MULTIPLE ALLELES

When more than two allelic forms of a gene occupy the same locus of the homologous chromosome, they are said to be multiple alleles. In other words all the mutant form of a single gene constitutes a series of multiple alleles.

Characteristic features of multiple alleles

1. The members of a multiple alleleic series occupy the same locus of homologous chromosomes.
2. Only two members of such alleles are present at a time in a diploid organism.
3. There is no crossing over in the multiple allelic series. If two alleles are involved in the cross the same two alleles are recovered in F2 or test cross progeny.
4. In a series of multiple alleles, wild type is always dominant. Rest of the alleles in the series may exhibit dominance or intermediate phenotypic expression.
5. The cross between two mutant alleles will always produce mutant phenotype (intermediate). Such cross will never produce wild phenotype. That is multiple alleles do not show complementation.
6. Multiple alleles always control the same character of an individual. However, the expression of the character will differ depending on the allele present.

Examples for multiple alleles

Several cases of multiple alleles are known both in animals and plants. Some of the examples are given below.

Blood groups in human beings

One of the most firmly established series of multiple alleles in humans involve the genetic locus controlling the blood types A,B AB and O. In 1900, Landsteiner discovered blood groups A, B, AB and O in human beings. He found that agglutination may occur during transfusion of blood from one person to another. This agglutination occurs due to antigen-antibody reaction'. **Antigen** is a specific protein found on the surface of the RBCs. **Antibody** is another kind of specific protein found in the plasma. There are two kinds of antigens *viz*., antingen A and antigen B and two kinds of antibodies viz., **A antibody'** and '**B antibody'**. The agglutination which is '**antigen antibody reaction'** is a highly specific one. '**A antigen'** can react with 'Aantibody' alone and 'B antigen' can react with 'B antibody' alone. When there are 'A antigen' and 'B antibody', there will be no reaction and agglutination will not occur. Among human beings, the blood group is classified on the basis of the antigen present. Persons with A antigen belong to A group. They have 'A antigen' on their RBCs and 'B antibody' in their plasma. Persons with B antigen belong to B group. They have 'B antigen on their RBCs and 'A antibody' in their plasma. Persons with both A and B antigens belong to AB group. They have A and B antigens on their RBCs and no antibodies in their plasma. Persons with no antigens belong to O group. Their RBCs are without A and B antigens. But they have both A and B antibodies in their plasma

Blood groups in human beings

Antigen on RBC	Antibody in Plasma	Blood group
A	B	A
B	A	B
A and B	No antibodies	AB
No antigen	Both a and B	O

Inheritance of blood group

Specific alleles control the production of specific antigens. Antibody is produced by immunological mechanism. The blood group is determined by a series of three alleles*viz*., I^A, I^B and i.

Blood group and their possible genotypes

Blood group	Genotype
A	$I^AI^A$and I^A i.
B	$I^BI^B$and I^B i.
AB	I^A I^B
O	ii.

The I^A controls the production of 'A antigen'. The allele I^B controls the production of 'B antigen'. Both IA and IB are dominant over the recessive allele i. I^A and I^B lack dominance over each other. The heterozygote I^A and I^B is not intermediate between the homozygote's $I^AI^A$and I^BI^B . It shows characteristics of both homozygotes. That is, both the alleles are expressed. This is called codominance

Showing blood groups and genotypes of parents and possible children.

S.No.	Parental blood group Male/Female or Vice versa	Possible genotype	Blood group of children
1.	A X A	I^AI^A, I^AI^O x I^AI^A, I^AI^O	A, O
2.	A X B	I^AI^A, I^AI^O x I^BI^B, I^BI^O	A, B, AB, O
3.	A X AB	I^AI^A, I^AI^O x I^A I^B	A, B, AB
4.	A X O	I^AI^A, I^AI^O x I^OI^O	A,O
5.	B X B	I^BI^B, I^BI^O x I^BI^B, I^BI^O	B, O
6.	B X AB	I^BI^B, I^BI^O x I^A I^B	A, B,AB
7.	B X O	I^BI^B, I^BI^O x I^OI^O	B, O
8.	AB X AB	I^A I^B x I^A I^B	A, B, AB
9.	AB X O	I^A I^B x I^OI^O	A, B
10.	O X O	I^OI^O x I^OI^O	O

2. Coat Colour in Rabbits

The coat of rabbit may have different colours as described below.

(i) Full colour: The coat of the ordinary (wild type) rabbit is referred to as "agouti" or full colour, in which individuals have banded hairs, the portion nearest the skin being gray, succeeded by a yellow band, finally a black or brown tip. The allele for full colour may be represented by capital letter c^+.

(ii) Chinchilla: In some individuals, the coat lacking the yellow pigment and due to the optical effect of black and gray hairs, have the appearance of silvery-gray. The allele for chinchilla is represented as c^{ch}.

(iii) Himalyan (Russian): The Himalyan type coat is white except for black extremities (nose, ears, feet and tail). The condition in which black pigmentation is confined to the ears, muzzle, feet and tail, is called acromelanism (Serra, 1965). In Himalyan rabbits eyes remain pigmented. The allele for Himalyan coat is represented by c^h.

iv) Albino: The albino coat totally lacks in pigmentation and the eyes of a albino also remain pink due to lack of pigment in iris of eye. The allele for albino is represented by c.

Crosses of homozygous agouti (c^+c^+) and albino (cc) individuals produce a uniform agouti F_1; interbreeding of the F_1 produces an F_2 ratio of 3 agouti: 1 albino. Two third of F_2 agouti are found to be heterozygous by testcrosses. Thus, it is a case of monohybrid inheritance, with agouti completely dominant to albino.

Likewise, crosses between chinchilla and agouti produce all agouti individuals in the F_1 and a 3 agouti: 1 chinchilla ratio in the F_2. Such complete dominance of agouti also occurs on Himalayan.

Further crosses, reveal that c^{ch} allele for chinchilla, though is recessive to c^+ allele for agouti coat or skin is incompletely dominant over Himalayan (c^h) and albino (c) alleles. Likewise, c^h allele for Himalyan coat is recessive to c^+ (agouti) and c^{ch} (chinchilla) but dominates over albino. The results of all these crosses exhibit that c^+ (agouti), c^{ch} (chinchilla), c^h (Himalayan) and c(albino) are allelic to each other and the alleles of this multiple allelic series have following dominance heirarchy: $c^+ > c^{ch} > c^h > c$The possible phenotypes and their associated genotypes of this multiple allelic series can be summarized in table. The phenotypes and genotypes of multiple allelic series for coat colour in rabbit.

Sl.NO.	Parent	F1	F2
1	Coloured x Albino	Coloured	3 Coloured:1 Albino
2	Coloured x Chinchilla	Coloured	3Coloured: 1 Chinchilla
3	Coloured x Himalayan	Coloured	3Coloured: 1Himalayan
4	Chinchilla x Himalayan	Chinchilla	3 Chinchilla: 1 Himalayan

5	Chinchilla x Albino	Chinchilla	3 Chinchilla :1 Albino
6	Himalayan x Albino	Himalayan	3Himalayan : 1 Albino

All these experiments clearly indicate that

1. The coat colour of the rabbit is controlled by a series of multiple alleles viz., C, C^{ch}, C^{h} and c.
2. The allele C is dominant over all other alleles.
3. The allele c is recessive to all other alleles.
4. The allele C^{ch} is recessive to C but dominant over C^{h} and c.
5. The allele $C^{h}$is recessive to C and C^{ch} but dominant over c.
6. Thus the alleles C, C^{ch}, C^{h}, c forms a series of multiple alleles.

Phenotypes	**Genotypes**
Full colour (Agouti)	$c^{+}c^{+}$, $c^{+}c^{ch}$, $c^{+}c^{h}$, $c^{+}c$
Chinchilla	$c^{ch}c^{ch}$
Light gray	$c^{ch}c^{h}$, $c^{ch}c$
Himalayan	$c^{h}c^{h}$,$c^{h}c$
Albino	cc

3. Skin Colour in Mice

In mice, the skin or coat colour is governed by a multiple allelic series. The gene A controlling the agouti pattern in mice has several alleles. Among the members of the series a gradation exists in dominance, similar to that of the c series in rabbits, but in this case two members, A^{y} (yellow) and A^{1} (agouti light belly) are dominant over the wild-type allele A^{+} (agouti). The alleles of agouti (A) series in mice can be listed according to dominance in table. In this multiple allelic series, the allele Ay, when homozygous, (i.e., A^{y} A^{y}) is lethal early in embryonic development but procedure yellow colour when in heterozygous condition with other alleles.

Phenotype	Allele
Yellow	A^{y}
Agouti light belly	A^{i}
Agouti	A^{+}
Black and Tan	a^{l}
Nonagouti(Black)	A
Dominance hierarchy:	A^{y}>A^{l}>A^{+}>a^{l}>a