Quantitative inheritance: a) Polygene inheritance- Concept, examples- Kernel colour in wheat, b) Population genetics- Hardy-Weinberg's law.

Introduction

Quantitative genetics (Inheritance of Multiple Genes)

The phenotypic traits of the different organisms may be of two kinds, viz., qualitative and quantitative. The qualitative traits are the classical Mendelian traits of kinds such as form (e.g., round or wrinkle seeds of pea); structure (e.g., horned or hornless condition in cattles); pigments (e.g., black or white coat of guinea pigs); and antigens and antibodies (e.g., blood group types of man) and so on. We have already discussed in previous chapters that each qualitative trait may be under genetic control of two or many alleles of a single gene with little or no environmental modifications to obscure the gene effects. The organisms possessing qualitative traits have distinct (separate) phenotypic classes and are said to exhibit discontinuous variations

The quantitative traits, however, are economically important measurable phenotypic traits of degree such as height, weight, skin pigmentation, susceptibility to pathological diseases or intelligence in man; amount of flowers, fruits, seeds, milk, meat or egg produced by plants or animals, etc. The quantitative traits are also called metric traits. They do not show clear cut differences between individuals and forms a spectrum of phenotypes which blend imperceptively from one type to another to cause continuous variations. In contrast to qualitative traits, the quantitative traits may be modified variously by the environmental conditions and are usually governed by many factors or genes (perhaps 10 or I00 or more), each contributing such a small amount of phenotype that their individual effects cannot be detected by Mendelian methods but by only statistical methods.

Such genes which are non-allelic and effect the phenotype of a single quantitative trait, are called polygenes or cumulative genes. The inheritance of poly genes or quantitative traits is called quantitative inheritance, multiple factor inheritance, multiple gene inheritance or polygenic inheritance. The genetical studies of qualitative traits are called qualitative genetics.

Polygenic Inheritance Definition

Polygenic inheritance is defined as **quantitative inheritance**, where multiple independent genes have an additive or similar effect on a single quantitative trait. Polygenic inheritance is also known as **multiple gene inheritance** or multiple factor inheritance.

Characteristics of Polygene-

- **Polygene** refers to a gene that exerts a slight effect on a phenotype along with other genes
- Effect of a single gene is too small, so it is difficult to detect
- Multiple genes produce an equal effect

- Each allele has a cumulative or additive effect
- Polygenic inheritance differs from multiple alleles, as in multiple alleles, three or more alleles are present in the same locus of which any two alleles are present in an organism, e.g. ABO blood group system, which is controlled by three alleles
- There is no epistasis involved, i.e. masking of the expression of an allele of the different locus
- There is no linkage or dominance, rather there exist contributing and non-contributing alleles, which are known as active or null alleles respectively
- Polygenic inheritance is characterised by the **continuous variation** of the phenotype of a trait
- The polygenic inheritance pattern is complex. It is difficult to predict phenotype
- The statistical analysis can give the estimate of population parameters

Qualitative genetics	**Quantitative genetics**
It deals with the inheritance of traits of kind, viz., form, structure, colour, etc.	It deals with the inheritance of traits of degree, viz., heights of length, weight, number, etc.
Discrete phenotypic classes occur which display discontinuous variations	A spectrum of phenotypic classes occur which contain continuous variations.
Each qualitative trait is governed by two or many alleles of a single gene.	Each quantitative trait is governed by many non-allelic genes or polygenes.
The phenotypic expression of a gene is not influenced by environment.	Environmental conditions effect the phenotypic expression of polygenes variously.
It concerns with individual matings and their progeny.	It concerns with a population of organisms consisting of all possible kinds of matings.
In it analysis is made by counts and ratios.	In it analysis is made by statistical

Qualitative traits are governed by the **Mendel's Laws of inheritance**. These are clear cut traits, resulting in two extremes such as the flower colour (**purple** or **white**), seed-shape

(**round** or **wrinkled**) and the seed colour (**yellow** or **green**). There is no intermediate phenotype. Variation in qualitative trait is called **discontinuous variation**.

However, Some other important characters in cultivated plants and domestic animals, such as the yield of seeds and fruits as well as the eggs, amount of milk or meat produced by animals, etc., do not fall into two clear-cut classes and all **gradations** appear between the two extremes), for example, between **black** and **white** skin-colour of humans, between **red** and **white** colour of wheat grain, etc.). These characters are called as **quantitative characters**. Variation in quantitative trait is called **continuous variation**.

Such **quantitative characters** show a **continuous variation**. Mendel's method of analysis is hard to apply in such continuously varying characters because they seem to **mix** or **blend** with each other instead of getting segregated in the offspring of hybrids

The problem of the inheritance of quantitative character was taken up by the Swedish botanist. **H. Nilsson-Ehle** (1908) and American scientist **E.N. East** (1910, 1916). These investigators showed that this apparent '**blending inheritance**' can be explained by supposing that continuously varying characters are due to the **combined** or **cumulative** action of several genes, each of which exerts a small effect on the same character. Such genes are called the **cumulative genes** or **additive genes** or **polygenes**.

A **cumulative gene** is one, which if added to another identical or similar gene, affects the **intensity** or **degree** of expression of a quantitative character. In other words, a quantitative character is simultaneously governed by several genes (= **polygenes**), and the effect or action of such genes is cumulative or additive in nature.

This is also known as the **multiple-factor hypothesis**. **Gene-pairs**, which act in a cumulative way to result into a **quantitative trait**, are known as **multiple-factors**. Since **quantitative inheritance** is controlled by many genes, it is also known as **polygenic inheritance**.

Few examples of polygenic inheritance in both plants and animals are listed below:

1. Grain color in wheat

2. Ear length in maize

3. Ray size in flower heads of *Compositae*

4. Seed colour in wheat

5. Corolla length in tobacco (*Nicotiana longiflora*)

6. Skin color in human beings

7. Height of man

Kernel (seed) colour in wheat

The Swedish botanist, **H. Nilsson-Ehle** (1908) first studied the **inheritance pattern** of the colour of the grain in wheat. He crossed two varieties of wheat, with **red** and **white** grain colour. He found that all the **F1** offspring were intermediate between red and white (with **light-red** colour), demonstrating as if **red** seed-colour was **incompletely dominant** over **white** seed-colour.

When the **F1** hybrid-plants were self fertilized, the F2 progeny showed a ratio of **15 red** to **1 white**. The red progeny, however, carried various shades between the red and white (such as **dark-red**, **medium-red**, **light-red** and **pink**). The ratio **15:1** clarifies that this was a dihybrid cross, in which two **identical genes** were involved for producing the red colour.

In this example, two pairs of **segregating genes** are responsible for the color variation in the wheat kernel. The red kernel wheat carries two pairs of dominant genes (two pairs of alleles: **R1R1R2R2**) both of which contribute some quantity of redness to the grain. These genes are duplicates of each other. The white kernel wheat had **recessive alleles** of both these pairs (**r1r1r2r2**) and does not contribute anything to red coloration.

The **F1** hybrid possesses two dominant genes (**R1r1R2r2**); hence, it is intermediate between **red** and **white**. In the F2 generation, the colour varies depending on the number 4

of **dominant genes** that the offspring gets from the hybrid-parents, i.e. 4, 3, 2, 1 or zero

Parents : Red Wheat $R_1R_1R_2R_2$ × White Wheat $r_1r_1r_2r_2$

Gametes R_1R_2 ↓ r_1r_2

F_1 Medium $R_1r_1R_2r_2$

Gametes R_1R_2 R_1r_2 r_1R_2 r_1r_2

Male gametes

F_2 / Female Gametes	R_1R_2	R_1r_2	r_1R_2	r_1r_2
R_1R_2	$R_1R_1R_2R_2$ Red	$R_1R_1R_2r_2$ Dark	$R_1r_1R_2R_2$ Dark	$R_1r_1R_2r_2$ Medium
R_1r_2	$R_1R_1R_2r_2$ Dark	$R_1R_1r_2r_2$ Medium	$R_1r_1R_2r_2$ Medium	$R_1r_1r_2r_2$ Light
r_1R_2	$R_1r_1R_2R_2$ Dark	$R_1r_1R_2r_2$ Medium	$r_1r_1R_2R_2$ Medium	$r_1r_1R_2r_2$ Light
r_1r_2	$R_1r_1R_2r_2$ Medium	$R_1r_1r_2r_2$ Light	$r_1r_1R_2r_2$ Light	$r_1r_1r_2r_2$ White

Summary of F_2 : 1/16 Red, 4/16 Dark, 6/16 Medium, 4/16 Light, 1/16 White.

Various **phenotypes** (and genotypes) have been shown in the above checker board (*Punnett square*). Of the possible 16 types, the following will be the phenotypes according to the number of **dominant genes** possessed by them. See the Table given below

S. No.	**Phenotypic ratio**	**Genotype and Number of dominant genes**	**Phenotypes**
1	**1/16**	**R**1**R**1**R**2**R**2 – 4 dominant	completely like the **red** grandparent
2	**4**/16	(**R**1**R**1**R**2**r**2), (**R**1**r**1**R**2**R**2) - 3 dominant	**Dark-red**
3	**6**/16	(**R**1**R**1**r**2**r**2),(**R**1**r**1**R**2**r**2),(**R**1**r**1**R**2**r**2),(**r**1**r**1**R**2**R**2),(**R**1**r**1**R**2**r**2) - 2 dominant	**Medium-red**
4	**4**/16	(**R**1**r**1**r**2**r**2), (**r**1**r**1**R**2**r**2) – 1 dominant	**Light-red**
5	**1**/16	(**r**1**r**1**r**2**r**2) – no dominant	completely like the **white** grandparent

Phenotypic ratio =1:4:6:4:1

Salient features of quantitative/polygenic inheritance

1. Quantitative traits are governed by multiple genes or polygenes.

2. Expression of polygenes results in continuous variation in phenotype of the individual

3. There is a marked effect of the environment on the expression of polygenes

4. Polygenes can be subjected to statistical analysis in order to assess their number regarding a particular trait.

5. Each gene produces a unit-effect or individual effect; hence, the effects of genes are additive or cumulative.

6. Dominance is absent or partial. **F1** hybrid shows blending in characters or in other words the **F1** hybrid is intermediate.

7. Segregation of genes occurs at many loci and not at a single locus of homologous chromosomes.

8. Polygenes are independently assorted in **F2** generation according to Mendelian inheritance, but the phenotype is in continuous range between the extreme limits of the parental phenotype.

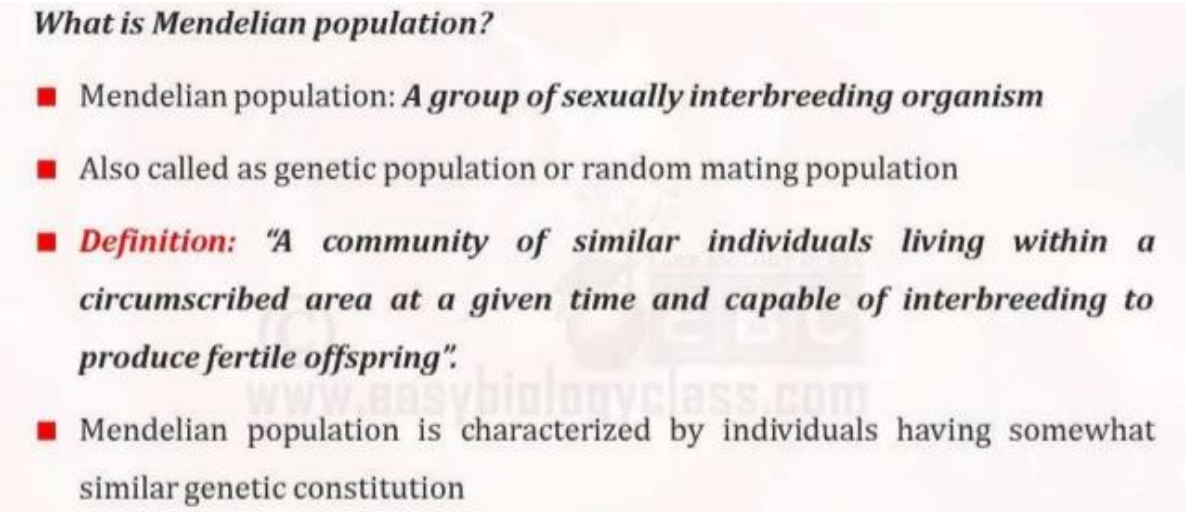
9. The phenotypic proportion of **F2** progeny is modified according to the number and nature of the genes.

10. Polygenes have pleotrophic effect, i.e. they may influence more than one trait

Population genetics- Hardy-Weinberg's law.

An ecosystem consists of many species. Species is a group of living organism comprising of similar individuals capable of exchanging genes through interbreeding. The individuals of a same species of a particular region are called population.

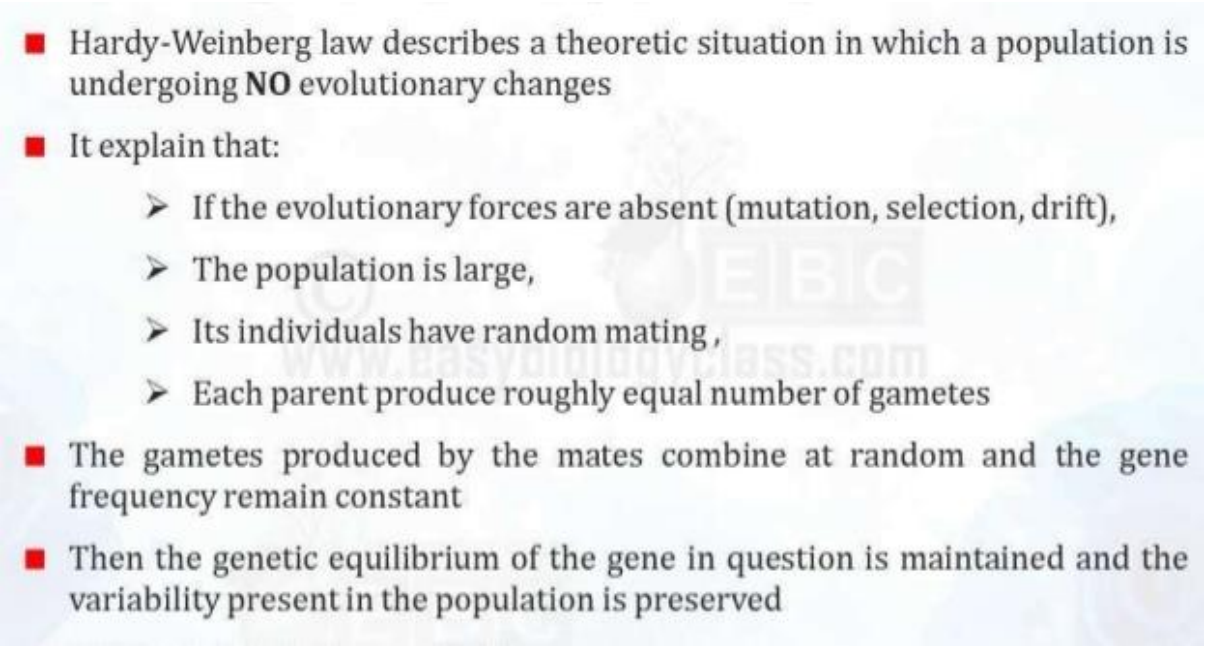
Definition – A group of individuals of a particular species occupying a definite space, in which the individuals interact, interbreed and exchange genetic materials.



In 1908, the mathematician G. H. Hardy in England and the physician W. Weinberg in Germany independently developed a quantitative theory for defining the genetic structure of populations. The Hardy-Weinberg Law provides a basic algebraic formula for describing the expected frequencies of various genotypes in a population.

The **Hardy-Weinberg's law** states that "the relative frequencies of genes in a large panmatic population after random mating remain constant from generation to generation if there is absence of evolutionary processes like migration, mutation, selection and genetic drift".

The Hardy–Weinberg principle, also known as the Hardy–Weinberg equilibrium, model, theorem, or law explains that allele and genotype frequencies in a population will remain constant from generation to generation in the absence of other evolutionary influences.



It states that **both gene frequencies and genotype frequencies will remain constant from generation to generation in an infinitely large interbreeding population in which mating is at random and no selection, migration or mutation occurs**.

Conditions of the Hardy-Weinberg population are:

- The population must be large.
- Mating must be random, with no selection for certain genotypes.
- There must be no emigration or immigration.
- There may be no mutations.
- There may be no incestuous mating

The Hardy-Weinberg Principle

- The Hardy-Weinberg principle predicts that the distributions of genotype frequencies will remain constant from generation to generation in a population that is not subject to evolutionary forced. That is, the frequency of alleles are in **equilibrium**. The equation is:
- **$p2 + 2pq + q2 = 1$**
- Where p and q are two **alleles** at a particular **locus** in a population.
- To understand the Hardy-Weinberg equilibrium, we first have to understand basic genetics.
- Initially, scientists thought that the inheritance of genetic information occurred by a '**blending'** mechanism. In this process, offspring generated by the sexual

reproduction of two individuals exhibit intermediates of the traits of each parent, just like the mixing of two colours in a cup.

- However, this is disputed under Darwin's theory of **natural selection**, which relies on the existence of **variable traits** that are passed on to offspring, making them more likely to survive. In a blending system, this variation would be quickly lost. The blending theory was opposed by the famous pea plant experiments of Gregor Mendel, which showed that alternative **alleles** in a locus account for variations in inheritance.

Each individual has two copies of each gene (i.e. is **diploid**). Each **gamete** (i.e. sperm or egg) only receives only one of these genes (**alleles**) that is to be passed on to the next generation. The selection of each allele is **random**, and so each copy of the gene has a 50% chance of being passed on to the next generation

- Thus, we expect half of an individual's gametes to contain one allele, and the other half to contain the other allele.
- We refer to the combination of two alleles the offspring receives at a particular locus as their **genotype**.
- If there are two alleles in a population at locus C, (allele C and allele c) then an individual could inherit all possible combinations to make their genotype (i.e. CC, cc or Cc.
- If an individual has CC or cc they are referred to as **homozygotes**, (two copies of the same allele), if they have the genotype Cc, they are **heterozygotes** (one copy of each allele).
- If the heterozygote (Cc) is phenotypically identical to one of the homozygotes, the allele found in the homozygote is said to be **dominant**, meaning this is the trait that is and the allele found in the other homozygote is **recessive**.
- That is, the effects of the recessive allele are masked by the effects of the dominant allele.
- The dominant allele is usually denoted with a capital letter, and the recessive allele with a lowercase letter.

The Hardy-Weinberg principle explained

The Hardy-Weinberg principle is a theorem that applies to diploid organisms that are sexually reproducing. It predicts that:

- The allele frequencies in a population will not change from generation to generation.
- If the allele frequencies in a population with two alleles at a locus are p and q, then the expected genotype frequencies are p2, 2pq, and q2.

- This frequency distribution will not change from generation to generation when a population is in Hardy-Weinberg equilibrium.
- For example,

  if the frequency of allele C in the population is p

  and the frequency of allele c in the population is q,

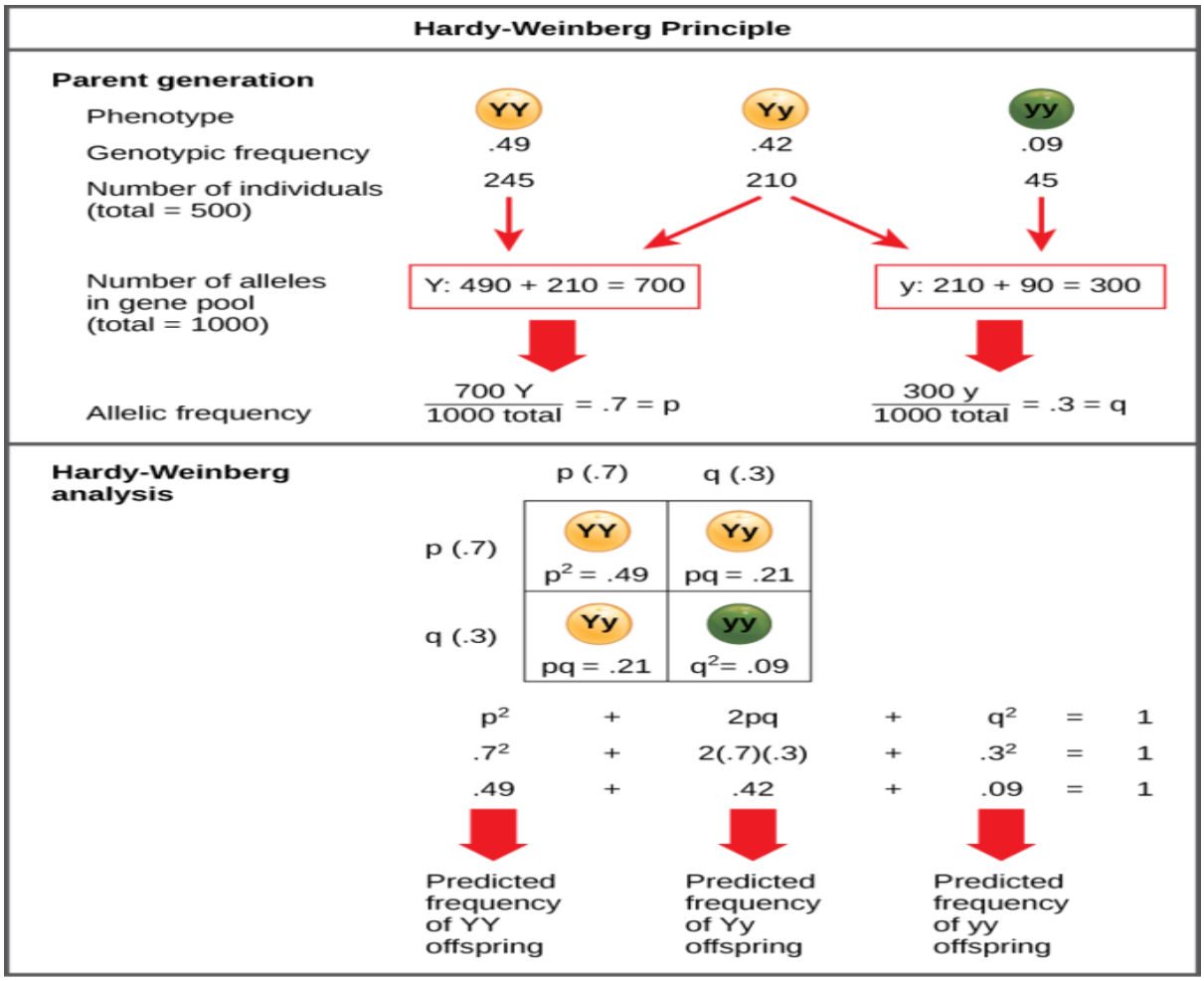
  then the frequency of genotype CC = p2,

  the frequency of genotype Cc = 2pq,

  and the frequency of genotype cc = q2.

  If there are only two alleles at a locus,

  Then p + q = 1



What are the significance of Hardy Weinberg's Equilibrium?

- Gene & Genotype frequencies of different alleles of a gene in a population remain equilibrium (generation after generation)
- Mating is a completely random phenomenon in a population
- Only large population follow Hardy-Weinberg's Law of equilibrium
- Gene frequencies will be unpredictable in small populations
- All the genotypes in a population reproduce equally successfully
- A population in Hardy-Weinberg equilibrium **do NOT** show evolution