**Topic: Genetic linkage**

**GENETIC LINKAGE**

**Linkage:**

Linkage is defined genetically the failure of two genes to assort independently.

* linkage occurs when two genes are close to each other on the same chromosome**.**

**Types of linkage**

Linkage is generally classified on the basis of three criteria

* Chromosomes involved
* Crossing over
* Genes involved

**1).Types of linkage based on chromosomes involved**

Based on the location of genes on chromosomes, linkages are characterized into

**(a)autosomal linkage:** it refers to the linkage of those genes which are located in autosomes other than sex chromosomes

**(b)Allosomal linkage/Sex linkage**

 It refers to the linkage of genes which are located in sex chromosomes i.e either ‘X’ or ‘Y’ (generally ‘X’)

**2).Types of linkage based on crossing over**

On the basis of crossing over linkage may be classified into (**a)**complete linkage

(**b**)incomplete or partial linkage **complete linkage**

It is known in the case of male drosophila an females of silkworms where there is complete absence of recombinant types due to the absence of crossing over. **incomplete or partial linkage**

If some frequency of crossing over also occurs between the link genes it is known as incomplete or partial linkage. incomplete linkage has been observed in Maize, pea, Drosophila female and several other organisms.

**3).Based on genes involved**

Depending on whether all dominant or some dominant and some recessive alleles are linked together linkage can be characterized into

**(a)**coupling phase

**(b)**repulsion phase

**coupling phase**

All dominant alleles are present on the same chromosomes or all recessive alleles are present on the same chromosomes.

**Repulsion phase**

Dominant alleles of some genes are linked with recessive alleles of other genes on same chromosome.

**Genetic linkage:**

Genetic linkage is the tendency of the DNA sequences that are close together on the chromosome to be inherited together during the meiosis phase of sexual reproduction.

* Each chromosome contains more than one gene.
* The genes for different characters may be either situated in the same chromosome or in different chromosomes.
* When the genes are situated in different chromosomes, the characters they control appear in the next generation together or apart, depending on the chance alone. They assort independently according to Mendel’s law of independent assortment

**Linked genes**

Genes on the same chromosome are said to exhibit linkage and are called linked genes.

* Linked genes and hence the phenotypic characters they control are inherited together because they are located on the same chromosome.
* Genes on nonhomologous chromosomes assort independently during meiosis.
* Genes whose loci are nearer to each other are less likely to be separated onto different chromatids during chromosomal cross over and are therefore called genetically linked.
* In the other words the nearer two genes on a chromosome the lower is the chance of swap occurring between them and the more likely they are to be inherited together.

**THEORIES OF LINKAGE**

**Sutton’s view on linkage**

Sutton in 1903, stated that each chromosome contain more than one gene and the genes present on one chromosome must be inherited together

* genes are arranged on chromosome in linear order. During meiosis, chromosomes move as a unit. So, all the genes of a chromosome are linked.
* Sutton could not prove his view.

**Bateson therapy:**

Bateson in 1930, proposed a theory that there is rapid division in gametes which have a parental combination due to linkage and in other gametes the division is slow.

Later on, it was explained there is no rapid division in such gametes. only one division takes place, so this theory was rejected.

**Bateson and punnett theory (coupling and repulsion theory)**

It was given by Bateson and Punnett(1906).They crossed pure blue and long pollen grains sweet pea plant with pure red and round green pea plant. In F1 generation blue color and long Pollen grain appeared. When a test cross was done 7:1:1:7 Was obtained but according to Mendel it should be 1:1:1:1.

7:1:1:7 ratio indicates that dominant alleles tend to remain together. Bateson and Punnett called it coupling recessive alleles tend to remain separate. it was called repulsion.

Pure Blue and long pollen grain **×**pure red and round pollen grains

P1

BBLL ×bbll

F1: BbLl (blue and long pollen grains)

Test cross

BbLl×bbll

F1 Hybrid recessive parent

7:1:1:7

Blue and round: red and long: red and round: blue and long.

Bateson and Punnett while working on sweet pea found that the factors for certain characters do not show independent assortment. then they argued that since sweet pea has only a few pairs of homologous chromosomes or chromosome must possess several factors which should be transmitted together.

**Morgan’s view on linkage**

H.Morgan stated in 1910 Genes of the homozygous parents are transferred in the same gamete to remain together Whereas same genes from heterozygous parents enters in different gametes to remain separate from each other he also stated that linked genes remains together Because these are found on chromosomes in linear(straight) manner

It was Morgan who clearly proved and defined linkage on the basis of breeding experiments and fruitfully Drosophila melanogaster in 1911 Morgan and Castle proposed chromosome theory of linkage it states that:

* The genes which shows linkage are In a linear manner in the same pair of chomosomes. Their arrangement is constant and definite.
* The genes which are very close show very strong linkage and the genes which Which have distance between them show weak linkage.

During the process of inheritance the linked gene always remain in their original combination.

**TYPES OF LINKAGES**

* Complete linkage
* Incomplete linkage

**Complete linkage(Morgan, 1919)**

The genes located on the same chromosome do not separate and are inherited together over the generations due to the absence of crossing over. Complete linkage allows the combination of parental traits to be inherited as such. It is rare but has been reported in male drosophila and some other heterogametic Organism.

**Example 1:**

A red eyed normal winged (wild type) pure breeding female drosophila is crossed with a homozygous recessive purple eyed and vestigial winged male. the progeny of F1 generation individuals are heterozygous red eyed and normal winged. when F1 males are test crossed to homozygous recessive female (purple eyed and vestigial winged) only two types of individuals are produced- red eyed normal winged and purple eyed vestigial winged in the ratio of 1:1 (parental phenotypes only).Similarly during inbreeding of F1 individuals, recombinant types are absent. In practice this 1:1 test ratio is never achieved because total linkage is rare.

**Example 2**

In Drosophila, genes of grey body and long wings are dominant over black body and vestigial (short) wings. If pure breeding grey bodied long winged Drosophila (GL/ GL) flies are crossed with black bodied vestigial winged flies (gl/gl), the F2 shows a 3 : 1 ratio of parental phenotypes (3 grey body long winged and one black body vestigial winged).

This is explained by assuming that genes of body color and wing length are found on the same chromosome and are completely linked.

#### **2. Incomplete Linkage:**

Genes present in the same chromosome have a tendency to separate due to crossing over and hence produce recombinant progeny besides the parental type. The number of recombinant individuals is usually less than the number expected in independent assortment. In independent assortment all the four types (two parental types and two recombinant types) are each 25%. In case of linkage, each of the two parental types is more than 25% while each of the recombinant types is less than 25%.

**Example 1:**

A red eyed normal winged or wild type dominant homozygous female Drosophila is crossed to homozygous recessive purple eyed and vestigial winged male. The progeny or F1 individuals are heterozygous red eyed and normal winged. F1 female flies are test crossed with homozygous recessive males. It does not yield the ratio of 1: 1: 1: 1. Instead the ratio comes out to be 9: 1: 1: 8. This shows that the two genes did not segregate independently of each other. The data obtained by Bridges (1916) is as follows:

Only 9.3% recombinant types were observed which is quite different from 50% recom­binants in case of independent assortment. This shows that in the oocytes of the F1, genera­tion only some of the chromatids undergo cross-over while the majority is preserved intact. This produces 90.7% parental types in the progeny.

**Example 2:**

In Sweet Pea (Lathyrus odoratus) blue flower color (B) is dominant over red flower colour (b) while the trait of long pollen (L) is dominant over round pollen (1). A Sweet Pea plant heterozygous for both blue flower color and long pollen (BbLl) was crossed with double recessive red flowered plant with round pollen (bbll). It is similar to test cross. In case the genes of the two traits are unlinked, the progeny should have four phenotypes (Blue Long, Blue Round, Red Long, and Red Round) in the ratio of 1: 1: 1: 1 (25% each). In case the two genes are completely linked the progeny should have both the parental types (Blue Long and Red Round) in the ratio of 1: 1(50% each).

Recombinants should not appear. However, in the above cross Bateson and Punnett (1906) found both parental and recombi­nant types but with different frequencies in the ratio of 7: 1: 1: 7. (7 + 7 Parental and 1 + 1 recombinant types).

Only 12.6% recombinant types were observed against the expected percentage of 50% in case of independent assortment. Therefore, the genes are linked but undergo recombination due to crossing over in some of the cases.

**Example 3:**

Morgan and his students have found that linked genes show varied recom­binations, some being more tightly linked than others,

1. In Drosophila, crossing of yellow bodied (Y) and white eyed (W) female with brown bodied (Y+) red eyed (W+) male produced F1 to be brown bodied red eyed. On intercrossing of F1 progeny, Morgan observed that the two genes did not segregate independently of each other and, therefore, the F2 ratio deviated significantly from expected 9: 3: 3: 1 ratio. He found 98.7% to be parental and only 1.3% recombinants
2. In a second cross in Drosophila between white eyed and miniature winged (wwmm) female with wild type or red eyed normal winged (w+w+m+m+) males, all the F1 were found to be of wild type, i.e., red eyed and normal winged. An F1 female fly was then test crossed with white eyed and miniature winged male. 62.8% of the progeny was of parental types while 37.2% were recombinants.

**Linkage in Drosophila**

When drosophila with Grey colors with long wings we VVBB were crossed with vestigial wings we vvbb in F1 generation all Drosophila were obtained black Color with vestigial wings (vvbb), in F1 generation all drosophila were obtained with grey color and long wings( VvBb).

Whenever one drosophila bar test crossed with recessive parents in F2 generation Instead of 1:1 ratio, Four types of phenotypes were obtained grey long=41.5%

grey vestigial=8.5%

 black long =8.5%

black vestigial=41.5%

Parents------grey with long wings×black with vestigial wings

Genes------BBVV --------×---------bbvv

Gametes---------BV--------×--------bv

\_\_\_\_\_\_\_\_ BbVv-( Grey long)\_\_\_\_\_BbVv-(Grey long wings)

**Test cross**

**Parents of F1\_\_\_\_\_\_× Recessive parents**

Genes\_\_\_\_BbVv--------bbvv

F2\_\_\_\_\_\_\_\_BbVv------bbvv------bbVv

\_\_\_\_\_grey long----grey vestigial---black long

\_\_\_\_\_\_\_41.5%\_\_\_\_\_\_8.5%\_\_\_\_\_8.5

**Linkage in Maize:**

Hutchison observed linkage in maize. When maize plant with color an full seeds( CS/CS) was crossed with color less and shrunken seeds (cs/cs). In F1 generation colored with full seeds Heterozygous plants were obtained.

When F1 plants are test crossed with double recessive parents (cs/cs), then in the next generation instead of expected ratio 1:1:1:1 due to incomplete linkage Results were obtained.

 Colored with full seeds=48%

 colored with shrunken seeds=2%

 colorless with full seeds =48%

colorless with shrunken seeds=2%

**Characteristics of linkage**

* Linkage involves two or more genes which are located in the same chromosome in a linear fashion.
* Linkage reduce variability.
* Linkage may involve either dominant or recessive alleles (coupling phase) or some dominant and some recessive alleles (repulsion phase).
* Linkage usually involves those genes which are located close to each other
* The strength of linkage depends on the distance between the linked genes lesser the distance higher the strength and vice versa
* Linkage can be determined from Test cross progeny data.

**Mcqs**

**1:**Linkage is defined genetically the\_\_\_\_\_\_\_ of two genes to assort independently.

**(a)**union

**(b)failure**

**(c)**combination

**(d)**none of these

**2:** When genes are located on the same chromosome, There is \_\_\_\_\_ chance to be inherited together into next generation.

**(a)**less

**(b) more**

**(c)**no

**(d)**All of these

**3:** Genes on the same chromosome inherited together into next generation during:

**(a)** Mitosis 1

**(b)** Mitosis 2

**(c) Meiosis**

**(d)** both a and b

**4:**Sutton stated that genes are arranged on chromosomes in\_\_\_\_\_\_\_ order

**(a)**Parallel

**(b)**anti-parallel

**(c)linear**

**(d)**horizontal

**5:** Morgan stated that the genes which are very close to each other show

**(a)** weak linkage

**(b)** strong linkage

**(c)**very weak linkage

**(d)very strong linkage**

**6:** Example of complete linkage is:

**(a)** Male drosophila

**(b)** Female Drosophila

**(c)** Heterogametic organism

**(d)both a and c**

**7:** Genes present on same chromosome have chances to separate during

**(a)** independent assortment

**(b) crossing over**

**(c)**genetic linkage

**(d)** both a and b

**8:** Genetic linkage is the most prominent exception to

**(a) Mendal law of segregation**

**(b)** Mendel law of independent assortment

**(c)** Crossing over

**(d)** None of these

**9:** Typical unit of genetic linkage is:

**(a)** dM

**(b)**DM

**(c)cM**

**(d)**CM

**10:** Linkage in Maize was explained by

**(a)** Morgan

**(b)** Sutton

**(c)Hutchison**

**(d)** Bateson