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# Recent Advances in Mariculture Genetics and Biotechnology

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Course Manual

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**INDIAN COUNCIL OF AGRICULTURAL RESEARCH**
**CENTRAL MARINE FISHERIES RESEARCH INSTITUTE**
P.B. No. 1603, Tatapuram P.O.,
Kochi – 682 014

# QUANTITATIVE GENETIC TOOLS FOR BROOD STOCK IMPROVEMENT

***P.C.Thomas and U. Rajkumar***

*Central Marine Fisheries Research institute, Cochin*

## Introduction

Success in aquaculture and fisheries management depends on viable concept, sound management and animals with high genetic potential. In farm animals and plants application of genetic principles and genetic tools lead to increased production in accordance with the demands of the nation. Breeding programmes like selective breeding and cross breeding played an important role in increased productivity, domestication and survival rate. Genetics in fisheries is relatively new. Of late genetics has acquired an important place in fisheries with the following objectives.

1. Production of high yielding strains of fish and shellfish.
2. Development of disease resistant strains.
3. Conservation and management of natural resources.

Gregor John Mendel, father of genetics postulated laws of inheritance in 1865 by conducting his experiments on pea plants. He was successful because he ensured that the plant bred true for a particular trait and selected simple, easily recognizable and highly heritable characters. He suggested that corresponding pairs of factors in the parents control the pairs of alternative characters. The offspring was supposed to have one of each factors contributed by each parent. Subsequently, those factors were called as genes by Batsen and their physical nature and chemical properties are established. The theory of inheritance provided the mathematical basis for predicting results of mating and testing the laws in animals and plants. Quantitative/ Population genetics is the logical development for the basic principles of inheritance. Quantitative genetics is the theoretical basis for all the breeding programmes in animals and plants. Continuous variation characterizes the most of the economic traits. These traits are called quantitative traits, which are controlled by many genes called minor genes. In contrast qualitative traits show discrete variation and controlled by few genes called major genes.

**Tools available to the breeder for improvement**

**Variation**

Variation among the population is the basic and most important pre- requisite for any genetic improvement programme. With out variation there is no improvement. Variation is defined as the mean of the squared deviations from the population mean. Variation is expressed in terms of Variance ($\sigma^2$).

In order to study the genetic properties of the population we have to partition the phenotypic variation in to component parts attributable to different causes. The phenotypic variation can be divided in to components attributable to the influence of genotype and environment. The genotype is the particular assemblage of genes possessed by the individual and the environment is the non-genetic effects. The two components associated with the genotype and environment is the genotypic variance and environmental variance.

$$V_P = V_G + V_E + V_{G\text{-}E}$$

Where,

$V_G$ = Genotypic variance

$V_E$ = Environmental variance

$V_{G\text{-}E}$ = Genotype and environmental interaction

The partition of the variance in to its components formulates the question of importance of individual portion in determining its phenotype. The relative importance of cause of variation means the amount of variation it contributes to the total variation. So the relative importance genotype as the determinant of phenotype is the ratio of genotypic variance to phenotypic variance ($V_G / V_P$). This is termed as the heritability ($h^2$).

Genotypic variance can be further divided in to additive genetic variance (breeding value) and non-additive genetic variance (Dominance and interaction deviations).

$$V_G = V_A + V_D + V_I$$

Where,

$V_A$ = Additive genetic variance

$V_D$ = Dominance deviations

$V_I$ = Epistatic interactions

**Additive genetic variance**: It is the sum of the effects of all the alleles that help to produce a phenotype. It is the variance of the breeding values. It is the important component because it is the chief cause of resemblances between the relatives. It defines the genetic properties and characters of the population. This portion of the variance is transmitted to the offsprings from the parents.

**Non-additive genetic variance**: These variations are due to the dominance and epistatic effects of the alleles, viz.,

**Dominance deviations**: This is due to the dominance effects of the alleles at the loci. $V_D$ is not transmitted to the next generation from the parents since the alleles are disrupted during the meiosis.

**Interaction (Epistasis) variation**: It occurs due to the interaction of the alleles between two or more genes. These interactions may be two factor or three factor or so on. The amount of variation due to interaction is rather small; some times the breeder can omit it also.

**Environmental variance**: It is the variance due to all non-genetic effects starting from feeding to environmental conditions. Environmental variance cannot be eliminated in a population. It plays a major role in determining the phenotypic variance of the population.

**Genotype and environmental interaction**: Apart from the above two components of variation there is interaction between the two components. That is a genotypic effect of the population is different in two different environments. A single genotype may perform differently in two different environments. This genotype may show good performance in one Environment but may be poor in second. Other one is the performance of the populations may be reduced or increased in degree of magnitude in different environments.

**Heritability ($h^2$)**

The heritability of the metric character is one of the most important properties of the economic traits. It expresses the proportion of the total variance attributable to genetic causes, which determines the degree of resemblance between relatives. But the important function of heritability in quantitative genetics/Animal or plant breeding is its predictive role in expressing the reliability of the phenotypic value as a guide to the breeding value.

The heritability is defined as the ratio of genetic variance to phenotypic variance in a broader sense.

$$\text{Heritability } (h^2) = \frac{\text{Genotypic Variance}}{\text{Phenotypic Variance}}$$

$$h^2 = V_G / V_P$$

It can be defined as the ratio of additive genetic variance to the phenotypic variance in narrow sense.

$$\text{Heritability } (h^2) = \frac{\text{Additive genetic Variance}}{\text{Phenotypic Variance}}$$

$$h^2 = V_A / V_P$$

Regression of breeding values on phenotypic value is the heritability,

$$h^2 = b_{AP}$$

Estimation of heritability

| **Method of estimation** | **Covariance** | **Regression/ Correlation** | **$h^2$** |
|---|---|---|---|
| Half sib mating | $1/4\ V_A$ | $t = 1/4\ h^2$ | 4t |
| Full sib mating | $1/2\ V_A + 1/4\ V_D + V_{EC}$ | $t = 1/2\ h^2$ | 2t |
| Offspring one parent regression | $1/2\ V_A$ | $b = 1/2\ h^2$ | 2b |
| Offspring mid parent regression | $1/2\ V_A$ | $b = h^2$ | b |

Heritability ranges from 0-1 or expressed in percentage. $h^2$, plays an important role in selection programmes for genetic improvement. It is the property of the population not of an individual for particular trait under selection. Thus it is valid for only given population in a given environment. It is useful in predicting the impact of selective breeding.

**Genetic correlations:** Economic traits are correlated; means selection for one trait may lead to increase or decrease in the other traits. These are called correlated responses and the traits are called correlated traits. This is expressed in terms of correlation co-efficient (r), which ranges from -1 to +1. Correlated response may be positive or negative. r, is due to the pleotrophic effect of the alleles. This plays an important role in trait selection for improvement.

Selective Breeding for fish stock improvement

Breeding is the practical aspect of the genetics, clear and thorough understanding of the genetic rationale and genetic principles will avoid the in advent mistakes during the breeding. So before planning a breeding programme breeder should have clear understanding of its pedigree records, genetic parameters like heritability, correlations and of course reproductive biology and behavior of the species.

Selective breeding means careful selection of superior performing individuals in a population as parents for the next generation. This is based on the Robert Backwell theory of "like begets like". Two elite/best performing individuals are selected and bred to produce the best performing progeny. In animals and plants this lead to production of pure strains and also to improve the production. Selective breeding of fishes started in recent years only. This has been useful approach for genetic improvement of cultured fish populations. However the breeder should well aware of the associated problems of selective breeding programme, viz.,

1. Inbreeding depression
2. It is time consuming and expensive
3. Selection of the superior animals is very cumbersome and difficult.

The selective breeding involves the following steps.

## Selection of species

Selection of the species is very important aspect of selective breeding programme. While selecting a species the breeder should consider two things, the first is it should have well established breeding and seed production technology and the second is its economic importance.

E.g.: Catla –is a good species for selective breeding

## Selection of trait

The trait or traits under selection should be economically important, highly heritable, positively correlated and it should be easily measurable. Some economically important traits in fishes are growth rate, body size & shape, meat quality and disease resistant.

## Methods of selection

Selection of the parents for next generation is based on its additive genetic variance or breeding value. The genetic potential of an individual is judged by the phenotypic performance of the individual in several ways.

### Individual selection

The individuals are selected based on their own performance, on their phenotypic value. This selection method is very effective when the $h^2$ of the trait is high. It is usually simple to operate and it yields the rapid response. Mass selection is the term used for individual selection when selected animals are kept together *en mass* for mating.

### Family selection

Families are selected or rejected as a unit according to the mean phenotypic value of the family. In this within the family variations are not considered. The accuracy of the family selection depends on the heritability of the trait, family size, family type and the variation due to the environment. This is more useful when selection is practiced for less heritable traits like reproductive traits, carcass quality and disease resistant.

**Pedigree selection**

In this method individuals are selected based on the performance of their parents or grand parents. Pedigree records of the ancestors considered for selection of parents.

**With in family selection**

In this method family is considered as a sub population and individuals are selected based on the performance in relation to the mean performance. Better performing individuals from the family are retained and the others are culled. This method is more efficient than individual and family selection. Selection within families would eliminate the non-genetic variation.

**Progeny testing**

Parents are selected based on the performance of the progeny. This method is reliable and best in farm animals; in fishes it is not suitable when we are using cryopreserved gametes during the selective breeding programme.

**Tandem selection**

In this method of selection one trait is considered at one time. The selection is aimed at improving one trait at a time for generations till the goal is reached than other trait is selected and it continued for all the traits. It is simple but time consuming, it is inefficient because it takes long time and there is a chance of negative correlation, which decreases the mean performance.

Millenbach (1950), Selection for age at maturation at 2 years instead of 3 and 4 in rainbow trout lead to poor growth rate and less egg production. Ehlinger (1977) brook trout selected for increased resistance to furunculosis had become more susceptible to gill disease.

**Independent culling levels**

Independent culling level is a selection programme employed when two or more traits are considered for selection simultaneously. In this the breeder has to fix the minimum performance level for each trait, and the fish must perform above the minimum level. The disadvantage of this method is a fish should be outstanding in all the traits under selection.

A fish with best performance in one trait and average performance in the other is liable for rejection. One more disadvantage is when selection is practiced for more traits at a time you may end up with few individuals, which satisfy the minimal performance levels of all the traits.

### Selection index

Index selection is the best and most efficient method of selection progrmme. In this method all the traits considered for selection are given due weightage according to their performance and a selection index is formulated based on the linear regression. In this all traits are given importance.

$$I = b_1X_2 + b_2X_2 + \ldots\ldots\ldots\ldots + b_nX_n$$

Where,

| | |
|---|---|
| I | Selection index |
| b | regression coefficient |
| X | Phenotypic value of the traits |

### Breeding plan

Selective breeding programme intends to exploit the existing natural population, so there should be vide genetic base in the base population. For this different stocks/animals of the species are selected from different areas/geographical regions and make sure about the presence wide range of germplasm. Before introducing the animals in to the breeding they should be evaluated and studied thoroughly with regard to genetic variation, heritability and genetic correlations. These parameters will help the breeder to visualize the success of the breeding programme.

Selective breeding is a type of inbreeding/pure breeding in which superior individuals from the population are selected and bred to produce the next generation. Continuous selection eliminates the deleterious recessive alleles present in the population. It makes the population complete homozygous. This breeding method is very much useful in evolution of different strains and lines.

### Crossbreeding

During the selective breeding breeding there is always chance of inbreeding depression, which a breeder should concern about. To overcome this crossbreeding between the strains or inbred lines is employed. Out crossing is very useful method in selective breeding where in unrelated individuals of same species are bred to minimize the effect of inbreeding depression. Crossing of two inbred lines increases the performance because of heterosis. Heterosis is the observed superiority of the parents from the population mean.

### Hybridization

It is the interspecific crossing of the fish. Hybridization is the rapid method of bringing about genetic modification.

### Evaluation of the response for selective breeding

The genetic gain from the selective breeding programme can be evaluated by calculating the following.

i. Heritability
ii. Selection differential
iii. Generation interval

**Heritability ($h^2$):** It is the important factor that determines the genetic progress after selection. $h^2$ varies from population to population and environment to environment. Thus the $h^2$ estimated under experimental conditions may not be same under practical conditions.

**Selection differential (S):** The difference between the mean phenotypic value of the population and mean phenotypic value of the selected individuals is called selection differential. The selection differential is more if there is more variation among the population because only superior animals were selected for next generation. So the selection intensity is high. Selection intensity can be calculated

SI = Selection differential/Standard deviation of the phenotype

**Response to selection (R):** It is the difference of mean phenotypic value between the offsprings of the selected parents and whole of parental generation before selection. It is average superiority of the selected parents.

$R = h^2 S$

**Generation interval:** It is defined as the age of the parents when their offsprings are born. It is the interval between the two generations. It varies between the species.

Examples: Salmon and Catla - 2-3 years
Zebra fish - 3 months

The expected response for generation is the product of the selection differential and heritability per generation.

Genetic gain per year(R) = $h^2$ S/GI

$$= \frac{h^2 \times Si \times sd}{GI}$$

During the evaluation of the selection response, the breeder should take a note whether it has any parallel effect on the traits other than the one selected in the breeding programme. The positive or negative correlation of other traits is called *correlated response*. For example, increased fecundity, fry survival and disease resistance were the correlated responses to selection for increased body weight in Channel catfish. On the other hand, selection of body weight did not affect the spawning, hatchability of eggs, fry survival and seinability, so they are negatively correlated (Smitherman and Dunham, 1985).

**Impacts of selective breeding programme on aquaculture productivity.**

Selective breeding has been found to be a very useful approach for improving the qualitative traits like the attractive colouration pattern in the ornamental fishes and the commercially important quantitative traits in food fishes. This has helped to improve the aquaculture productivity of Atlantic salmon in Norway, Channel catfish in USA and Tilapia (*O. niloticus*) in Philippines. The body weight of *O. niloticus* and Channel catfish increased by about 15% by mass selection. (Bondrai *et al.,* 1983; Smitherman and Dunham, 1985). Six generations of selection has increased the body weight by 30% in Rainbow trout. In Coho salmon, 50% increase in growth rate was observed after 10 generations of selection (Hershberger *et al.,* 1990). Selective breeding of *Labeo rohita* for improving the growth rate is being carried out at Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, India. Faster growing seeds have been distributed on a limited scale for culture. Selection has also helped to improve disease resistance ability in some fishes like resistance to bacterial disease dropsy in Common carp (Kirpichinikov *et al.,* 1993). Newkirk and Haley (1983) conducted selective breeding experiments for increased growth rate in European oyster, *Ostrea edulis* and found that the offsprings of selected group were heavier than the controls and the rate of survivability was higher. Mallet and Haley (1983) studied the inbreeding effect on larval and spat performance in the American oyster, *Crassostrea virginica* and reported that there was an increased survival rate in inbred families but there was decrease in shell surface area.

Oyster breeding programs to select for fast growth in Sydney rock oysters in NSW and Pacific oyster in Tasmania have been successful in increasing the growth rate (Nell et al., 1999). Mortality rate from QX disease was reduced in progeny of a second generation disease resistant line as compound with controls (Nell and Hand, in press). Triploids in pacific oyster have been successful in commercial level in North America, Europe and Australia. (Nell, 2002)

However, the selection for the higher growth rate was either unsuccessful or had some negative effects in certain cases. Five generations of selection for increasing the growth rate in Common carp in Israel had led to decrease in the body size (Moav and Wolhforth, 1976). Similar effect was also observed in case of *O. niloticus*.

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