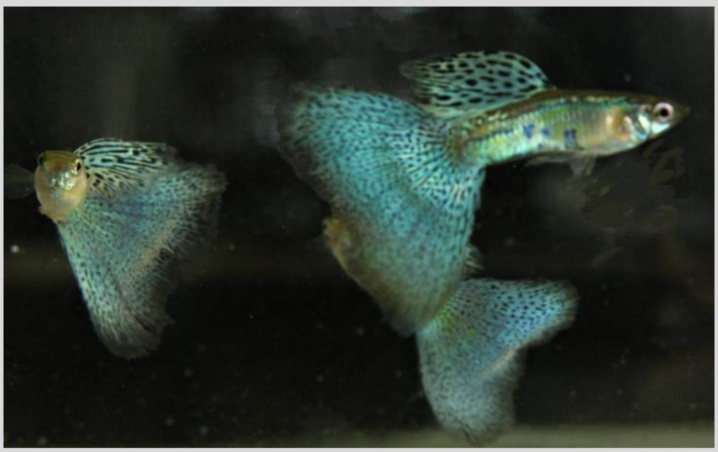

Fig 17 F2 Blue Grass

Fig 19 F2 "Christmas Guppies"
Notice the green color from the *EGl* gene at the base of the caudal.

Fig 20 F2 Yellow Snakeskin Male

[12] His yellow color is due to the presence of the *Mg* gene combined with the *absence* of the *Ab* gene. (If *Ab* had been present, it would have suppressed the yellow color.)

Discussion

This article describes a few pitfalls I encountered in breeding guppies. I quickly learned that a basic understanding of guppy genetics could save time, money, and effort.

When outcrossing, it makes a big difference which strain is used as the sire. For example, because the *Ca* gene for the Japan Blue (JB) color is on the Y-chromosome, I did not waste time breeding a male BG to a female JB. Generally, the male's Y-chromosome carries the color genes, so when in doubt I will use the male for bringing color into the progeny. The opposite situation (e.g., BG guppies carrying the *Ab* blue color gene on the autosomes of both sexes) is less common.

I would caution readers not to judge guppy genetics solely on my limited experience. You may have to work with your guppies for a few generations to understand their genetics.

I used outcrosses with swordtail guppies to introduce more color variety and fitness into my BG strain. In general, swordtail guppies are more fit, live longer, and have more color variety than delta strains. Although I considered crossing guppies with Endlers, I found Endlers too small and skittish for my taste. While guppies and Endlers will interbreed, authorities consider them to be separate species (i.e., *Poecilia reticulata* and *P. wingei*) [7]. Such a wide genetic gap may require many generations of selective breeding to produce desirable offspring.

Although crossing swordtail and BG guppies produced beautiful F1 hybrids, I did not declare victory until the F2 generation. For it is in F2 where one can get the expression of bad recessive genes. Moreover, it is in the F2 where outbreeding depression would become evident [6].

However, outcrossing produced no major problems for me. The F2s were far better than I had expected. I obtained at least four beautiful phenotypes to work with. As I mix and match their descendants, I hope to get even more unique phenotypes. For the guppy (*P. reticulata*) is outstanding—among fishes—in its capacity to produce an infinite variety of colors and patterns.

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