

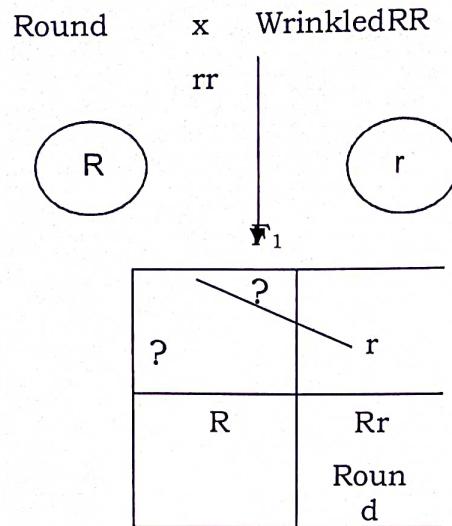
GENE ACTION

Gene action refers to the manner in which genes control the phenotypic expression of various characters in an organism. Alleles of the gene may interact with one another in a number of ways to produce variability in their phenotypic expression. The dominant and recessive relationship is fundamental and is essentially constant with each pair of alleles.

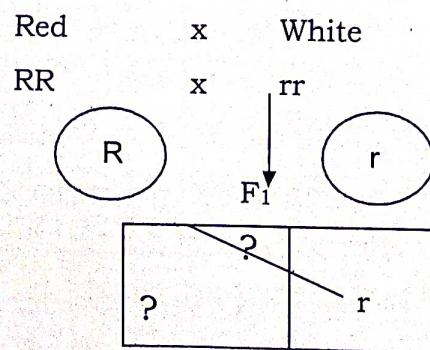
Gene action can be of the following types:

1. Based on the dominance effect:
 - a) Complete dominance
 - b) Incomplete dominance
 - c) Co-dominance
 - d) Over dominance
 - e) Pseudo-dominance
 2. Based on lethal effects :
 - a) Dominant lethals
 - b) Recessive lethals
 3. Based on epistatic action :
 - a) Epistatic factors
 - b) Supplementary factors
 - c) Duplicate factors
 - d) Complementary factors
 - e) Additive factors
 - f) Inhibitory factors
 4. Based on number of genes involved:
 - a) Monogenic
 - b) Digenic
 - c) Oligogenic
 - d) Polygenic
 5. Based on pleiotropism / pleiotropic gene action
- 1. Based on dominance effect:** It was noted by many workers that many characters of F_1 hybrid were exactly the same as those of one or the other parent of a hybrid. The phenomenon of F_1 hybrid being identical to one of its parents for a character is termed as dominance. The form of a character that is seen in F_1 hybrid is called dominant, while that form of the concerned trait which does not appear in F_1 is known as recessive.
- Dominance relationship is of the following types:**

a) **Complete dominance:** The phenotype produced by a heterozygote is identical to that produced by the homozygotes for the concerned dominant allele. The dominant allele in such a situation is said to be completely or fully dominant. Eg: In garden pea, round seed shape is completely dominant over wrinkled.

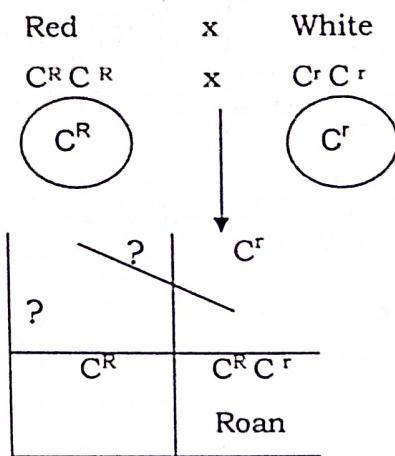


b) **Incomplete dominance:** In many cases, the intensity of phenotype produced by heterozygote is less than that produced by the homozygote for the concerned dominant allele. Therefore the phenotype of heterozygote falls between those of the homozygotes for the two concerned alleles. Such a situation is known as Incomplete or partial dominance and the dominant allele is called incompletely dominant or partially dominant. Eg : In *Mirabilis jalapa* (Four 'O' clock plant) a partially dominant allele 'R' produces red flowers in homozygous state, while its recessive allele 'r' produces white flowers in homozygous state. When a red (RR) flower type plant is crossed with white (rr) flower type plant, the hybrid (Rr) has pink flowers. Thus the intensity of flower colour in F_1 is intermediate between the intensities of flower colour produced by two homozygotes. This phenomenon is also called blending inheritance.



R	Rr
	Pin k

c) **Co-dominance:** Both the alleles of a gene express themselves in heterozygotes. As a result, heterozygotes for such genes possess the phenotypes produced by both the concerned alleles. The coat colour of short horned breed of cattle presents an excellent example of co-dominance.



Roan colour is that which has patches of red and white colours.

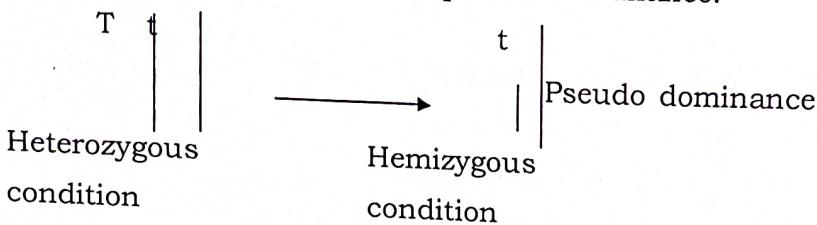
d) **Over dominance:** In case of some genes, the intensity of character governed by them is greater in heterozygotes than in the two concerned homozygotes. This situation is known as over-dominance. True over dominance is known in case of very few genes. Over-dominance is not the property of an allele but is the consequence of heterozygous state of concerned gene. Eg: white eye gene (W) of *Drosophila* exhibits over-dominance for some of the eye pigments such as sepiapteridine and Himmel blaus. These two eye pigments are present in low concentration in the recessive homozygotes (ww), while the dominant homozygotes (WW) have relatively higher concentrations of these pigments. However, the flies heterozygous for this gene (Ww) have an appreciably higher concentration of these two pigments than the two homozygotes.

Transgressive segregation: The appearance of individuals in F_2 or subsequent generation which exceed the parental types with reference to one or more characters is known as transgressive segregation.

(or)

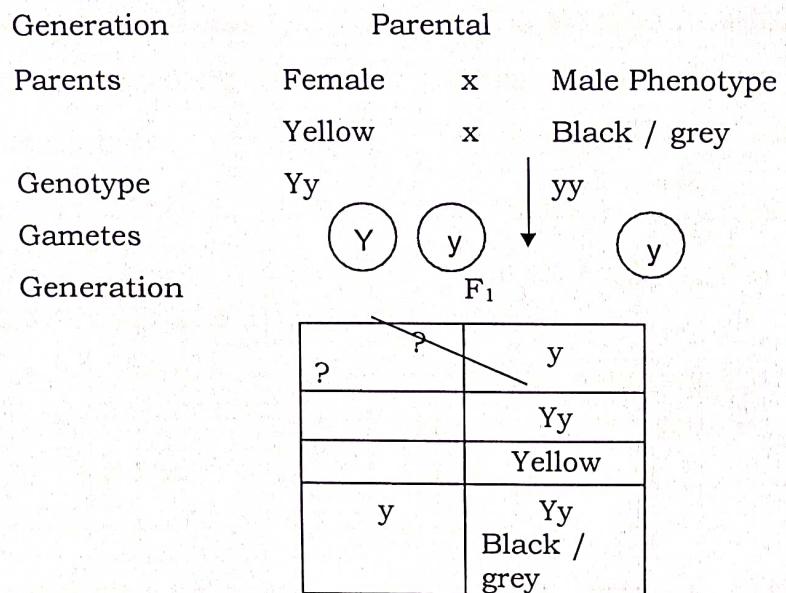
The segregants which fall outside the range of both the parents are called transgressive segregants and the phenomenon is called transgressive segregation.

- e) **Pseudo-dominance:** Expression of recessive allele of the gene in the hemizygous state / condition either due to sex linkage (Eg: colour blindness in human beings) or chromosomal aberrations (deletion in heterozygotes) is known as pseudo-dominance.

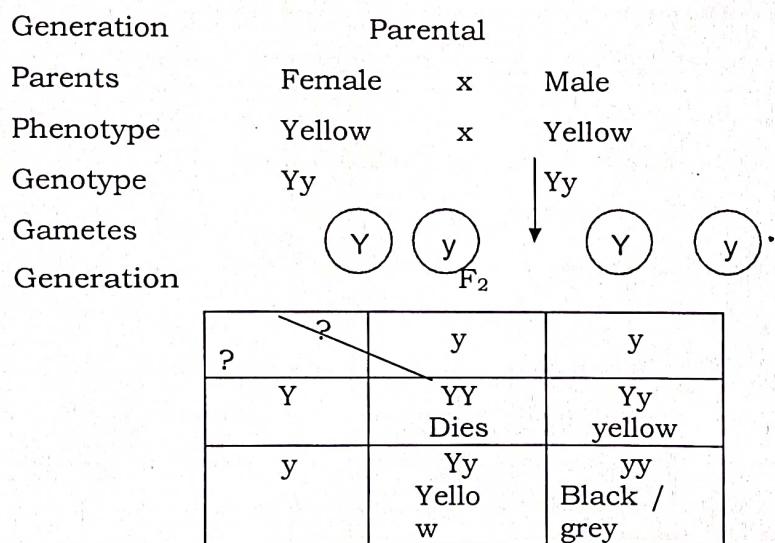


2. Based on lethal effect: One of the most important assumptions for inheritance of any trait is the equal survival of all gametes and zygotes produced as a result of segregation. The assumptions are true for a vast majority of genes. However, some genes affect the survival of those zygotes or individuals in which they are present in the appropriate genotype. Such genes are known as lethal gene. A lethal gene causes death of all the individuals carrying the gene in the appropriate genotype before they reach the adult stage. Most of the lethal genes express their lethal effect only when they are in homozygous state while the survival of heterozygotes remains unaffected. The stage of development at which a lethal gene produces a lethal effect varies considerably from one gene to another. Some genes cause the death of embryo very early in developmental stage. (Eg: 'Y' gene in mice); while others allow survival for a certain period of time and then produce lethal effect (Eg: 'g' gene producing albino seedlings in crop plants like rice, barley etc.).

- a) **Dominant Lethal gene action:** A lethal gene affecting coat colour in mice was discovered by French geneticist Cuenot in 1905. He found that yellow coat colour in mice was produced by a dominant gene 'Y' while its recessive allele 'y' determines the normal black / grey coat colour. Further, he found that all the mice with yellow coat colour were heterozygous Yy and he was unable to find a mouse homozygous for 'Y' allele (YY). The dominant allele 'Y' is lethal and hence it causes death of homozygous 'YY' embryos at an early stage of development.



On intermating of yellow progeny

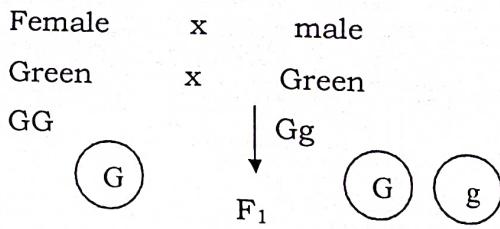


Phenotypic ratio : 2 Yellow ; 1 Black / Grey

Genotypic ratio : 2 Yy : 1 yy

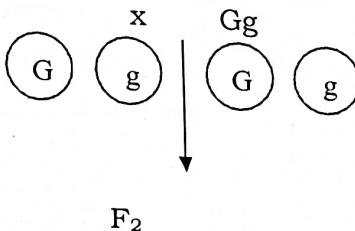
- b) **Recessive lethals:** Albino seedling character in plants such as rice and barley is governed by recessive alleles. Whenever these alleles are in the homozygous state the seedlings are near white or almost white and totally devoid of chlorophyll. Albino seedlings survive only as long as the food material stored in the seeds is available to them because they are not able to carry out photosynthesis. The heterozygotes, however are normal green and are identical with the dominant homozygotes in their phenotype as well as their survival. Segregation of such genes produces 3 green : 1 albino seedling if

they are counted within a week from germination. However, if the plants are counted at maturity, there will be only green plants in the progeny.



?	G	g
?	G	g
G	GG	Gg
Green	Green	Green

On selfing of Gg individuals Gg



?	G	g
?	G	g
G	GG Green	gg Green
g	Gg Green	Gg albin o (dies)

The heterozygous individuals carrying the lethal genes without expression in the heterozygous condition but giving rise to lethals in F_2 generation is called a carrier.

In the above examples Yy , or Gg are carriers

3. Based on epistatic gene action: When expression of one gene depends on presence / absence of another gene in an individual, it is known as gene interaction. Interaction of genes at different loci that affect the same character is called epistasis. The term epistasis was first used by Bateson in 1909 to describe two different genes which control the same character, out of which one masks / suppresses the expression of another gene. Gene that masks the action of another gene is called

epistatic gene while the gene whose expression is being masked is called hypostatic gene. Epistatic gene interaction can be of the following types.

- (i) Epistatic factors - 12 : 3 : 1 (ii) Supplementary factors - 9 : 3 : 4
- (iii) Duplicate factors - 15 : 1 (iv) Complementary factors - 9 : 7
- (v) Additive factors - 9 : 6 : 1 (vi) Inhibitory factors - 13 : 3

4. Based on number of genes involved:

- a) Monogenic - Each character is controlled by one gene
- b) Digenic - Each character is controlled by two genes
- c) Oligogenic - Each character is controlled by few genes
- d) Polygenic - Each character is controlled by many genes

Polygenic or polymerism: In general, one gene controls or affects a single character. But some characters are known to be controlled by more number of genes. Such genes are called poly genes and the phenomenon is called polymerism.

Eg : Yield in plants.

5. Based on pleiotropism / pleiotropic gene action: In general, one gene affects a single character. But some of the genes are known to affect or control more than one character. Such genes are called pleiotropic genes and the phenomenon is known as pleiotropism. Many fold phenotypic expressions of a single gene is called pleiotropism or pleiotropic gene effects. Eg: White eye gene affects the shape of sperm storage organs and other structures in *Drosophila*. These genes are found in all crop plants. Good example of pleiotropism has been reported in wheat. A gene governing awns in Ona's variety of wheat also increases the yield as well as seed weight.

ALLELES

Alternate forms of a gene is known as allele. Alleles are of two types *viz.*, either dominant and recessive or wild type and mutant type.

Characteristic features of alleles:

1. They occupy the same locus on a particular chromosome.
2. They govern the same character of an individual. (T and t – control plant height)
3. A haploid cell has a single copy of an allele for a character. A diploid cell has two copies of an allele for a character, while a polyploidy cell has more than two copies of an allele for a character.
4. An individual may have identical alleles at the corresponding locus of homologous chromosomes in the homozygote or two different alleles in the heterozygote.
5. The alleles may be dominant and recessive or wild and mutant types.

Multiple alleles

Generally a gene has two alternative forms called alleles. Usually one of them is dominant over the other. The two alleles of a gene determine the two contrasting forms of a single character. Ex. Tall (T) and dwarf (t) plant height in garden pea. But in many cases, several alleles of a single gene are known to exist and each one of them governs a distinct form of the concerned character or trait. Such a situation is known as multiple allelism and all the alleles of a single gene are called multiple alleles. Many genes in both animals and plants exhibit multiple alleles. Ex: Blood group in human beings, fur colour / coat colour in rabbits and self-incompatibility alleles in plants.

1. **Blood groups in human beings:** 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. – I^A , I^B and i . Allele I^A controls the production of antigen A, I^B controls the production of antigen B and i does not produce any antigen.

Individuals with the genotype $I^A I^A$ or $I^A i$ produce antigen 'A' and are classified in blood group A. Individuals with genotype $I^B I^B$ or $I^B i$ 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 $I^A I^B$ 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

2. Fur or coat colour in rabbits: The fur colour in rabbits is a well known example of multiple alleles. In rabbits, the fur colour is of four types viz., agouti, chinchilla, himalayan and albino. It is due to multiple alleles of a single gene 'C'.

Phenotype	Gene symbol	Genotype
1. Agouti	C	CC , Cc^{ch} , Cc^h , cc
2. Chinchilla	C^{ch}	$c^{ch}c^{ch}$, $c^{ch}c^h$, c^hc^{ch}
3. Himalayan	C^h	c^hc^h , c^hc
4. Albino	c	cc

The order of dominance for fur colour in rabbits can be represented as follows :

C	>	C^{ch}	>	C^h	>	c
Agouti	>	Chinchilla	>	Himalayan	>	Albino
Full colour or wild type		Mixture of coloured and white hairs over the body		Main body is white, while the tips of ears, feet, tail and snout are black		No pigment and with pure white fur colour

3. Self incompatibility alleles in plants: A series of self incompatibility alleles insures cross pollination in many plants. Such alleles were described first in tobacco and later they were found in several other plant species like *Brassica*, radish, tomato, potato etc. In these species, self incompatibility is governed by a single gene 'S' which has multiple alleles *viz.*, S_1 , S_2 , S_3 , S_4 and so on.

Characteristic features of multiple alleles:

1. Multiple alleles always belong to the same locus in a chromosome.
2. One allele is present at a locus at a time in a chromosome.
3. Multiple alleles always control the same character of an individual. However, the phenotypic expression of the character will differ depending on the alleles present.
4. There is no crossing over in a multiple allelic series.
5. In a multiple allelic series, wild type is almost always dominant over the mutant type.
6. A cross between two strains homozygous for mutant alleles will always produce a mutant phenotype and never a wild phenotype. In other words, multiple alleles do not show complementation.
7. Further, F_2 generations from such crosses show typical monohybrid ratio for the concerned trait.

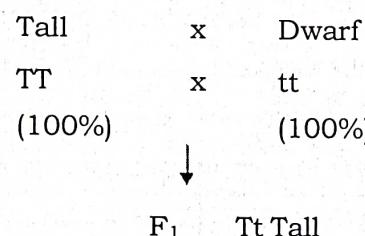
Pseudo alleles: Two alleles each of two or more tightly linked genes affecting the same function as a result of which, they appear as multiple alleles. (or) Alleles, which have two separate gene loci, but often inherit together due to close linkage and have very rare chance of crossing over are called pseudo alleles. Eg: Lozenge eye in *Drosophila*.

Iso allele: An allele which is similar in its phenotypic expression to that of other independently occurring allele is called isoallele.

Penetrance; It is the ability of a gene to express itself in all the individuals, which carry it in the appropriate genotype. (or) The frequency with which a gene produces a phenotypic or visible effect in the individuals which carry it in the appropriate genotype is known as penetrance. It refers to the proportion of individuals which exhibit phenotypic effect of a specific gene carried by them.

1. Penetrance of some genes is limited to one sex only. For example : Milk production in cattle or human beings.
2. It may be affected by environmental conditions
3. Penetrance is expressed in percentage It is of two types

1. Complete penetrance: When all the individuals that carry a particular gene exhibit its phenotypic effect, it is known as complete penetrance. In this case, all homozygous dominant individuals will exhibit one phenotype, while all homozygous recessives will exhibit another phenotype. Recessive alleles have no or zero penetrance in heterozygous condition.



[T exhibits Complete (100%) penetrance while t has no(0%) penetrance]

2. Incomplete penetrance: When specific gene does not express their effect in all the individuals which carry them in appropriate genotype, it is known as incomplete penetrance. For example : The recessive gene producing partial chlorophyll deficiency in the cotyledony leaves of lima bean shows incomplete penetrance as it expresses itself only in 10% of the individuals.

Almost all the genes showing incomplete penetrance exhibit variable expressivity as well

Expressivity: The degree of phenotypic expression of a gene in different individuals is called expressivity. It is also influenced by environmental conditions in some cases. Expressivity is also two types.

1. Uniform expressivity: When the phenotypic expression of a gene is identical or similar in all the individuals, which carry such a gene, it is known as uniform expressivity. Most of the qualitative characters exhibit uniform expressivity. Eg: Seed shape in pea rr genotypes have wrinkled seed shape, while RR or Rr genotypes exhibit round seed shape.

- 2. Variable expressivity:** When the phenotypic expression differs in different carriers of a gene, it is known as variable expressivity. Eg: Recessive gene producing partial chlorophyll deficiency in cotyledonary leaves of lima beans.

Lecture No.: 21

QUALITATIVE AND QUANTITATIVE CHARACTERS

The phenotype of any individual can be classified into two types:

- 1) Qualitative characters and 2) Quantitative characters

- 1. Qualitative characters :** The characters that show discontinuous variation and which can not be measured easily are known as qualitative characters. These are also known as classical mendelian traits.

Eg : Corolla colour – Red □ white or pink no continuous variation Seed shape – Round □ wrinkled variation is not continuous

- 2. Quantitative characters** are those showing continuous variation and which can be measured easily. These characters are also known as metric traits. The data obtained from such characters is known as quantitative data. This data can be subjected to statistical analysis and the branch of science which deals with such analysis is known as quantitative genetics or biometrical genetics.

Eg : Yield, Plant height

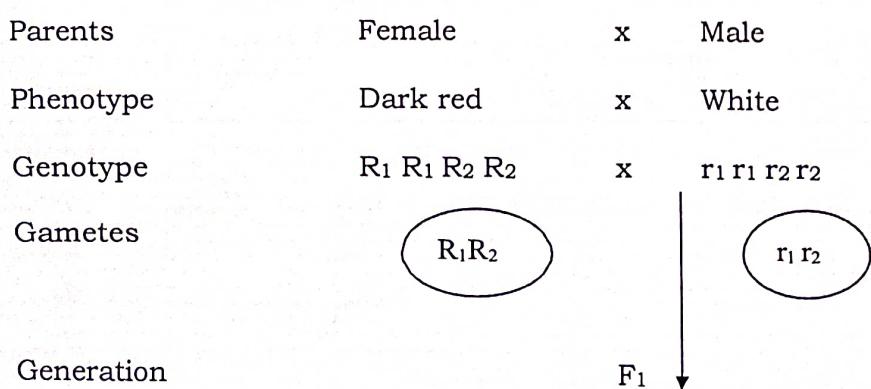
Differences between quantitative and qualitative characters

	Quantitative characters	Qualitative characters
Deals with	Traits of degree Eg : Plant height, seed weight, yield etc.	Traits of kind Eg : Corolla colour, seedshape, appearance etc.
Variation	Continuous	Discontinuous
Effect of individual gene	Small and undetectable	Large and detectable
No. of genes involved	Several (polygenic)	one or few (mono / oligogenic)
Grouping into distinct classes	Not possible	Possible
Effect of environment	High	Low
Metric measurement	Possible	Not possible
Statistical analysis	Based on mean, variance, standard deviation etc.	Based on ratios and frequencies
Stability	Low	High

Transgressive segregation of F ₂	Yes	No
Dominance effect	No	Yes
Cumulative effect of each gene	Yes	No

MULTIPLE FACTOR HYPOTHESIS

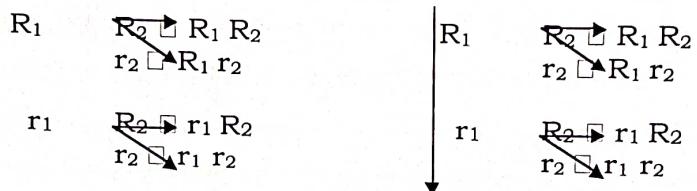
In early days of mendelian genetics it was thought that there was a fundamental difference in inheritance pattern of quantitative and qualitative traits. One of the examples which helped to bridge the gap between these two kinds of traits is "multiple gene model" developed by Swedish Geneticist H. Nilsson Ehle in 1910 to explain inheritance of kernel colour in wheat. In studies on inheritance of kernel colour in wheat and oats, he obtained 3:1, 15:1 and 63:1 ratio between coloured and white seeds from different crosses. It is clear from these ratios that the seed colour was governed by one (3:1 ratio in F₂), two (15:1 ratio in F₂) or three (63:1 ratio in F₂) genes. Nilsson-Ehle found that in crosses showing 15:1 ratio in F₂ kernel colour is governed by two genes. However, on a closer examination of the coloured seeds, he found that there was a marked difference in the intensity of their colour. When he crossed a dark red strain to a white strain (or variety), he observed that all the F₁s were medium red (intermediate between the parental types). But in F₂ generation only one out of the sixteen were of parental types. He interpreted the results in terms of two genes, each with a pair of alleles exhibiting cumulative effects. Each of the dominant alleles R₁ and R₂ adds some red colour to the phenotype, while the recessive alleles r₁ and r₂ add no colour to the phenotype. Thus dark red genotypes contain only R₁ and R₂ alleles while the white genotype contains none of these alleles.



?	?	$r_1 r_2$
$R_1 R_2$		$R_1 r_1 R_2 r_2$ Medium Red

On selfing

Parents	Female	x	Male
Phenotype	Medium Red	x	Medium Red
Genotype	$R_1 r_1 R_2 r_2$	x	$R_1 r_1 R_2 r_2$ gametes



Generation F_2

?	?	$R_1 R_2$	$R_1 r_2$	$r_1 R_2$	$r_1 r_2$
$R_1 R_2$		$R_1 R_1 R_2 R_2$ Dark Red	$R_1 R_1 R_2 r_2$ Red	$R_1 r_1 R_2 R_2$ Red	$R_1 r_1 R_2 r_2$ Medium Red
$R_1 r_2$		$R_1 R_1 R_2 r_2$ Red	$R_1 R_1 r_2 r_2$ Medium Red	$R_1 r_1 R_2 r_2$ Medium Red	$R_1 r_1 r_2 r_2$ Light Red
$r_1 R_2$		$R_1 r_1 R_2 R_2$ Red	$R_1 r_1 R_2 r_2$ Medium Red	$r_1 r_1 R_2 R_2$ Medium Red	$r_1 r_1 R_2 r_2$ Light Red
$r_1 r_2$		$R_1 r_1 R_2 r_2$ Medium Red	$R_1 r_1 r_2 r_2$ Light Red	$r_1 r_1 R_2 r_2$ Light Red	$r_1 r_1 r_2 r_2$ White

Phenotypic ratio: 1 Dark Red : 4 Red : 6 Medium Red : 4 Light red : 1 white

Genotypic ratio: 1 $R_1 R_1 R_2 R_2$: 2 $R_1 R_1 R_2 r_2$: 1 $R_1 R_1 r_2 r_2$
 : 2 $R_1 r_1 R_2 R_2$: 4 $R_1 r_1 R_2 r_2$: 2 $R_1 r_1 r_2 r_2$
 : 1 $r_1 r_1 R_2 R_2$: 2 $r_1 r_1 R_2 r_2$: 1 $r_1 r_1 r_2 r_2$

S.No.	No. of alleles for red colour	Phenotype	Frequency	Genotype	Frequency
1.	4	Dark Red	1	R ₁ R ₁ R ₂ R ₂	1
2.	3	Red	4	R ₁ R ₁ R ₂ r ₂	2
				R ₁ r ₁ R ₂ R ₂	2
3.	2	Medium Red	6	R ₁ R ₁ r ₂ r ₂	1
				R ₁ r ₁ R ₂ r ₂	4
				r ₁ r ₁ R ₂ R ₂	1
4.	1	Light Red	4	R ₁ r ₁ r ₂ r ₂	2
				r ₁ r ₁ R ₂ r ₂	2
5.	0	white	1	r ₁ r ₁ r ₂ r ₂	1

Lecture No: 22

SEX DETERMINATION

Sex refers to the contrasting features of male and female individuals of the same species. Thus sex is usually of two types *viz.*, male and female. Sex determination is a process of sex differentiation which utilizes various genetical concepts to decide whether a particular individual will develop into male or female. Plants also have sex as there are male and female parts in flowers. All organisms, however do not possess only two sexes. Some of the protozoa may have as many as eight sexes. In most higher organisms, the number of sexes has been reduced to just two. The sexes may reside in different individuals or within the same individual. An animal possessing both male and female reproductive organs is usually referred to as hermaphrodite. In plants where staminate and pistillate flowers occur in the same plant, the term of preference is monoecious Eg. maize, castor, coconut etc. However, most of the flowering plants have both male and female parts within the same flower (perfect flower). Relatively few angiosperms are dioecious i.e. having male and female elements in different individuals Eg: cucumber, papaya, asparagus, date palm, hemp and spinach. The sex cells and

reproductive organs form the primary sexual characters of male and female sexes. Besides these primary sexual characters, the male and female sexes differ from each other in many somatic characters known as secondary sexual characters.

Whether or not there are two or more sexes in the same or different individuals is relatively unimportant. The importance of sex itself is that it is a mechanism, which provides for the great amount of genetic variability characterizing most natural populations.

The various mechanisms of sex determination are:

1. Chromosomal sex determination
2. Genic balance mechanism
3. Male haploidy or Haplodiploidy mechanism
4. Single gene effects (or) monofactorial mechanism of sex determination
5. Metabolically controlled mechanism
6. Hormonally controlled mechanism
7. Sex determination in *Coccinia indica* and *Melandrium album*,
8. Sex determination due to environmental factors

I. Chromosomal sex determination: The chromosomes, which have no relation with sex and contain genes, which determine the somatic characters of an individual are known as autosomes. These chromosomes do not differ in morphology and number in male and female sex. Those chromosomes, which differ in morphology and number in male and female sex and contain genes responsible for the determination of sex are known as allosomes or sex chromosomes.

Differences between Autosomes and Allosomes

Autosomes	Allosomes or Sex chromosomes
1. Refer to other than sex chromosomes.	1. These are sex chromosomes.
2. Morphology is similar in male and female sex.	2. Morphology is different in male and female sex.
3. The number is same in both the sexes.	3. The number is sometimes different in male and female sex.
4. Generally control traits other than an	4. Usually determine sex of an

sex.

5. Number of autosomes differs from species to species.

6. Do not exhibit sex linkage.

individual.

5. Each diploid organism usually has two allosomes.

6. Exhibit sex linkage.

The chromosomal influence on sex, in certain insects, has been shown for the first time by McClung in 1902 to be associated with a special sex determining 'X' chromosome. McClung proposed that a male had one 'X' chromosome per cell (XO) and a female has two 'X' chromosomes (XX). Later Stevens and Wilson (1905) found same number of chromosomes in both sexes of milk weed bug. In females all chromosomes were paired and the homologues were equal in size (homomorphic). In the male, all the chromosomes were paired, but the chromosome identified as homologous to the "X" Chromosome was distinctly smaller and was called the "Y" Chromosome (Heteromorphic).

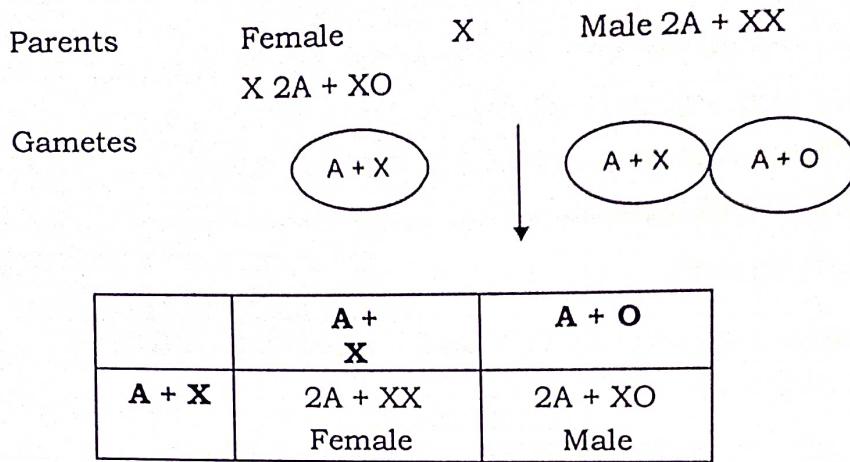
Thus, allosomes are generally of X and Y types, but in birds they are of Z and W types. Sex with similar type of sex chromosomes (XX or ZZ) is known as homogametic sex and with dissimilar type of sex chromosomes (XY or ZW) as heterogametic sex. These are two types: a) Heterogametic male and b) Heterogametic female

a) **Heterogametic male:** In this mechanism, the female sex has two 'X' chromosomes, while the male sex has only a single 'X' chromosome. As the male lacks a 'X' chromosome during meiosis, 50% of the gametes carry 'X' chromosome, while the rest do not have the 'X' chromosome. Such a mechanism, which produces two different types of gametes in terms of sex chromosome is called heterogametic sex. The female sex here is called homogametic sex because it produces similar type of gametes. The heterogametic male may be of the following two types.

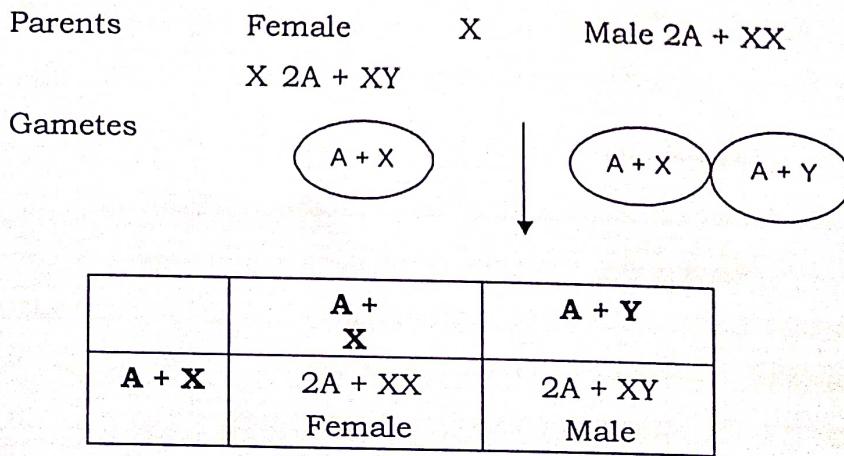
i) XX - XO ii) XX - XY

i) **XX - XO:** In certain insects belonging to orders *Hemiptera* (true bugs), *Orthoptera* (grass hoppers) and *Dictyoptera* (cockroaches), female has two 'X' chromosomes (XX) and are, thus homogametic, while male has only single 'X' chromosome (XO). This mechanism was found by C.E. McClung in 1902. The presence of an unpaired X chromosome determines the masculine sex. The

male being heterogametic sex produces two types of sperms, half with X chromosome and half without X chromosome in equal proportions. The sex of the offspring depends upon the sperm that fertilizes the egg, each of which carries a single X chromosome. Thus fertilization between male and female gametes always produced zygotes with one 'X' Chromosome from the female, but only 50% of the zygotes have an additional X Chromosome from the male. In this way, 'XO' and 'XX' types would be formed in equal proportions, the former being males and the latter being females.

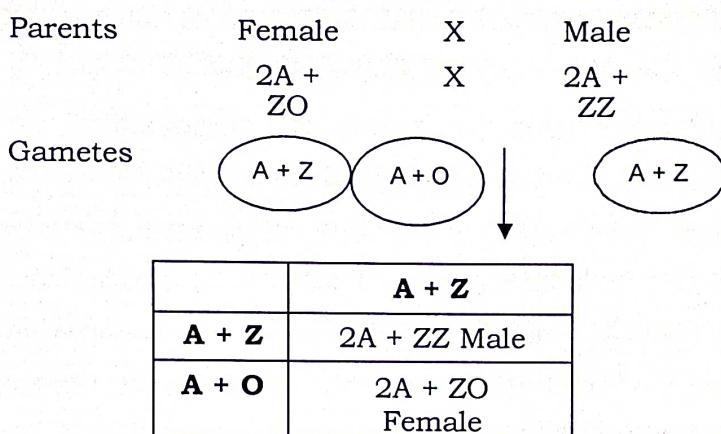


ii) **XX - XY:** In man, other mammals, certain insects including *Drosophila*, certain angiospermic plants including *Melandrium*, the females possess two X chromosomes (XX) and are thus homogametic and homomorphic, while the males possess one X and one Y chromosome (XY) and are hence heterogametic and heteromorphic. When an egg is fertilized by 'Y' bearing sperm, a male is produced.



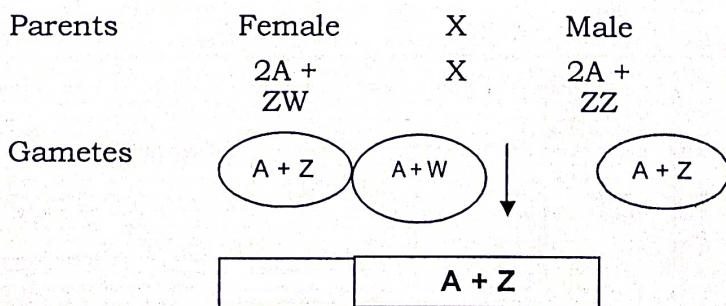
b) **Heterogametic female:** In this mechanism the male possess two homomorphic sex chromosomes and are thus homogametic, while the female possesses either a single 'X' chromosome or one 'X' and one 'Y' chromosome and are hence heterogametic. To avoid confusion with earlier types, instead of X and Y, the alphabets Z and W are used. This mechanism of sex determination is also known as "Abraxas mechanism of sex determination" (Kuspira and Walker, 1973) The heterogametic females may be of followingtwo types. i) ZO – ZZ
ii) ZW – ZZ

i) **ZO – ZZ:** This mechanism is found in certain moths and butterflies. In this case, female possess one single 'Z' chromosome and hence is heterogametic. Male possesses two Z chromosomes and thus homogametic.



The sex of the offspring depends on the kind of egg.

ii) **ZW – ZZ:** This system is found in certain insects (gypsy moth) and vertebrates such as fishes, reptiles and birds. In this system, the female is heterogametic and produces two types of gametes, one with 'Z' chromosome and the other with 'W' chromosome. On the other hand, male is homogametic and produces all sperms of same type carrying one 'Z' chromosome. The sex of the offspring depends on the kind of egg being fertilized. The 'Z' chromosomebearing eggs produce males, but the 'W' chromosome bearing eggs produce females.



A + Z	2A + ZZ Male
A + W	2A + ZW Female

II) Genic balance mechanism: By studying the sex chromosomal mechanism of sex determination, it may appear at first glance that some genes carried by sex chromosomes i.e. X and Y are entirely responsible for determining sex. But this may not always be true. Extensive experiments on different organisms by different workers have revealed the fact that most organisms generally have inherent potentialities for both sexes and each individual is found to be more or less intermediate between male and female. Hence may be referred to as inter sex. There seems to exist a delicate balance of masculine and feminine tendency in the hereditary compliment of an individual. Such a genic balance mechanism of determination of sex was first observed and studied by C.B. Bridges in 1921 while working with *Drosophila* for the inheritance of vermillion eye colour. According to this mechanism, the sex of an individual in *Drosophila melanogaster* is determined by a balance between the genes for femaleness located in the X-chromosome and those for maleness located in autosomes. Hence, the sex of an individual is determined by the ratio of number of its X chromosomes and that of its autosomal sets, the 'Y' chromosome being unimportant. The ratio is termed as sex index and is expressed as follows.

$$\text{index} = \frac{\text{No. of X chromosomes}}{\text{No. of autosomal sets}} = A$$

X Sex

Different doses of X - Chromosomes and autosome sets and their effect on sex determination

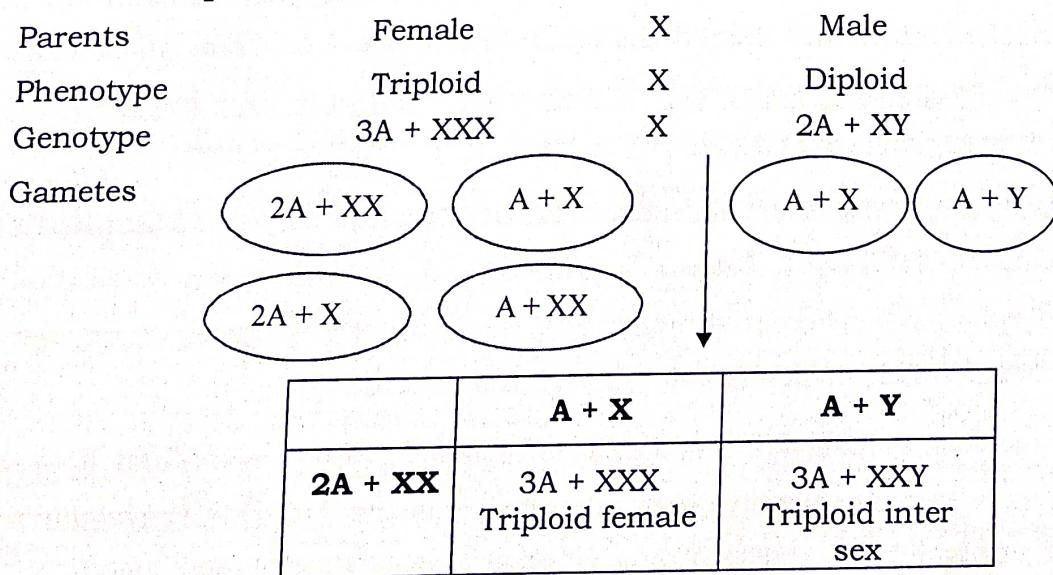
S.No.	Ploidy level	X-Chromosomes	Sets of autosomes	Sex index (X/A ratio)	Sex Expression
1.	Diploid	3(xxx)	2(AA)	1.50	{ Super female
2.	Triploid	4(xxxx)	3(AAA)	1.33	{ or meta female
3.	Haploid	1(x)	1(A)	}	
4.	d	2(xx)	2(AA)	{ 1.00	Female
	Diploid				
5.	Triploid	3(xxx)	3(AAA)	}	
6.	Tetraploid	4(xxxx)	4(AAAA)	}	
7.	Triploid	2(xxy)	3(AAA)	0.67	}

8.	Tetraploid	3(xxxy)	4(AAAA)	0.75	Inter sex
9.	Diploid	1(xy)	2(AA)	}	
10.	Tetraploid	2(xxyy)	4(AAAA)	} 0.5	Male
11.	Triploid	1(xyy)	3(AAA)	0.33	Super male or meta male

Individuals with sex index of 0.5 develop into normal males and those with sex index of 1 into normal females. If the sex index is between 0.5 and 1, the resulting individuals will be neither a female nor a male, but have an intermediate sex expression and is called inter sex. Such individuals are sterile. Some flies have sex index of >1 , such flies have more pronounced female characteristics than normal females and are called super females or metafemales. These are generally weak, sterile and non-viable. Super male flies have a sex index value of <0.5 and are also weak, sterile and non-viable.

Bridges drew the observation by crossing triploid females ($3A + XXX$) with normal diploid males ($2A + XY$). From such a cross he obtained normal diploid females, males, triploid females, intersexes, super males and super females. The occurrence of triploid intersexes from such a cross clearly established that autosomes also carry genes for sex determination. Triploid individuals, which had two 'X' Chromosomes as in the case of normal female, here were inter sexes as they had an extra set of autosomes indicating that the autosomes play a definiterole in the determination of sex.

Results obtained from a cross of a triploid ($3A+XXX$) female fly with a diploid ($2A+XY$) male fly in *Drosophila*



not have a female

A + X	2A + XX Diploid female	2A + XY Diploid male
2A + X	3A + XX Triploid inter sex	3A + XY Super male
A + XX	2A + XXX Super female	2A + XXY Diploid female

III. Male haploidy or haplodiploid mechanism or arrhenotokous parthenogenesis:

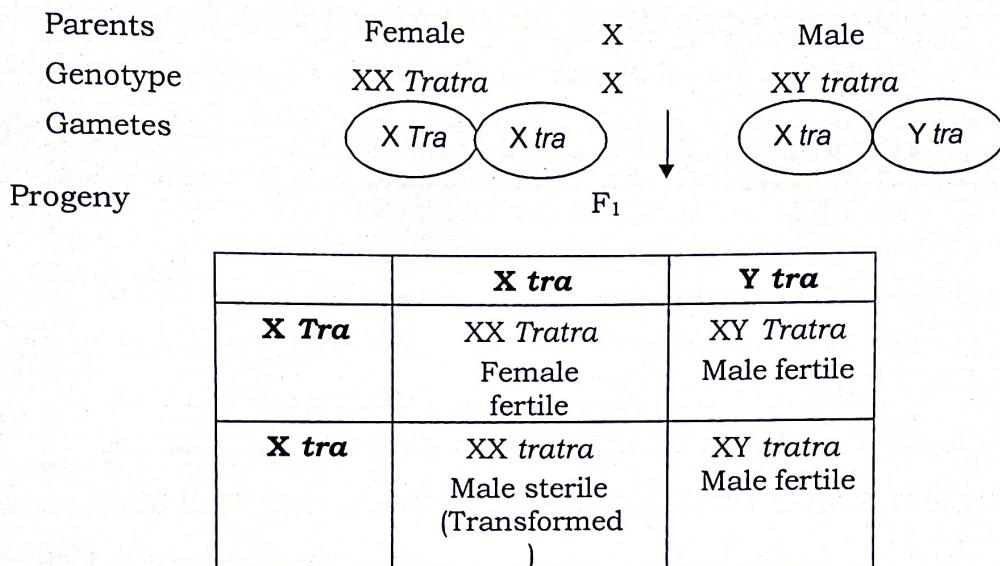
parthenogenesis: It is common in hymenopterous insects (ants, bees, wasps). In honey bees, queens usually mate only once during its life time and the sex ratio of offspring is under the control of queen. Fertilized eggs develop into diploid female and those eggs which the queen chooses not to be fertilized develop parthenogenetically into haploid but fertile males (drones). This phenomenon is known as arrhenotoky and is a form of reproduction as well as a means of sex determination. Meiosis is normal during oogenesis in case of females and produces all haploid eggs. But crossing over and reduction division fails to occur during spermatogenesis in males due to their haploid nature. Thus arrhenotokous parthenogenesis determines the sex in hymenopterans and sex chromosomes have no identity here (unlike *Drosophila*). It seems that heterozygosity for specific genes induces femaleness. The haploid can never be heterozygous. Most of the eggs laid in the hive will be fertilized and developed into worker females. Further during investigation, it has been found that the quantity and quality of food available to the diploid larvae determines whether that female will become a sterile worker or a fertile queen. The diploid larva, which feed on royal jelly, develop into fertile female called queen and the remaining larvae give rise to workers, which are sterile females. Thus, environment here determines sterility or fertility but does not alter the genetically determined sex.

IV. Single gene effect or monofactorial mechanism of sex determination:

In *Neurospora*, *Asparagus*, *Drosophila*, maize and *Asparagus*, sex determination is influenced by the differential action of a single autosomal gene, which overrules the effect of sex chromosomes present in the individual.

Autosomal recessive transformer (*tra*) gene of *Drosophila*; when it is present in the homozygous recessive state, it transforms the female (XX) zygote to develop into males which are sterile. The gene *tra* is recessive and hence does

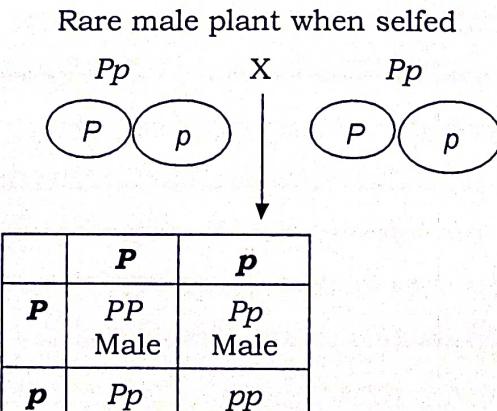
not have any effect in heterozygous condition ($Tratra$) on either sex i.e male or female. In homozygous condition, ($tratra$), this gene has no effect in male. When a heterozygous (XX $Tratra$) female is mated with a homozygous recessive male (XY $tratra$), only 25% of the progeny are females (heterozygous) while remaining 75% are males. Among the males, 1/3 are sterile (XX individuals homozygous recessive for tra gene) as they are transformed to maleness by the tra .



Ratio: 3 Males : 1 Female

Monogenic control of sex has also been reported in some plants like *Asparagus*, maize, papaya, spinach, etc. *Asparagus* is a dioecious plant. However, rarely female flowers bear rudimentary anthers and male flowers bear rudimentary pistils. Occasionally, male flowers with poorly developed pistils set seed on selfing and segregate in 3 : 1 ratio of male and female.

Segregation of sex in seed obtained from a rare bisexual flower in *Asparagus* showing monogenic control



	Male	Female
--	------	--------

Ratio: 3 Males : 1 Female

Maize being a monoecious plant bears both female (silk) and male (tassel) inflorescences on the same plant. A recessive gene *ba* (barren cob) in homozygous condition (*baba*) makes the cobs barren or non-functional. Similarly, a recessive gene *ts* in homozygous condition (*tsts*) converts the male flowers of tassel into female flowers. Thus, homozygous state of gene *ba* (*baba*) converts the monoecious plant into male. Similarly, gene *ts* in homozygous condition (*tsts*) converts the monoecious plant into female. The plants with both dominant genes (*Ba_Ts*) are monoecious, with *babaTs* - normal male, with *Ba_tsts* female, and with *babatsts* rudimentary females.

In papaya, the sex is postulated to be governed by three alleles, viz., *m*, *M₁* and *M₂* of a single gene. Homozygous recessive (*mm*) produces female plants, heterozygous, viz., *M₁m* and *M₂m* produce male and hermaphrodite plants, respectively. However, combination of both dominant alleles (*M₁* and *M₂*) produces inviable plants both in homozygous (*M₁M₁* and *M₂M₂*) and heterozygous conditions (*M₁M₂*). Crosses between female (*mm*) and male (*M₁m*) produce females (*mm*) and males (*M₁m*) in 1 : 1 ratio. Similarly, crosses between female (*mm*) and hermaphrodite (*M₂m*) will produce females (*mm*) and hermaphrodite (*M₂m*) in 1 : 1 ratio. Selfing of hermaphrodite (*M₂m*) plants produce hermaphrodite (*M₂m*) and female (*mm*) progeny in 2 : 1 ratio and about $\frac{1}{4}$ of the zygotes (*M₂M₂*) do not survive.

V. Metabolically controlled mechanism: Riddle found that metabolism has some definite role in the determination of sex in pigeon and dove because increased rate of metabolism lead to the development of maleness while decreased rate of metabolism caused femaleness.

VI. Hormonally controlled mechanism: Crew in 1923 reported a complete reversal of sex in hen. Female chicken that have laid eggs been known to undergo not only a reversal of the secondary sexual characteristics such as development of cock feathering, spurs and crowing, but also the development of testis and even the production of sperm cells (primary sexual characteristics). This might have occurred when a disease destroyed the ovarian tissue and in absence

of female sex hormones, rudimentary testicular tissue present in center of ovary began to proliferate or multiply and secrete male hormones, which lead to the development of maleness.

Sexual differentiation in man is influenced by hormones. When the testis of the male is removed before puberty, female characteristics of body form, voice and hair pattern develop in the adult. Tumors of adrenals in women are associated with the development of masculine characters such as low pitched voice and increased growth of hair.

VII. Sex determination in *Coccinia indica* and *Melandrium album*:

Ploidy level	Chromosome Constitution (Autosomes) + (Allosomes)	Sex	X/A ratio
Expression			
Diploid	AA + XX	Female	1.00
Diploid	AA + XY	Male	0.50 (1/2)
Diploid	AA + XYY	Male	0.50 (1/2)
Triploid	AAA + XXX	Female	1.00
Triploid	AAA + XXY	Male	0.67 (2/3)
Tetraploid	AAAA + XXXX	Female	1.00
Tetraploid	AAAA + XXXY	Male	0.75 (3/4)

two organisms, studies have revealed that irrespective chromosomes, and / or autosomal sets, presence of a single

of number of X'

'Y' chromosome is

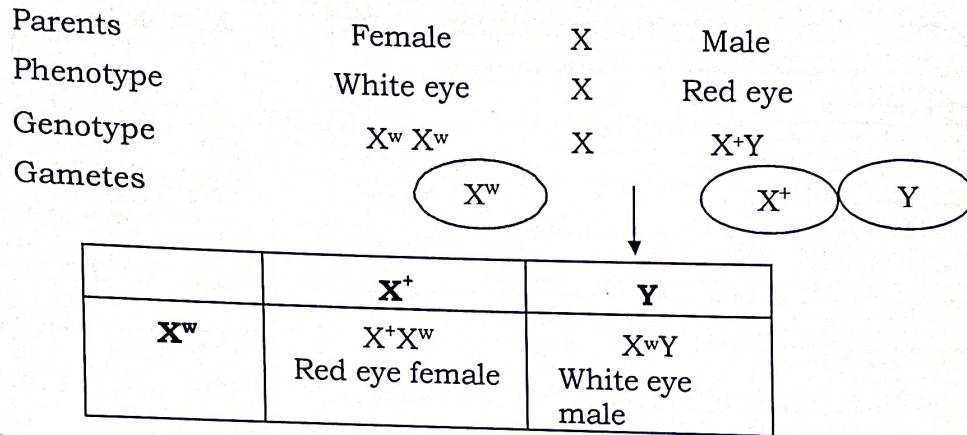
essential to produce male flowers in diploid, triploid and tetraploid species. The pistillate plants are XX and the staminate plants are XY.

VIII. Sex determination due to environmental Factors: In many reptiles, sex is determined by environmental factors like temperature. In most turtle species only females are produced at high temperature ($30 - 35^{\circ}\text{C}$) while only males are produced at low temperatures ($23 - 28^{\circ}\text{C}$). Sex ratio changes suddenly from all males to all females with just change in temperature of 2°C during the incubation. In Crocodiles and Lizards, (reverse is the case) the males are produced at high temperature while females are produced at low temperature. In *Bonellia viridis*, a marine worm, all larvae are genetically and cytologically similar. If a particular larva settles near proboscis of adult female, it becomes a male individual. If larva develops freely in water, it becomes a female. In some plants, sex determination depends on day length, temperature and hormones. For example, in cucumber

(*Cucumis sativa*) and muskmelon, treatment with ethylene enhances production of female flowers.

Sex linked inheritance

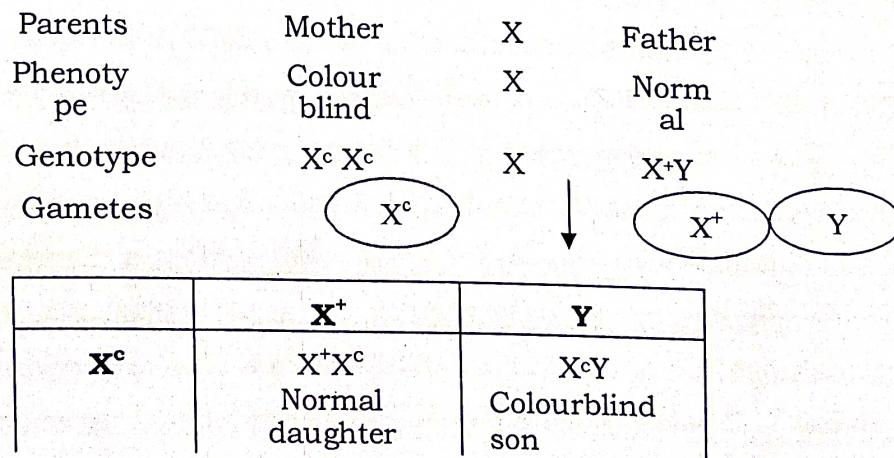
The characters for which genes are located on sex or 'X' or analogous 'Z' chromosomes are known as sex linked traits. Such genes are called sex linked genes and linkage of such genes is referred to as sex linkage. Inheritance of such genes or characters is known as sex linked inheritance. The sex linkage was first discovered by T.H. Morgan in *Drosophila* and the first sex linked gene found in *Drosophila* was recessive gene 'w' responsible for white eye colour.



When white eyed females are crossed with wild type (red eye) males, all the male offspring have white eyes like the mother and all the female offspring have red eyes like their father.

In human beings, colour blindness and haemophilia (bleeder's disease) are well known hereditary characters showing a peculiar relationship to sex.

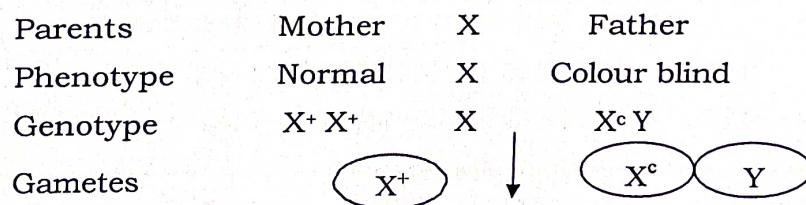
Colour blindness: A marriage between colour blind woman and a normal man gives rise to all normal daughters and colour blind sons.



The allele for colour blindness (c) is found on both 'X' chromosomes of mother and therefore she is colour blind. The only one 'X' chromosome of father in this marriage carries a wild type (+) allele and hence he has normal vision. The 'Y' chromosome lacks both the alleles (+ and c). The reduction division produces one kind of egg in contrast to two kinds of sperms. Fertilization results in the usual sex ratio of 1 male : 1 female. All the daughters have normal vision since they receive dominant allele '+' from their father. All the sons are colour blind, because their single 'X' chromosome derived from mother carries the allele 'c' for colour blindness. This result is known as crisscross inheritance because daughters are normal like father and sons have colour blindness like mother. However, the daughters are heterozygous carriers. This crisscross method of inheritance is characteristic of sex-linked genes. This peculiar type of inheritance is due to the fact that Y chromosome carries no alleles homologous to those on the X chromosome. Thus males carry only one allele for sex linked traits. This one allelic condition is termed as hemizygous in contrast to homozygous and heterozygous possibilities in female. The expression of recessive gene in hemizygous condition is termed as pseudo-dominance.

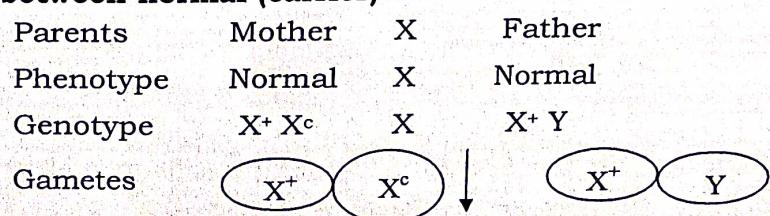
The inheritance of colour blindness can be studied in the following three other possible types of marriages:

a) Marriage between normal woman and colour blind man:



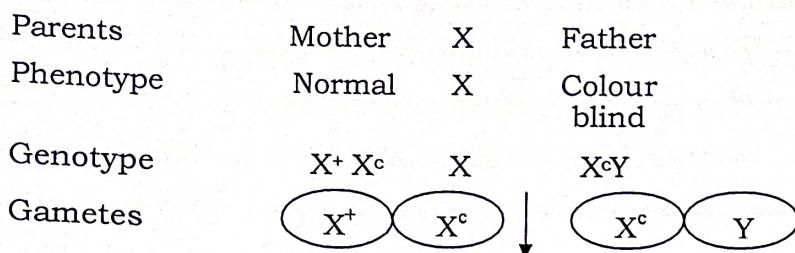
	X^c	Y
X^+	$X^+ X^c$ Normal daughter (Carrier)	$X^+ Y$ Normal son

b) Marriage between normal (carrier) woman and normal man:



	X⁺	Y
X⁺	X⁺X⁺ Normal daughter	X⁺Y Normal son
X^c	X⁺X^c Normal daughter	X^cY Colour blind son

c) Marriage between normal (carrier) woman and colour blind man:



	X^c	Y
X⁺	X⁺X^c Normal daughter	X⁺Y Normal son
X^c	X^cX^c Colour blind daughter	X^cY Colour blind son

Results of possible four marriages make it clear why there are more colour blind males than females in the population. In three marriages colour blind sons were produced whereas in only one of the marriages, colour blind daughters were observed, where the mother is heterozygous (carrier) and the father is colour blind. Nearly all colour blind women must come from the last type of marriage, since the only other possible source of colour blind females is mating between two colour blind persons – naturally a rare occurrence.

Haemophilia is a recessive sex linked disease and the inheritance pattern of haemophilia is similar to that of colour blindness in human beings.

Genes present in the non-homologous region of the Y chromosome pass directly from male to male. In man, the genes present on Y chromosome (holandric genes) such as the gene causing hypertrichosis (causing excessive development of hairs on the pinna of ear) are transmitted directly from father to son.

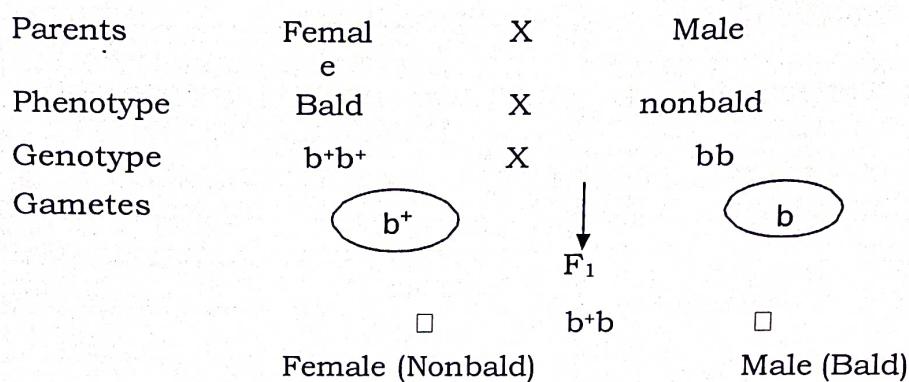
Sex influenced inheritance

Sex influenced genes are the autosomal genes present in both males and females, whose phenotypic expression is different in different sexes in such a way that they act as

dominant in one sex and recessive in the other i.e. in a pair of alleles one seems to be dominant in males while the other in females.

Eg.: Pattern baldness in human beings and horns in sheep. Pattern baldness in human beings is a condition in which a low fringe of hair is present on the head in human beings. It is a genetically inherited condition, where the allele for baldness B is dominant in males and recessive in females. In heterozygous condition, males are bald and females are non-bald. If a woman heterozygous for this gene marries a heterozygous bald man, in the offspring, the ratio of bald to non-bald in males is 3 : 1, while in females it is 1 : 3.

Inheritance of pattern baldness in human being



Phenotypic expression of pattern baldness in man and woman

Genotype	Phenotype	
	Female	Male
b^+b^+	Nonbald	Nonbald
b^+b	Nonbald	Bald
bb	Bald	Bald

Sex limited characters or Secondary Sexual characters

Sex limited genes are autosomal genes, whose phenotypic expression is limited to one sex only. Their phenotypic expression is influenced by the sex hormones. The sex limited genes are mainly responsible for secondary sex characters in cattle, human beings and fowl. Eg.: milk production in cattle, beard development in human beings, plumage in male fowls etc.

Milk production in cattle : Just as the cow, the bull carries genes for milk production, but the bull obviously cannot express this trait. Bull may however

transmit these genes for high milk production to the female progeny and the male progeny are unable to express this trait. Some bulls are so well endowed with such genes that they are known to breed calves, which always yield greater milk than their mothers.

However, in plants no secondary sexual characters are known except the absence of one or the other sporangia.

Differences between sex linked and sex limited characters

Sex Linked characters	Sex Limited characters
1. They are located on sex or X chromosome	1. They are located on sex chromosomes or autosomes
2. They can express in both the sexes	2. They can express in one sex only
3. Include characters not related to sex	3. Include primary and secondary sex characters
4. Examples: White eye in <i>Drosophila</i> , haemophilia and colour blindness in human beings	4. Examples: milk production in cattle, beard development in human beings, plumage in male fowls etc