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Impact of Linkage on Plant Breeding

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Linkage: Two or more non allelic genes are more likely to inherit jointly during meiosis than would be expected in an independent assortment.

Complete Linkage of Gene:

Complete (or total) linkage is described in genetics as the state in which two loci are so close together that their alleles are almost never separated.

Incomplete Linkage of Gene:

It's unusual to find complete linkage between genes on the same chromosome. As a rule, linkage is incomplete, and most linkage groups' gene pairs assort at least partially independently of one another. Physical crossing over during meiosis between gene pairs on homologous chromosomes can alter linkage, which is a physical interaction between genes. This imperfect linking phenomena has been explored in female Drosophila and other animals, as well as maize, tomato, and a variety of crop species.

Phases of linkage:

1. Coupling phase: It is tendency of two genes or alleles to inherit together.

2. Repulsion phase: It is tendency of two genes which repel each other and never inherit together.

Remembrance in relation to linkage:

1. **R.C. Punnett (1905):** His book Mendelism (1905) is credited as the first textbook on genetics, and it was most likely the first popular scientific book to explain genetics to the general public.
2. **W. Bateson (1905):** With Reginald Punnett and Edith Saunders, Bateson co-discovered genetic linkage, and he and Punnett created the Journal of Genetics in 1910. The term "epistasis" was coined by Bateson to characterise the genetic interaction of two separate loci.
3. **T.H. Morgan (1911)**: Thomas Hunt Morgan, of Columbia University in New York City, New York, conducted an experiment in 1910 that helped to uncover the role of

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chromosomes in inheritance. Morgan was raising Drosophila, or fruit flies, at the time. He got one with white eyes after witnessing millions of fruit fly babies with red eyes. Morgan began rearing the white-eyed mutant fly and discovered that the characteristic was only present in males in one generation of flies. Morgan discovered that the genetic component determining eye colour in the flies was on the same chromosome that determined sex through extensive breeding study. This revealed that eye colour and sex were also linked to chromosomes, which aided Morgan and her colleagues.

4. **A.H. Sturtevant (1913)**: He was a geneticist from the United States. In 1911, Sturtevant created the first genetic map of a chromosome. He collaborated with Thomas Hunt Morgan on the organism Drosophila melanogaster throughout his career. He estimated the embryonic distance between organs in a unit named after him, the Sturt, by studying the development of flies in which the initial cell division produced two distinct genomes.

Pleiotropy:

A single gene has many independent phenotypic manifestations. Genes code for proteins, and a same protein may interact differently with different tissues. Linkage of iris shape and personality through the action of the PAX6 gene.

In pea plants linkage b/w

- Coloured seed coats ,colored flowers , colored leaf axils
- Colourless seed coats, white flowers and no pigmentation on their axil. (Fairbanks & Rytting, 2001)

Table 1. Linkage vs. Independent assortment

Factors	Linkage	Independent assortment
Genes Assortment	do not assort independently	Assort independently
Gametic variability	Reduces	Increase
Phenotypic ratios in F_2 and in test cross	Deviation from normal	No deviation
Distance b/w genes is measured by	frequency of crossovers	Not possible

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Detection of Linkage

Deviation of phenotypic ratios as expected from independent assortment viz.,

- Deviation from 9:3:3:1In second felial
- Deviation from 1:1 in test cross

F_1 plants were crossed. Specifically, the two parental classes, purple(P), long (L)and red(p), round(l), were over represented in the progeny.

Table no. 2: Observed and expected outcomes.

Trait	Observed	Expected
Purple, long (*P_L_*)	284	215
Purple, round (*P_ll*)	21	71
Red, long (*ppL_*)	21	71
Red, round (*ppll*)	55	24
Total	**381**	**381**

Positive impact of linkage on Plant Breeding with some examples:

1. **Soybean:** Four seeded pod is linked with narrow leaf in soybean (Takashaki, 1934). Eg: JS95-60, JS93-05 and JS90-41.
2. **Common Wheat** (Izumi *et al.*, 1983): Genes for dwarfness and male sterility are linked and linked to a common marker WMc617
   - Dwarfness Rht-D1c
   - Male sterility MS 2
   - Chromosome no. 4D
   - Distance 1 cM
3. **Identification of Male sterile line at any of the following stages can be used in recurrent selection**
   - ✓ At seed stage
   - ✓ At seedling stage
   - ✓ By herbicide resistant
4. **Drought-resistance traits in rice cultivars by QTL**
   - ✓ Identification and listed a number of qtls for drought-resistance traits.
   - ✓ Identification of 4 key genomic regions on chromosomes 1, 4, 8, and 9 .

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- ✓ They are co-located for a number of qtls considered to be directly or indirectly responsible for grain yield under stress.

5. **Watermelon:** In wild watermelon , gene for sweetness is positively linked with red flash

Negative impacts of linkage on Plant Breeding

1. **Wheat**: In wheat several rust resistant traits linked with undesirable traits influence yield.
2. ***Brassica napus***: In *Brassica napus QTL* responsible for low eruic acid and low oil content are linked.
3. **Rice** Introgression line of Khao dawk mali 105(KDML105) has a linkage drag between Bph 3 and Wxa allele (Jairin *et.al* 2009)
4. **Linkage In Tomato**: High fruit weight is associated with low soluble solid concentration
5. ***Lycopersicon penellii:*** Genes resistant to armyworm, fruit worm, aphids, leaf miners and whitefly are linked with poor horticultural quality such as

- ✓ Delayed germination
- ✓ Reduced fruit set
- ✓ Reduced size
- ✓ Delayed maturity
- ✓ Reduced seed set

How to break linkage

- Grow a large number of F_2 population
- Inter matting in large population of second generation
- Mutation

SAMBA MAHSURI

- ➢ Leading rice variety of AP
- ➢ Also known as BPT 5204
- ➢ Major five states – Andhra Pradesh, Karnataka, Orissa, Chhatisgarh and Uttar Pradesh
- ➢ Originally developed by Acharya N.G. Ranga Agricultural University in Andhra Pradesh.
- ➢ Currently occupies 3.3 percent of the Area under Rice cultivation in India

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- Popularity is due to exceptional yielding ability and quality attributes.
- Major limitation is the susceptibility to Bacterial blight.
- Effective bactericides (antibiotic) are not available for controlling blight.

OBJECTIVE

Introduce genes for BB resistance into Samba *Mashuri* background without loss of its unique quality attributes and yielding ability. Rice resistant genes that are effective against Indian strains of Xoo

Table 3. Globally available resistant genes were as follow:

Xa3	*IR*	*BB3*
Xa4	*IR*	*BB4*
Xa5	*IR*	*BB5*
Xa7	*IR*	*BB7*
Xa13	*IR*	*BB13*
Xa21	*IR*	*BB21*

Performance of Resistant Genotypes

- Bacterium can overcome single resistance gene present for bacterial blight disease.
- Pyramiding of two or more resistance gene essential for developing resistant variety against bacterial blight disease.
- It is possible through marker assisted selection.
- Goal to exploit the genetic diversity in wild relatives.

Procedure

Two tightly linked genes, termed breaker and inhibitor are identified. Involved in preferential transmission. Advantage: Induce and recover translocations between wheat chromosomes and the alien donor.

Aegilops sharonesis

- Genes will be studied on the group 4 chromosomes *of Aegilops sharonesis*,
- Why these special linked genes
- Genes on these chromosomes induce chromosomal breakages which frequently result in translocations.

Conclusion

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Linkage is the simultaneous transmission of two genes from one generation to the next. It can be complete or imperfect. The impact of linkage is determined by the genes that are connected. The linking principle was used to generate the Bacterial Bight Resistant Rice Samba *Mashuri* developed by MAS. *Aegilops sharonesis* has two tightly coupled genes (breaker and inhibitor) that are being used in a research project that could lead to a revolution.

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