

8. BLOOD GROUP GENETICS

On the basis of presence / absence of certain antigens, four blood groups in human beings have been established by Karl Landsteiner in 1900. The blood group system in human beings is believed to be controlled by a single gene generally designated as “I.” The gene “I” has three alleles. – IA, IB and i. Allele IA controls the production of antigen A, IB controls the production of antigen B and i does not produce any antigen. Individuals with the genotype IAIA or IAi produces antigen ‘A’ and are classified in blood group A. individuals with genotype IBIB or IBi are classified in blood group B. Individuals with genotype ii are grouped in ‘O’ blood group and such individuals produce neither antigen A nor antigen B. individuals with genotype IAIB produce both antigens A and B and hence classified as ‘AB’ blood group.

Human blood groups, their antigen, antibody and compatible blood groups for transfusion:

Blood group	Genotypes	Antigen found	Antibody present	Compatible blood group
A	I ^A I ^A or I ^A i	A	B	A and O
B	I ^B I ^B or I ^B i	B	A	B and O
AB	I ^A I ^B	AB	None	A, B, AB and O Universal recipient
O	ii	None	AB	O (Universal donor)

LINKAGE

Sutton and Boveri proposed the chromosome theory of inheritance. According to chromosome theory of inheritance, it is well established that many genes are located in each chromosome in a linear fashion. It may therefore be expected that all genes located in same chromosome would move to same pole during cell division. As a consequence, such genes will fail to show independent segregation and would tend to be inherited together. This tendency of genes to remain together in their original combination during inheritance is called linkage. Mendel’s law of independent assortment is applicable only when the genes are located in different chromosomes while linkage refers to the genes located in the same chromosome.

The phenomenon of linkage was first reported by Bateson and Punnet in 1906. They studied flower colour and pollen shape in sweet pea involving two varieties / races.

Phases of linkage: In the two races experimented one parent has purple flowers with long pollen grains. The other parent has red flowers and round pollen grains. The character purple (P) is a simple monogenic dominant to red (p); while long (L) pollen is dominant to round (l) pollen, when these two plants were crossed the F₁ (PL/pl) was purple flowered with long pollen. But in F₂, the ratio of four types of plants deviated from the normal dihybrid ratio of 9:3:3:1 expected on the principle of independent assortment of flower colour and pollen shape.

PARENTS	Purple Long PL/PL	x	Red Round pI/pI		
F1		↓		Purple Long PL/pl	
F2	Purple long	Purple round	Red long	Red round	Total
Actual numbers	4831	390	393	1338	6952
Expected numbers	3910.5	1303.5	1303.5	434.5	6952
Expected Ratio	9/16	3/16	3/16	1/16	

The plants with the character combination as in the original parents are known as parental forms or parental combinations, i.e., (i) Plants with purple flowers and long pollen and (ii) Plants with red flowers and round pollen. Plants possessing one character from one parent and another character from the second parent are known as recombined types or recombinations or new combinations or cross-overs, i.e. (i) plants with red flowers and long pollen and (ii) plants with purple flowers and round pollen.

From the above table, the following features can be noted that in F₂, there are both parental forms and recombination's. The chief peculiarity of the results in the above table was that parental forms are in far excess of the expected number while the recombinations were fewer. This deviation from the expected ratio is due to linkage of the character pairs, viz., 1. Purple flowers (P) and long pollen (L) are linked because both the genes are located on the same chromosome. Similarly, red flowers (p) and round pollen (l) are linked together because the genes are located in the same chromosome (which is the homologue of the previous one). The recombinations are obtained due to crossing over between the two concerned genes in some of the spore mother cells.

Another cross was made in sweet peas with the following combinations:

PARENTS	Purple Round PI/PI	x	Red Long pL/pL	
		↓		
		Purple Long PI/pL		

F ₂	Purple long	Purple round	Red long	Red round	Total
Actual numbers	225	95	97	2	419
Expected numbers	235.7	78.5	78.5	26.2	419
Expected Ratio	9/16	3/16	3/16	1/16	

Here again the parental types are more while the recombinant types are less than expected on the basis of independent assortment, viz., 9:3:3:1. This deviation is also due to linkage.

In the above two examples, it can be seen that in one cross the two dominant factors (PL) are linked in one parent and two recessive factors (pl) are linked in the

other. Linkage in such crosses is said to be in coupling phase. In the second cross, dominant allele of one-character pair (P) and the recessive allele of another character pair (I) are linked together in one parent, while in the second parent the other recessive (p) and dominant alleles (L) are linked. Linkage in such crosses is said to be in repulsion phase.

Later, T H Morgan put forth the theory of linkage and concluded that coupling and repulsion were two phases of single phenomenon, linkage.

Types of Linkage: Linkage is generally classified on the basis of three criteria viz., (i) Crossing over, (ii) Genes involved and (iii) Chromosomes involved

(i) **Based on crossing over:** Linkage may be classified into (a) complete and (b) Incomplete / partial depending up on absence or presence of recombinant phenotypes in test cross progeny.

(a) **Complete linkage:** It is known in case of males of *Drosophila* and females of silkworms, where there is complete absence of recombinant types due to absence of crossing over.

(b) **Incomplete / partial linkage:** If some frequency of crossing over also occurs between the linked genes, it is known as incomplete / partial linkage. Recombinant types are also observed besides parental combinations in the test cross progeny. Incomplete linkage has been observed in maize, pea, *Drosophila* female and several other organisms.

(ii) **Based on genes involved:** Depending on whether all dominant or some dominant and some recessive alleles are linked together, linkage can be categorized into (a) Coupling phase and (b) Repulsion phase

(a) **Coupling phase:** All dominant alleles are present on the same chromosome or all recessive alleles are present on same chromosome.

TR	tr	
-----	---	<i>Coupling phase</i>
TR	tr	

(b) **Repulsion phase:** Dominant alleles of some genes are linked with recessive alleles of other genes on same chromosome.

Tr tR
----- --- **Repulsion phase**

Tr tR

(iii) **Based on chromosomes involved:** Based on the location of genes on the chromosomes, linkage can be categorized into (a) autosomal linkage and (b) X-chromosomal linkage / allosomal linkage / sex linkage

(a) **Autosomal linkage:** It refers to linkage of those genes which are located in autosomes (other than sex chromosomes).

(b) **X-chromosomal linkage / allosomal linkage / sex linkage:** It refers to linkage of genes which are located in sex chromosomes i.e. either 'X' or 'Y' (generally 'X')

Characteristic features of Linkage:

1. Linkage involves two or more genes which are located in same chromosome in a linear fashion.
2. Linkage reduces variability.
3. Linkage may involve either dominant or recessive alleles (coupling phase) or some dominant and some recessive alleles (repulsion phase).
4. It may involve either all desirable traits or all undesirable traits or some desirable and some undesirable traits.
5. It is observed for oligo-genic traits as well as polygenic traits.
6. Linkage usually involves those genes which are located close to each other.
7. The strength of linkage depends on the distance between the linked genes. Lesser the distance, higher the strength and vice versa.
8. Presence of linkage leads to higher frequency of parental types than recombinants in test cross. When two genes are linked the segregation ratio of dihybrid test cross progeny deviates significantly from 1:1:1:1 ratio.
9. Linkage can be determined from test cross progeny data.
10. If crossing over does not occur, all genes located on one chromosome are expected to be inherited together. Thus, the maximum number of linkage groups possible in an organism is equal to the haploid chromosome number.

Eg. Onion $2n = 16$ $n = 8$ maximum linkage groups possible = 8
Maize $2n = 20$ $n = 10$ maximum linkage groups possible = 10

11. Linkage can be broken by repeated intermating of randomly selected plants in segregating population for several generations or by mutagenic treatment.
12. Besides pleiotropy, linkage is an important cause of genetic correlation between various plant characters.

Linkage and pleiotropy: A close association between two or more characters may result either due to linkage or pleiotropy or both. Pleiotropy refers to the control of two or more characters by a single gene. A tight linkage between two loci can be often confused with pleiotropy. The only way to distinguish between linkage and pleiotropy is to find out a crossover product between linked characters. Intermating in segregating populations may break a tight linkage, but a huge population has to be raised to find out the crossover product. If a cross over product is not found in spite of repeated intermatings, there seems to be the case of pleiotropy rather than linkage.

Linkage groups: Linkage group refers to a group of genes which are present in one chromosome. In other words, all those genes which are located in one chromosome constitute one linkage group. The number of linkage groups is limited in each individual. The maximum number of linkage groups is equal to the haploid chromosome number of an organism. For example, there are ten linkage groups in corn ($2n = 20$), seven in garden pea ($2n = 14$), seven in barley ($2n = 14$), four in *Drosophila melanogaster* ($2n = 8$) and 23 in man ($2n = 46$).

Detection of linkage: Test cross is the most common method of detecting the linkage. In this method, the F₁ heterozygous at two loci (AB/ab) is crossed to a double recessive parent (ab/ab) and the phenotypic ratio of test cross progeny is examined. If the phenotypic ratio of test crosses progeny shows 1:1:1:1 ratio of parental and recombinant genotypes, it indicates absence of linkage. If the frequency of parental types and recombinant types deviate significantly from the normal dihybrid test cross ratio of 1:1:1:1, it reveals presence of linkage between two genes under study.

Another way to detect the presence or absence of linkage is to self-pollinate the individual heterozygous at two loci. If there is complete dominance at each locus and no epistasis, the segregation ratio of the progeny will be 9:3:3:1. Presence of linkage either in coupling or repulsion phase will lead to significant deviation from 9:3:3:1 ratio. The deviation of observed values from the expected ratio is tested with the help

of χ^2 test.

Significance of Linkage in Plant Breeding:

1. Linkage limits the variability among the individuals.
2. Linkage between two or more loci controlling different desirable characters is advantageous for a plant breeder. A linkage between genes controlling two different desirable characters will help in simultaneous improvement of both the characters.
3. Linkage is undesirable when desirable and undesirable genes are linked together.
4. The estimates of genetic variances for quantitative characters are greatly influenced by the presence of linkage