INTERACTION OF GENES

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Introduction:

Mendelian inheritance assumed that a character was controlled by a single gene. However, the inheritance of majority of traits in different organisms are found to be governed by two or more genes. These genes influence the development of concerned characters in various ways leading to different modifications of the typical dihybrid (9:3:3:1), trihybrid (27:9:9:9:3:3:3:1) and other F_2 ratios.

The phenomenon of two or more genes interacting in various ways and influencing the expression of a character in an organism is called Interaction of Genes. On the basis of the manner in which the concerned genes interact and influence the expression of each other, Gene interactions are classified into various categories.

Kinds of Gene Interactions

① Typical Dihybrid Ratio (9:3:3:1)

(i) This type of gene interaction gives the typical dihybrid ratio of 9:3:3:1 in F_2 for a single character.

(ii) Obviously, the concerned character is controlled by two genes exhibiting full dominance.

(iii) The dominant alleles of each of the two genes produce separate forms of the character (phenotypes) when the dominant

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alleles of one gene is present with the homozygous recessive allele of the other locus.

But when the dominant alleles of both the genes are present together, they produce a distinct phenotype, and the homozygous recessive state at both the loci gives rise to yet another phenotype.

<u>Example</u>- In chickens, comb shape is controlled by two genes, p and r. The dominant allele P alone (with rr) produces <u>pea comb</u>, while R alone (with pp) produces <u>rose comb</u>. But when both the dominant genes P and R are present together, e.g., PpRR, they give rise to <u>walnut comb</u>.

Recessive condition at both the loci, i.e., pprr gives rise to a distinct comb shape called <u>single</u>.

When a breed of poultry with pea comb (PPrr) is crossed with another breed having rose comb (ppRR), the F_1 (PpRr) has <u>walnut comb</u>.

Segregation for the two genes produces 16 possible zygotic combinations in F_2. Nine of these combinations have at least one P and one R allele, and consequently, <u>walnut comb</u>. Three combinations have one or two P alleles but with homozygous rr; as a result, they have <u>pea comb</u>. Three other zygotes are homozygous for p (pp), but have one or two R alleles; therefore, these individuals develop <u>rose comb</u>. The remaining one individual has the genotype pprr and develops <u>single comb</u>.

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Thus an interaction between two dominant genes controlling the development of a single trait gives a 9:3:3:1 ratio in F_2 for a single character. The cross results are shown below:

Parents → PPrr (PEA) × ppRR (ROSE)

Gametes → Pr, pR

F_1 → PpRr (WALNUT)

F_2 →

♀ \ ♂	PR	Pr	pR	pr
PR	PPRR walnut	PPRr Walnut	PpRR Walnut	PpRr Walnut
Pr	PPRr Walnut	PPrr Pea	PpRr Walnut	Pprr Pea
pR	PpRR Walnut	PpRr Walnut	ppRR Rose	ppRr Rose
pr	PpRr Walnut	Pprr Pea	ppRr Rose	pprr Single

F_2 Phenotypic Ratio : 9 WALNUT : 3 PEA : 3 ROSE : 1 SINGLE

(2) Duplicate Gene Interaction (15:1)

Characters showing duplicate gene interaction are determined by two completely dominant genes, which produce the same phenotype whether they are alone (i.e., with the recessive allele of the other gene) or together; the contrasting phenotype is produced only when both the genes are in homozygous recessive state.

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Example —

The nonfloating habit in rice is controlled by two dominant genes Dw_1 and Dw_2.

Genes Dw_1 and Dw_2 alone, e.g., $Dw_1 Dw_1 dw_2 dw_2$, $dw_1 dw_1 Dw_2 Dw_2$, etc., as well as together, e.g., $Dw_1 Dw_1 Dw_2 Dw_2$, etc., produce the same phenotype, viz., nonfloating.

The floating habit is obtained only when both these genes are in the recessive state, e.g., $dw_1 dw_1 dw_2 dw_2$.

When a nonfloating rice strain with the genotype $Dw_1 Dw_1 Dw_2 Dw_2$ is crossed with a floating strain ($dw_1 dw_1 dw_2 dw_2$), the F_1 ($Dw_1 dw_1 Dw_2 dw_2$) is nonfloating. In the F_2 generation, on an average, 15 plants will have one Dw_1 or Dw_2 allele or both these alleles; all these individuals will have nonfloating habit. Only one of the 16 zygotic combinations will be homozygous recessive for both dw_1 and dw_2, and will exhibit the floating habit.

Thus a 15:1 ratio is obtained in F_2 generation.

Parents → $Dw_1 Dw_1 Dw_2 Dw_2$ (Nonfloating) × $dw_1 dw_1 dw_2 dw_2$ (Floating)

Gametes → $Dw_1 Dw_2$; $dw_1 dw_2$

F_1 → $Dw_1 dw_1 Dw_2 dw_2$ (Nonfloating)

F_2 →

♀ \ ♂	$Dw_1 Dw_2$	$Dw_1 dw_2$	$dw_1 Dw_2$	$dw_1 dw_2$
$Dw_1 Dw_2$	$Dw_1 Dw_1 Dw_2 Dw_2$ (N)	$Dw_1 Dw_1 Dw_2 dw_2$ (N)	$Dw_1 dw_1 Dw_2 Dw_2$ (N)	$Dw_1 dw_1 Dw_2 dw_2$ (N)
$Dw_1 dw_2$	$Dw_1 Dw_1 Dw_2 dw_2$ (N)	$Dw_1 Dw_1 dw_2 dw_2$ (N)	$Dw_1 dw_1 Dw_2 dw_2$ (N)	$Dw_1 dw_1 dw_2 dw_2$ (N)
$dw_1 Dw_2$	$Dw_1 dw_1 Dw_2 Dw_2$ (N)	$Dw_1 dw_1 Dw_2 dw_2$ (N)	$dw_1 dw_1 Dw_2 Dw_2$ (N)	$dw_1 dw_1 Dw_2 dw_2$ (N)
$dw_1 dw_2$	$Dw_1 dw_1 Dw_2 dw_2$ (N)	$Dw_1 dw_1 dw_2 dw_2$ (N)	$dw_1 dw_1 Dw_2 dw_2$ (N)	$dw_1 dw_1 dw_2 dw_2$ (F)

(N) = Nonfloating (F) = Floating phenotypic ratio in F_2 = 15 : 1

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Thus in duplicate gene interaction, the presence of a single dominant allele of any one of the two genes governing the trait produces the dominant phenotype, while the recessive phenotype is produced only when both the genes are in the homozygous recessive state.

A similar gene interaction governs fruit shape in Shepherd's purse (*Capsella bursa-pastoris*), nodulation in groundnut and certain traits in many other organisms.

③ Complementary Gene Interaction (9:7)

(i) In this type of gene interaction production of one of the two phenotypes of a trait requires the presence of dominant alleles of both the genes controlling the concerned trait.

(ii) When any of the two or both the genes are present in the homozygous recessive state, the contrasting phenotype is produced.

Example –

(i) In sweet pea, the development of coloured flowers requires the presence of two dominant genes, C and R, e.g., CCRR.

(ii) When either C (e.g., ccRR) or R (e.g., CCrr) or both the genes (e.g., ccrr) are present in homozygous recessive condition, white flowers are obtained.

(iii) When a coloured flower variety of sweet pea (CCRR) is crossed with a white flowered variety with the genotype ccrr, the F_1 (CcRr) has coloured flowers. In the F_2 generation,

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on an average 9 plants will have at least one dominant allele of both the genes C and R; these plants will produce coloured flowers. The remaining 7 plants will be homozygous for c (e.g., cc), r (e.g., rr) or both (ccrr); all these plants will have white flowers.

(iv) Complementary gene interaction modifies the typical 9:3:3:1 ratio of F_2 into a 9:7 ratio.

(v) A similar complementary gene action controls the development of aleurone (grain) colour in maize, HCN (Hydrocyanic Acid) production in clovers and other traits in several organisms.

Parents → CCRR (Coloured) × ccrr (White)

Gametes → CR, cr

F_1 → CcRr (Coloured)

♀ \ ♂	CR	Cr	cR	cr
CR	CCRR (P)	CCRr (P)	CcRr (P)	CcRr (P)
Cr	CCRr (P)	CCrr (W)	CcRr (P)	Ccrr (W)
cR	CcRR (P)	CcRr (P)	ccRR (W)	ccRr (W)
cr	CcRr (P)	Ccrr (W)	ccRr (W)	ccrr (W)

(P) = Coloured; (W) = White; F_2 Phenotypic ratio = 9 : 7

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④ Supplementary Gene Interaction (9:3:4)

(i) In supplementary gene interaction, the dominant allele of one of the two genes governing a character produces a phenotypic effect.

(ii) However, the dominant allele of the other gene does not produce a phenotypic effect on its own. But when it is present with the dominant allele of the first gene, it modifies the phenotypic effect produced by that gene.

Example – In rats and guinea pigs, coat colour is governed by two dominant genes A and C. The agouti coloured guinea pigs have genotype CCAA. The black mice possesses the factor for black colour (C) but not the gene A for agouti colour.

If gene for black colour is absent, agouti is unable to express itself and mice with a genotype ccAA are albino.

Here presence of gene C produced black colour and addition of gene A changes its expression to agouti colour.

The F2 phenotypic ratio becomes 9:3:4.

P1 → Agouti CCAA × Albino ccaa

P1 Gametes → (CA) (ca)

F1 → CcAa Agouti

F1 gametes → CA cA Ca ca

F2 →

♀ \ ♂	CA	cA	Ca	ca
CA	CCAA Agouti	CcAA Agouti	CCAa Agouti	CcAa Agouti
cA	CcAA Agouti	ccAA Albino	CcAa Agouti	ccAa Albino
Ca	CCAa Agouti	CcAa Agouti	CCaa Black	Ccaa Black
ca	CcAa Agouti	ccAa Agouti	Ccaa Black	ccaa Albino

Agouti : Black : Albino = 9 : 3 : 4

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(5) Inhibitory Gene Interaction (13:3)

(i) In this kind of gene interaction, one of the two completely dominant genes produces the concerned phenotype, while its recessive allele produces the contrasting phenotype.

(ii) The second dominant gene, called inhibitory gene, has no effect of its own on the character in question; however, it can stop the expression of the dominant allele of the first gene. As a result, when the two dominant genes are present together, they produce the same phenotype as that produced by the recessive homozygote of the first gene.

(iii) The recessive allele of the ~~first~~ second gene does not affect development of the character.

(iv) The 9:3:3:1 F_2 ratio is modified to 13:3 ratio in this case.

Example: (i) Inhibitory gene interaction occurs in the development of aleurone colour in maize.

(ii) A dominant gene R produces red colour, while its recessive allele r produces no colour.

(iii) Another dominant gene I does not produce any colour by itself; it only prevents colour production by R when both I and R are present together.

(iv) The recessive allele i does not affect colour production.

As a result, colour in aleurone is produced only when R is present with the homozygous recessive allele of the inhibitory locus (RRii).

(v) When a maize inbred with red aleurone (RRii) is crossed with another

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inbred having the genotype rrII and white grains, the F_1 (RrIi) has white grains since gene I stops colour production by R-gene.

(vi) In the F_2 generation, nine seeds will have at least one dominant allele of both R and I; these seeds will be white in colour.

Three seeds will have the dominant allele R, but will be homozygous for the recessive allele i; these seeds will develop red colour.

Three other seeds will be homozygous rr, but will have dominant allele I, while the remaining one seed will be homozygous recessive for both the genes (rrii); these four seeds also will be white.

(vii) Thus in the case of inhibitory gene interaction, one dominant inhibitory gene prevents the expression of another dominant gene. This modifies the typical 9:3:3:1 F_2 ratio into a 13:3 ratio and leads to an excess of the recessive phenotype (white grain) produced by the recessive allele of the dominant gene (R).

Parents: RRii (Red) × rrII (White)

Gametes: Ri, rI

F_1: RrIi (White)

F_2:

♀ \ ♂	RI	Ri	rI	ri
RI	RRII White	RRIi White	RrII White	RrIi White
Ri	RRIi White	RRii Red	RrIi White	Rrii Red
rI	RrII White	RrIi White	rrII White	rrIi White
ri	RrIi White	Rrii Red	rrIi White	rrii White

F_2 Phenotypic Ratio: 13 White : 3 Red

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⑥ Masking Gene Interaction (12:3:1) [Epistasis]

(i) In this interaction, dominant alleles of the two genes affecting the same character produce distinct phenotypes when they are with homozygous recessive state of the other gene. But when dominant alleles of both the genes are present together, the expression of one gene masks that of the other.

(ii) When both the genes are present in the recessive state, a different phenotype is produced.

(iii) Thus, in this case, both the genes express themselves when their dominant alleles are present together, but the expression of one gene is so intense or strong that the expression of the other gene cannot be observed. That is why this gene interaction is called <u>masking gene interaction (Epistasis)</u>.

<u>Example:</u>

(i) Seed coat colour in barley is governed by two dominant genes B and Y.

(ii) Gene B leads to the development of black colour, while its recessive allele b produces white seed coats.

(iii) The other gene Y produces yellow seed coats, while its recessive allele (y) also gives rise to white seed coat colour.

(iv) When the dominant allele of B and Y genes are present together, both the genes express themselves. However, the black colour produced by the gene B is so intense that it does not permit the detection of yellow colour produced by Y.

(v) When a barley strain with black seed coat and the genotype BByy is

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crossed with another strain having yellow seed coat (bbYY), the F_1 (BbYy) plants produce seeds having black seed coat.

In the F_2, on an average, 9 plants will have at least one dominant allele of both the genes B and Y; these will develop black seed coats.

Three of the 16 zygotic combinations will have a dominant allele of B, but will be homozygous for the recessive allele y (BByy, Bbyy). Seeds of these plants will also have black coat.

In three other plants, recessive allele b will be in homozygous state, while one or two dominant alleles of Y gene will be present (bbYY, bbYy); these plants will produce yellow seed coats.

The remaining one genotype (bbyy) is homozygous recessive for both the genes, and will develop white seed coat colour. As a consequence of <u>masking gene action</u>, the 9:3:3:1 ratio is modified into 12:3:1 ratio.

Parents: BByy (Black) × bbYY (Yellow)

Gametes: (By) (bY)

F_1: BbYy (Black)

F_2:

♀ \ ♂	BY	By	bY	by
BY	BBYY Black	BBYy Black	BbYY Black	BbYy Black
By	BBYy Black	BByy Black	BbYy Black	Bbyy Black
bY	BbYY Black	BbYy Black	bbYY Yellow	bbYy Yellow
bY	BbYY Black	BbYy Black	bbYY Yellow	bbyy White

F_2 phenotypic ratio: 12 Black : 3 Yellow : 1 White

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7. Polymeric Gene Interaction (9:6:1)

(i) In this interaction of genes, two completely dominant genes controlling a character produce identical phenotypes when their dominant alleles are present with the homozygous recessive condition of the other gene.

(ii) But when dominant alleles of both the genes are present together, their phenotypic effect is enhanced as if the effects of the two genes were cumulative or additive.

(iii) It should be noted that if the two genes showing polymeric gene action also show an absence of dominance, an additive gene action will result.

Example: (i) In barley, two completely dominant genes A and B affect the length of awns.

(ii) Gene A or B alone (e.g., AAbb and aaBB respectively) gives rise to awns of medium length.

- But when both the genes A and B are present together, they produce long awns.

- Individuals homozygous recessive for both these genes are awnless.

(iii) When a long-awned (AABB) variety of barley is crossed with an awnless (aabb) one, the F_1 (Aa Bb) has long awns. In the F_2 generation, on an average, nine plants will have dominant alleles of both the genes A and B; as a result, these plants will produce long awns. Three plants will have at least one dominant allele of A, but will be homozygous for b, while three others will be homozygous for a, but will have at least one dominant allele of B.

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All these six plants will have medium-sized awns. The remaining one plant will be homozygous recessive for both the genes (aabb) and will, therefore, be awnless.

Parents → AABB (Long Awn) × aabb (Awnless)

Gametes → (AB) (ab)

F_1 → AaBb (Long Awn)

F_2

♀ \ ♂	AB	Ab	aB	ab
AB	AABB Long Awn	AABb Long Awn	AaBB Long Awn	AaBb Long Awn
Ab	AABb Long Awn	AAbb Medium Awn	AaBb Long Awn	Aabb Medium Awn
aB	AaBB Long Awn	AaBb Long Awn	aaBB Medium Awn	aaBb Medium Awn
ab	AaBb Long Awn	Aabb Medium Awn	aaBb Medium Awn	aabb Awnless

F_2 ratio: 9 (Long Awn) : 6 (Medium Awn) : 1 (Awnless)

(iv) Thus polymeric gene interaction changes the typical 9 : 3 : 3 : 1 F_2 ratio into a 9 : 6 : 1 ratio.

Modifications of the Gene Interaction F_2 Ratios:

In all the foregoing examples, complete dominance is the rule at both the loci affecting the same character. Several modifications of these ratios are possible due to one or more of the following:

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(1) Involvement of more than two genes in the same type of interaction, e.g. three complementary genes governing aleurone colour in maize;

(2) Involvement of three or more genes exhibiting different type of interaction, e.g., genes R, Pr and I governing aleurone colour in maize;

(3) Partial dominance at one or both the loci;

(4) Dominance modification at one or both the loci; and

(5) Lethal gene action at either or both the loci.

<u>Modifying Genes:</u>

Modifying genes are a group of genes which enhance and/or reduce the phenotypic effect produced by a major gene. Such genes have small cumulative effect on the expression of that major gene the activity of which they modify. As a result, a continuous variation is generated in the phenotype governed by a single major gene; this converts an otherwise qualitative character into a quantitative one. Modifying genes exert a variety of influences:

- Alteration of dominance relationship at a locus
- Generation of quantitative variation in a character produced by a major gene, and
- Suppression of mutant alleles of some genes.

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