EVERYTHING YOU NEED TO KNOW ABOUT

TILAPIA GENETICS

XELECT
GENETIC SOLUTIONS FOR AQUACULTURE

GENETICS: THE BIG PICTURE

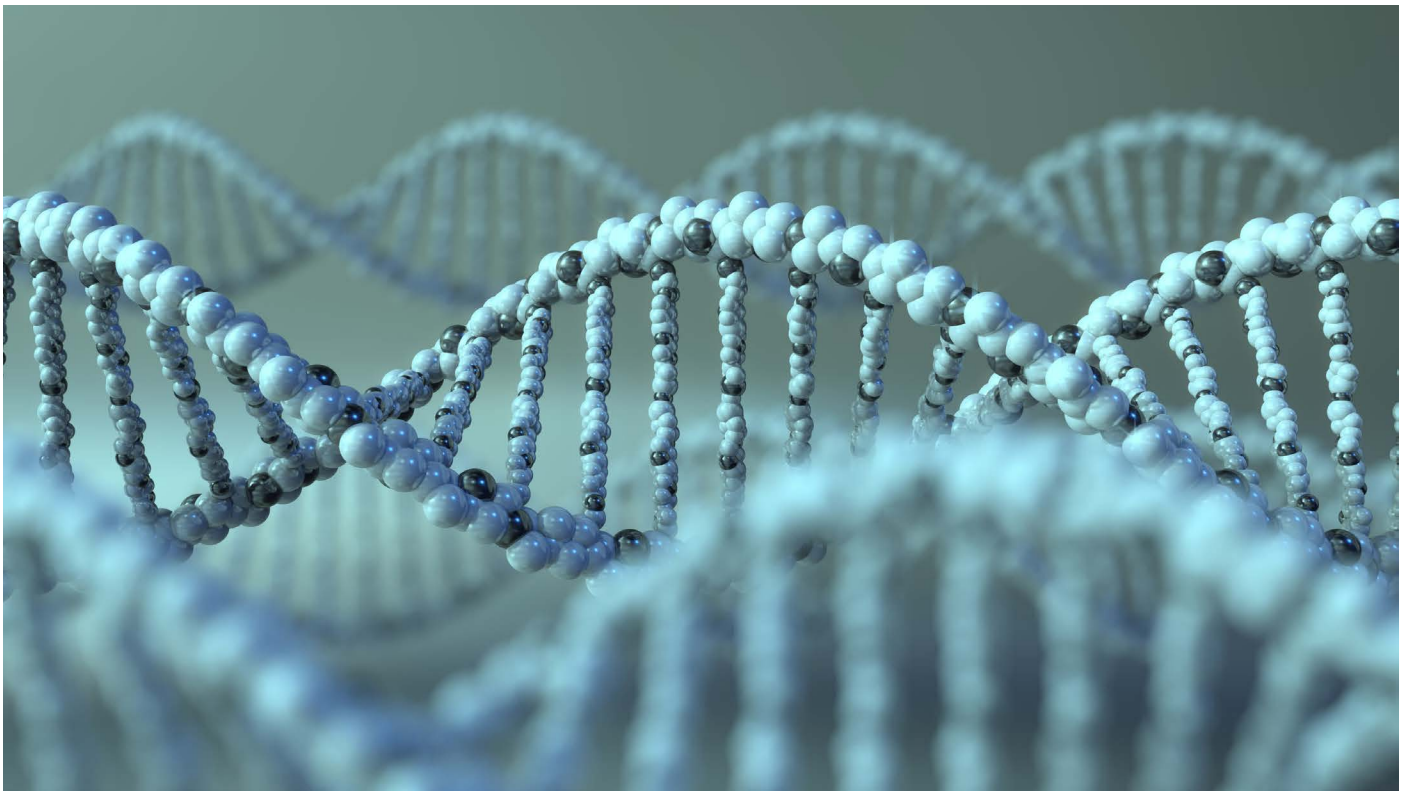
For thousands of years humans have used natural variations in genes to create a step change in the quality of our crops and livestock. For example, a modern farmed chicken now grows 400% faster than it did just 50 years ago.

Aquaculture, however, has been much slower to react. It's time to play catch up. The good news is that our industry is perfectly placed to do just that. In recent years we've seen time and time again that a well-managed breeding programme will give a huge return on investment. It's not uncommon to see increases of well over 10% every generation in key traits such as growth just by careful selection using natural genetic diversity.

We've long believed that the latest technologies should be for the many, not the few. There's a lingering myth in aquaculture that genetics is expensive, and that only the largest producers can benefit. The reality is that – due to breakthroughs in computing power and sequencing methods – even small companies should now be able to access the tools they need.

This guide is intended as a quick overview of how genetics is changing the game for tilapia aquaculture, including:

- **an overview of tilapia genetics**
- **how breeding programmes work in practice**
- **tips on how to get started.**



WHY TILAPIA?

Few species have played as significant a role in the development of aquaculture as tilapia. In fact it is widely believed to be one of the first fish ever cultured, and has been discovered in tomb paintings dating back to Ancient Egypt.

They were originally native to tropical and subtropical regions in Africa and the Middle East but are now farmed in more than 140 countries. You'll find tilapia farms everywhere from Sweden to South Africa, thanks to the advent of RAS farming techniques.

In the last few years global production has increased significantly, hitting 6 million tonnes of production for the first time a couple of years ago. It makes a considerable contribution to global food supply, and in many parts of the world the word "fish" is, effectively, synonymous with "tilapia". However it is actually a common name given to around 110 freshwater and brackish water species and subspecies.

The main taxonomic genus are:

- **Oreochromis** (where the fertilised eggs are incubated in the mother's mouth)
- **Sarotherodon** (where fertilised eggs are incubated in the father's mouth)
- **Tilapia** (who do not incubate eggs in their mouths).

Nile tilapia *(Orechromis niloticus*) is the most dominant farmed species, accounting for more than 70% of total production, but other common species include Blue tilapia (*Oreochromis aureus*) and Mozambique tilapia (*Oreochromis mossambicus*).

There are many reasons why tilapia has emerged as such a popular fish for aquaculture:

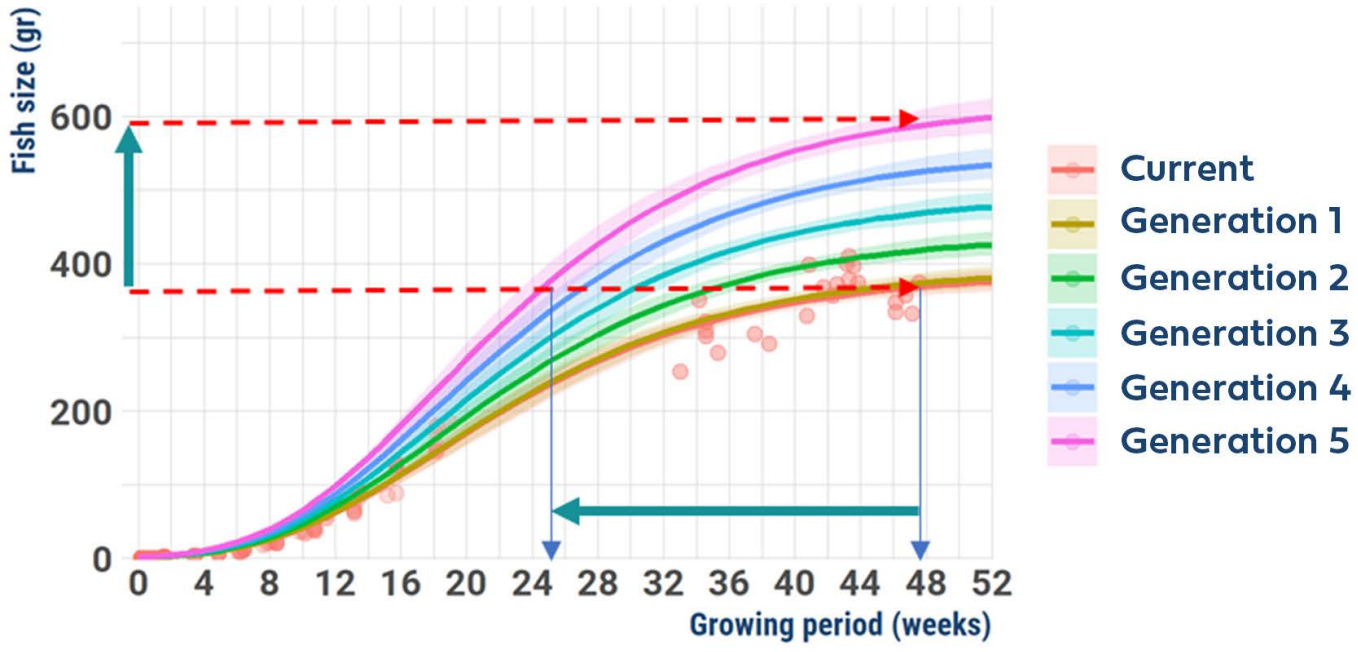
- They can survive and thrive in a **wide range of habitats**, including rivers, lakes, and even irrigation channels. They're also well suited to polyculture, often grown alongside shrimp.
- They are a **very robust** and adaptable fish, with tolerance for a relatively wide range of salinity, and even low oxygen levels.
- They are omnivorous, so can be fed on **lower cost diet**, including algae and plant-based feeds.
- They can **spawn all year round**, providing a continuous supply of product.
- They're relatively resilient to many **diseases.**
- They **grow quickly** to a large size.
- They are **prolific breeders**, allowing high volume production from a relatively small broodstock.

TILAPIA BREEDING

Mass selection - simply selecting fast growing fish based on their appearance - is an extremely risky strategy, because you are highly likely to be selecting closely related animals from a small number of families, which rapidly leads to "inbreeding depression". This loss of genetic variation causes increased deformity, reduced vigor and poor survival. Once that happens there's no way back, without purchasing new broodstock animals from a different source. Careful monitoring of the genetic pedigree can prevent this risk.

The good news is that tilapia are highly responsive to genetic selection. The benefits of selection are cumulative over generations, which means that each generation improves on the last. For example, a local strain of Nile tilapia can typically take around 48 weeks to harvest at 400g in ponds. After five generations of 10% improvement in growth it would only take 26 weeks to reach that same harvest size. That's a remarkable improvement of 5 months to harvest. This would also mean a reduction in production costs, because of the lower risk of losses, quicker turnaround time per crop and lower overhead costs.

COMPARISON OF TILAPIA GROWTH OVER MULTIPLE GENERATIONS



An integrated genetics programme allows you to balance performance with sustainability. The fastest growing animals can be selected but inbreeding rates can also be carefully managed.

Tilapia inbreeding has traditionally been managed using a rotational system where the breeders are kept in separate groups, and the males from one group are crossed with the females from another group. This system can help to manage inbreeding but does little to improve key traits such as growth or disease resistance.

No matter your size or the technical knowledge of your team, Xelect can work with you to develop alternative mating strategies, whether you're working with group mating in hapas or directed mating of specific pairs. A genetics-backed breeding programme helps you get rapid performance gains and protect the sustainability of your broodstock.

MALE VS FEMALE PRODUCTION

Male tilapia grow faster than females, reach a larger marketable size and have better meat yields. These differences can be even more extreme in uncontrolled breeding. Tilapia species reach sexual maturity before they reach harvest size so, without appropriate management, harvest values can be diminished with a wide range of fish sizes. Although it has been observed in pilot studies that harvest yield from mixed-sex tilapia production can be improved by using a prolonged nursing period and periodic removal of small females rearing in freshwater cage systems, male only ('monosex') tilapia production makes the most commercial sense for many farmers. In fact, in a traditional pond culture system, all male tilapia production can give returns well over 100% greater than mixed-sex tilapia.

There are genetic and environmental factors that influence the physical development of tilapia into a male or female. During the development of tilapia farming, those factors have been studied and exploited to produce all male tilapia. To date, there are 3 main known strategies for a monosex male production:

- **Sex-reversal**
- **Hybridisation**
- **YY male technology**

Sex reversal

This technique involves either applying a hormone treatment (using 17-alpha-methyl testosterone) or heat shock at >30°C at an early stage of sexual differential. Hormonal treatment is the preferred method as it gives a more predictable male ratio under farming conditions, with 95-98% male ratio. Heat shock gives lower, very variable rates and is mainly used at low scale and for experimental purposes.

Tilapia whose sex has been altered by hormonal or heat treatment are known as 'neomales' or 'neofemales'.

Hormonal sex reversal treatments for male monosex production are the most accessible and affordable practice to date. However, it also brings significant environmental impacts, additional risks for the farm operators during the preparation and administration of hormonal feeds and can also compromise the immune system of the fish for life.

Use of hormones for sexual reversion can be problematic when exporting to some regions, such as European Commission zones, and the restriction on the use of hormones on animals for human consumption is becoming more strict.

Hybridization

The genetic sex of tilapia is determined in some species by either the male with an XY chromosome sex determination system (e.g. Nile tilapia), or by the female with a WZ system (e.g. Wami tilapia, *Oreochromis urolepis*). Hybridization involves crossing two tilapia species with different sex determination systems such as a female XX Nile or Mozambique tilapia with a male ZZ blue tilapia (*Oreochromis aureus*) or Wami tilapia. The resulting hybrid cross is expected to result in around 90% of the offspring being males, but this might vary depending on the purity of the parental populations. This can be combined with hormonal treatment to bring it over 95% male. Another appeal of this approach is that the characteristics of the hybrid strain can mean additional trait improvements in a tilapia that is already fast-growing. For example they can have increased salinity tolerance or low temperature tolerance.

YY 'Supermale' technology

In this more sophisticated approach all-male tilapia are generated by breeding male tilapia with YY chromosomes (known as YY supermales) with complementary females (usually XX natural females or YY neo-females).

This technology has proved to be very successful for monosex production, due to the superior male rates (almost 100%) without the use of risky hormones in production fish. However, this approach is more costly compared to the conventional hormone treatment, as it does require the management of an additional breeding line alongside the routine breeding programme for a continuous YY supermale production. Whilst more complex, this approach is suitable for more ambitious commercial tilapia programmes specialised in supplying high quality fingerlings to national and international markets.

A female (top) and male (bottom) tilapia

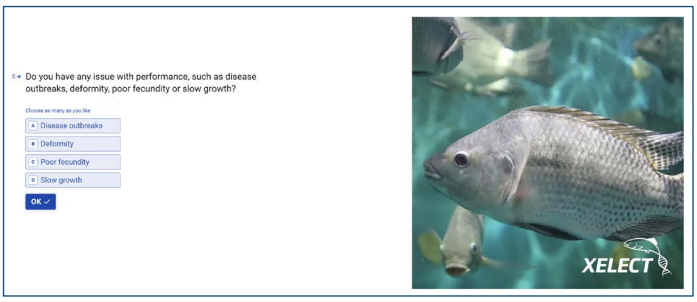
SEX-LINKED GENETIC MARKERS

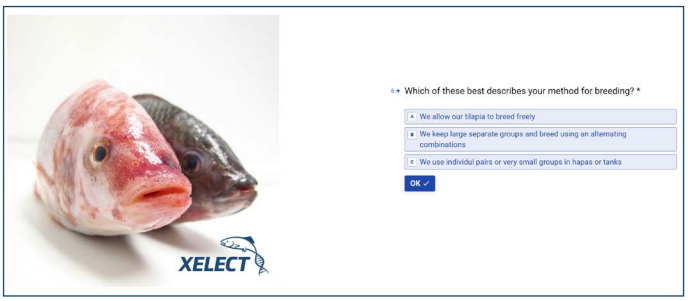
In recent years, as technologies evolve and new tilapia genome resources are published, it has been possible to identify relevant genetic sex-linked markers that allow easier and more effective management and production of YY supermale tilapia.

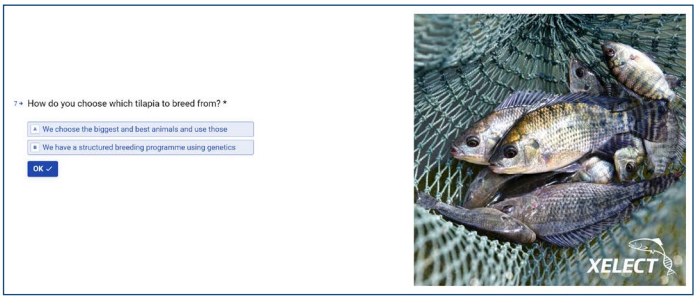
Xelect is now applying a combination of customised genetic and genomic techniques for isolating highly accurate sex-linked markers on particular tilapia populations.

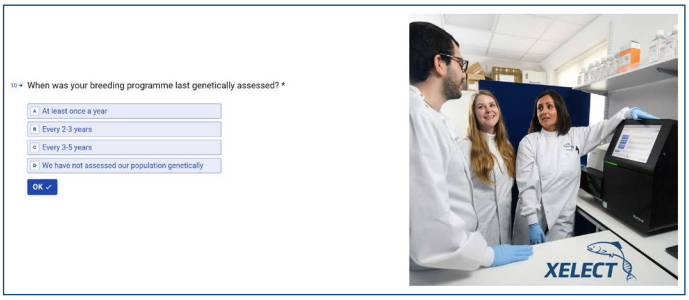
TAKE THE TWO MINUTE TILAPIA GENETICS HEALTH CHECK

Is your tilapia broodstock in good hands? Find out with our free Genetics Health Check. It takes less than 2 minutes to complete, and gives you a general picture of how you're doing, and what to watch out for in the future.









Try it for yourself at:
xelect-genetics.com/tilapia-broodstock

STEP BY STEP: A TYPICAL BREEDING PROGRAMME

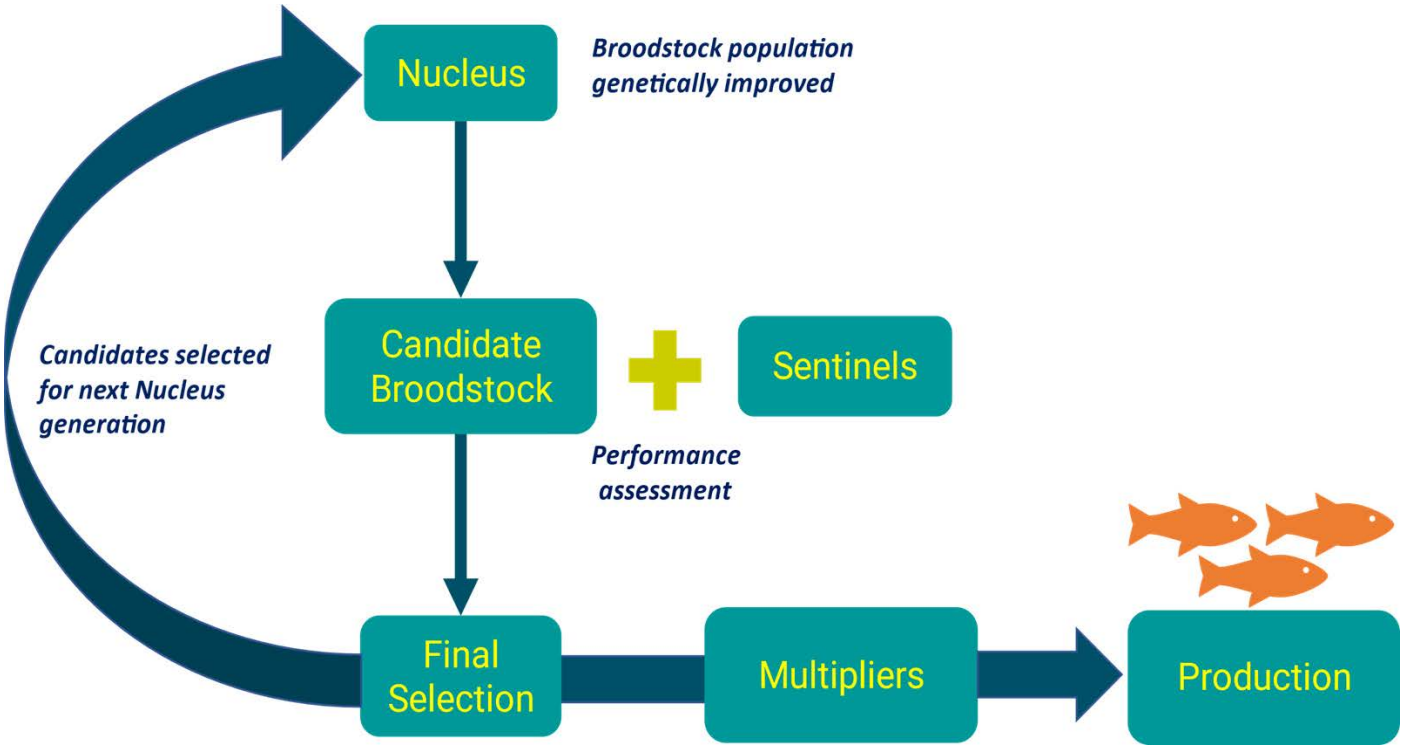
Well first things first – there's actually no such thing as a 'typical' breeding programme at Xelect. Rather than an off-the-shelf solution we prefer to design all of our programmes from scratch, to reflect the priorities and scale of our customers. However there are some general approaches that can provide a framework.

The first thing we do with a customer is to make sure we fully understand the commercial aspects of their production. This allows us to develop programmes that specifically zero in on the traits that will give them the most profitable results.

Typical traits include:

- Growth
- Disease resistance
- Increased feed conversion efficiency
- Appearance (e.g. a particular colour or body shape).

STRUCTURING A GENETIC SELECTION PROGRAMME



The basics of a formal genetic selection programme are shown above. At the heart of any selection programme is a single genetic **Nucleus** - the core of your production. The ultimate goal of the programme is to deliver significant gains in valuable traits in this nucleus (meaning that each generation of fish is a significant improvement on the last) whilst also maintaining a high genetic diversity and low inbreeding. Common target traits for selection include growth, survival, resistance to disease, reduced Feed Conversion Ratio (FCR) and increased fillet yield. We typically use a carefully selected group of the offspring of the **Candidate Broodstock** as an evaluation **Sentinel** group and observe their 'real world' performance in production conditions.

This allows us to calculate the 'estimated breeding value' (EBV) for each fish against the target traits – an assessment of the likely contribution that they would make towards a particular trait in a programme. We then analyse the EBVs across multiple traits using a 'selection index' to get an overall score for each individual. For example, a selection index could have a weighting of 50% for growth, 25% for disease resistance and 25% for fillet yield.

We then use our custom-built genetics software, OptiMate, to run thousands of potential mating combinations to identify which individuals should be returned to the Nucleus to give the optimal balance of performance and genetic diversity - the **Final Selection**. This approach is known as Optimum Contribution Selection. The trade-off between high performance and low inbreeding is critical, we analyse numerous scenarios to identify exactly how many families need to be maintained in the nucleus to carefully balance the two.

We also retain some of the fish from a more limited number of the best performing elite families to become a **Multiplier** broodstock, which can be bred from for breeding **Production** fish. This scales production and boosts genetic gain. Because the resulting fish are never used for breeding, and are sold, crosses can be planned without considering inbreeding control.

PICKING THE SOPHISTICATION THAT'S RIGHT FOR YOU

Whilst the principles of most genetic programmes are the same there are numerous options for producers to select the level of complexity that is appropriate for their scale and priorities.

FAMILY SELECTION

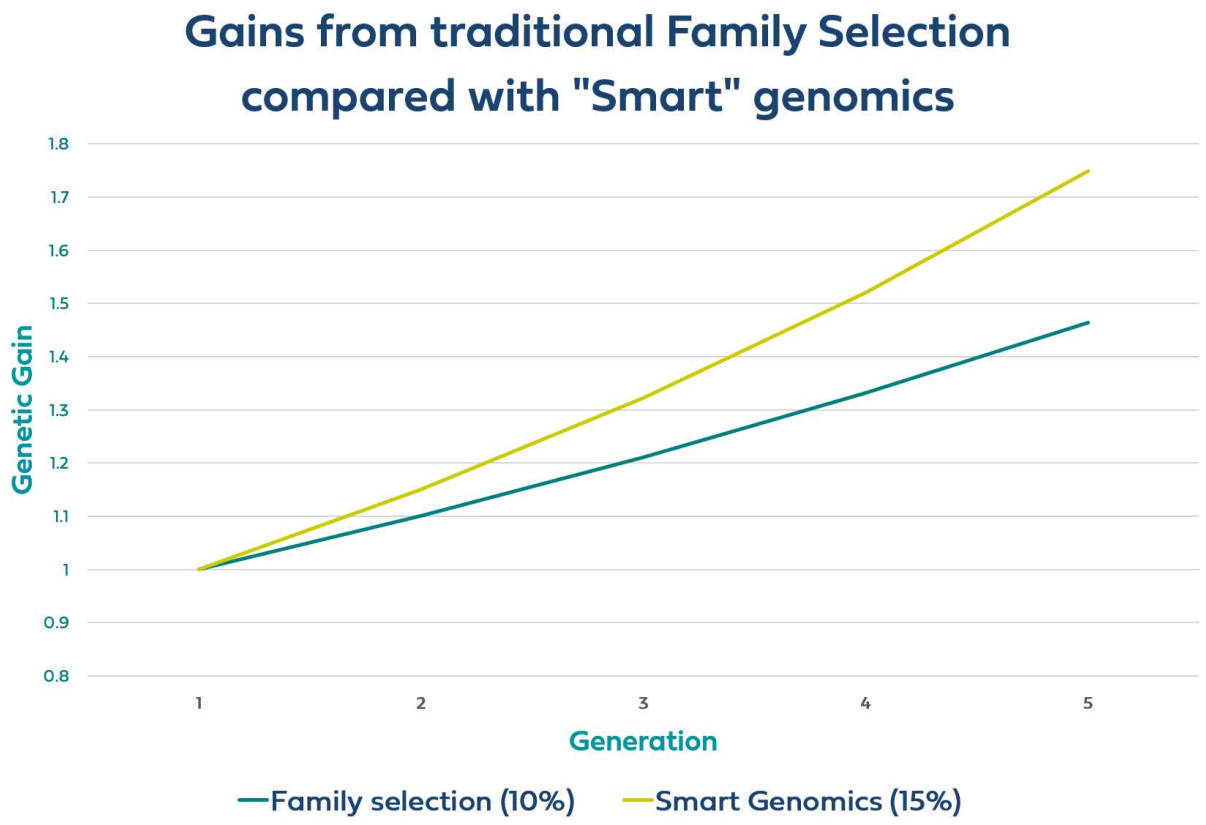
Most breeding programmes operate a pedigree (family) selection programme. By measuring traits across a pedigree (family tree) we can calculate an overall breeding value. The rate of genetic gain depends on how much pressure you put on that trait (for example, is it a primary trait of high importance, or a secondary trait?) and what's known as 'heritability' (how much a trait is based on genetic factors, rather than – for example – the environment). For growth, gains of 10-15% per generation are not uncommon, whilst maintaining low inbreeding.

HIGH DENSITY GENOMIC SELECTION

Genomic selection is a more sophisticated approach, using high numbers of genetic 'markers' located throughout the genome. By genetic analysis of the siblings of selection candidates under production conditions we can develop a genomic prediction model. Genomic selection is particularly useful for deleterial traits which can't be measured on broodstock candidates. By testing selection candidates at these markers, we can predict their breeding value more accurately than with pedigree selection. Genomic selection can be used to select the best individuals from a broad range of families, giving even more genetic diversity to work with. Genomic selection is regarded as the "gold standard" for advanced breeding programmes and can result in up to 20% greater selection accuracy. However, it is typically best suited to larger scale breeding programmes for major producers.

SMART GENOMICS

Xelect has partnered with the world famous Roslin Institute to develop a ground-breaking new approach to bring the benefits of genomic selection to all producers. With this new technique parents are analysed with powerful, high density panels of genetic markers, but future generations can be genotyped at a lower density, using powerful algorithms to predict breeding values. We are one of the first companies to offer this commercially, and whilst we can't share precise figures for existing customers (due to client confidentiality) we are delivering a high proportion of the gains of traditional high density genomic selection for a fraction of the cost.



WANT TO START SIMPLE?
GENEXPERTISE

Even if you're not yet ready for a long-term genetics programme you still need to protect and nurture your broodstock.

GeneXpertise is a quick, simple and affordable way to give your broodstock a boost. We've created a full suite of genetic tools for tilapia, and it's a great way to kick start your production and safeguard your future, for only a modest investment. We'll analyse up to 960 of your broodstock and then provide you with the practical guidance you need, whether it's getting a heads up on the genetic health of your population or providing you with an initial plan of which crosses to make, and which to avoid. The whole service takes just a few weeks from start to finish.

The one-stop genetic health check includes:

- Expert advice and guidance for your team, including a confidential review of your operation
- A detailed report on the genetics and inbreeding levels for your broodstock
- Practical, profitable recommendations
- Access to our experts.

Find out more at **www.xelect-genetics.com**

XELECT'S MISSION

Xelect is trusted by major producers globally to manage their breeding programmes and to provide critical support services. We don't offer off-the-shelf breeding solutions. Our programmes are completely tailored to the needs of each customer, and delivered in-house to make sure results are on time, every time.

We have designed and managed genetic improvement programmes for 16 species, supporting companies across the Americas, Europe, Africa, SE Asia and Oceania. Our scientific team comprises 14 PhDs with extensive work experience in aquaculture, quantitative genetics, molecular biology, physiology and bioinformatics. Xelect has genetic marker IP and best in class proprietary genetics software.

We work closely with our clients to produce faster growth, increased yield, greater disease resistance, premium traits and more sustainable breeding programmes. From our state-of-the-art laboratory in St Andrews, Scotland we can work internationally with all species of fish, shrimp and shellfish.

Whether you're looking for an extensive breeding program to create a premium product, or just looking for some advice and guidance Xelect can help.

www.xelect-genetics.com

info@xelect.co.uk

www.xelect-genetics.com
info@xelect.co.uk

Horizon House, Abbey Walk
St Andrews, Scotland
UK, KY16 9LB

XELECT
GENETIC SOLUTIONS FOR AQUACULTURE