Mendelian crosses and ratios

Contents: Contrasting characters that Mendel studied (1857-65)**;** Monohybrid crosses**;** Dihybrid crosses; Trihybrid crosses; Methods of analyses; Determination of phenotypic ratios; Determination of genotypic ratios; Formulae for calculating different parameters; Suggested reading.

Contrasting characters that Mendel studied (1857-1865)

For his experiments with garden peas, Mendel chose seven contrasting characters that were well-defined and easily recognizable. The characters included length of the stem (tall or dwarf), form of the ripe seed (round or wrinkled), colour of the seed cotyledons (yellow or green), form of the ripe pods (inflated or constricted), colour of the seed coat (grey or white), colour of the unripe pods (green or yellow), and position of the flower (axial or terminal). The traits mentioned in the parentheses are dominants and recessives, respectively.

Monohybrid crosses: Crosses between two parents that differ *in only one contrasting heritable character* under consideration. A few examples from plants and animals are described below.

1. TT (Tall plant) × tt (dwarf plant) in garden peas
2. BB (Black hair) × bb (white hair) in guinea pigs
3. ++ (Grey body) × bb (black body) in fruit flies

A monohybrid cross in garden peas *Pisum sativum*

P:	♂♂ Tall plant (TT) ×	♀♀ dwarf plant (tt)	
G:	T	t	
F_1:	Tt (all Tall plants)		
G:	T, t	T, t	
$F_1 \times F_1$:	Tt ×	Tt	
F_2:	TT:	Tt:	tt
Phenotypes:	Tall	Tall	dwarf
Genotypic ratio:	1 (homo):	2 (hetero):	1 (homo)
Phenotypic ratio:	3 Tall: 1 dwarf	=4 types of offspring	

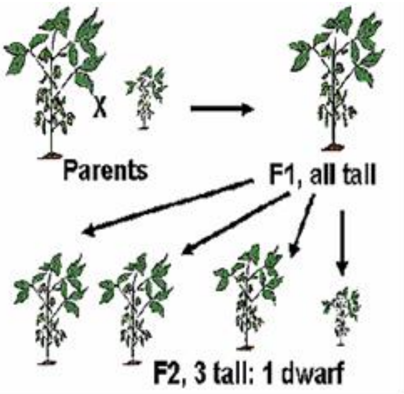


Fig 2.1 Monohybrid cross in garden peas and its phenotypic ratio in F_2

A monohybrid cross in guinea pigs *Cavia porcellus*

P: ♂♂ Black hair (BB) × ♀♀ white hair (bb)

G: B b

F_1: Bb (all Black hair)

G: B, b B, b

$F_1 \times F_1$: Bb × Bb

F_2:	BB:	Bb:	bb
Phenotypes:	Black	Black	white
Genotypic ratio:	1 (homo):	2 (hetero):	1 (homo)
Phenotypic ratio:	3 Black:	1 white =4 types of offspring	

Punnett square (checkerboard):

♂♂/♀♀	B	b
B	BB	Bb
b	Bb	bb

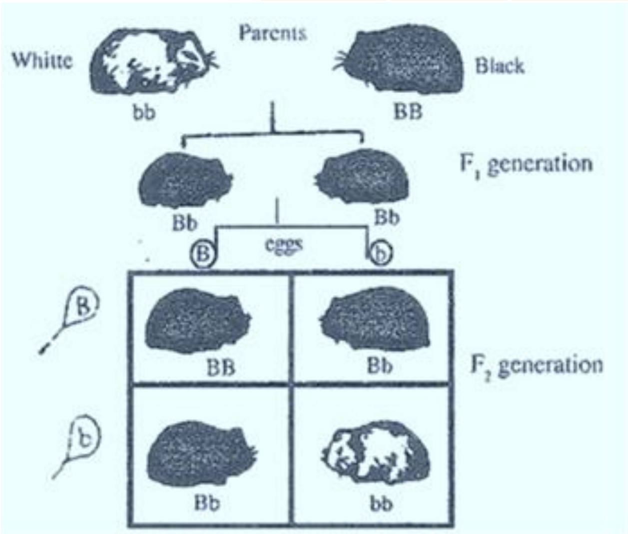


Fig 2.2 Monohybrid cross in guinea pigs and its phenotypic ratio in F_2

A monohybrid cross in fruit flies *Drosophila melanogaster*

P: ♂♂ Grey body (++) × ♀♀ black body (bb)

G: + b

F_1: +b (all Grey)

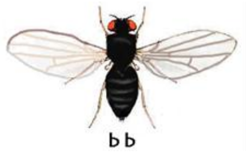
G: +, b +, b

$F_1 \times F_1$: +b × +b

F_2:	++:	+b:	bb
Phenotypes:	Grey	Grey	black
Genotypic ratio:	1 (homo):	2 (hetero):	1 (homo)
Phenotypic ratio:	3 Grey:	1 black	=4 types of offspring

Punnett square (checkerboard):

♂♂/♀♀	+	b
+	++	+b
b	+b	bb



Grey-bodied (++)   black bodied

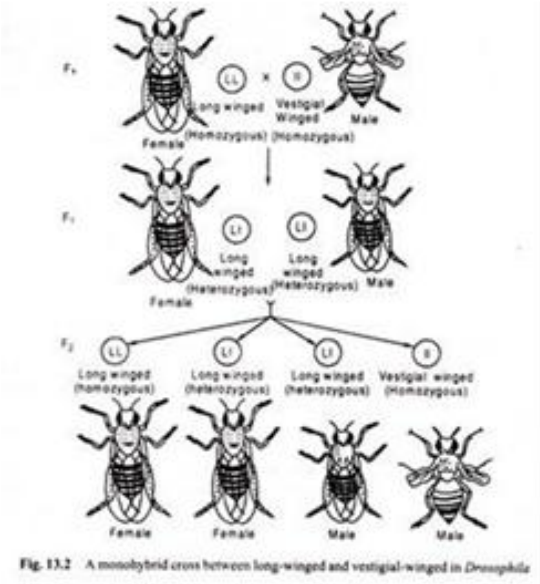


Fig 2.3 Monohybrid cross in *Drosophila* and its phenotypic ratio in F_2

Dihybrid crosses: Crosses between individuals differing in *two contrasting heritable characters* under consideration. Examples of such crosses from plants and animals are narrated below.

TTRR (Tall-Round) × tt (dwarf-wrinkled) in garden peas
BBSS (Black-Short) × bbss (white-long) in guinea pigs
++++ (Grey-Long) × bbvgvg (black-vestigial) in fruit flies

A dihybrid cross in garden peas

P: ♂♂Tall-Round (TTRR) × ♀♀dwarf-wrinkled (ttrr)
G: TR tr
F_1: TtRr (all Tall-Round)
$F_1 \times F_1$: TtRr × TtRr
G: TR, Tr, tR, tr TR, Tr, tR, tr
F2: 9T-R-: 3T-rr: 3ttR-: 1ttrr
Phenotypes: 9Tall-Round: 3Tall-wrinkled: 3dwarf-Round: 1dwarf-wrinkled
Punnett square: 4 × 4 = 16 types

♂♂/♀♀	TR	Tr	tR	tr
TR	TTRR	TTRr	TtRR	TtRr
Tr	TTRr	Ttrr	TtRr	Ttrr
tR	TtRR	TtRr	ttRR	ttRr
tr	TtRr	Ttrr	ttRr	ttrr

A dihybrid cross in guinea pig

P: ♂♂Black-Short (BBSS) × ♀♀white-long (bbss)

G: BS bs

F_1: BbSs (all Black-Short)

$F_1 \times F_1$: BbSs × BbSs

G: BS, Bs, bS, bs BS, Bs, bS, bs

F_2: 9B-S-: 3B-ss: 3bbS-: 1bbss

Phenotypes: 9Black-Short: 3Black-long: 3white-Short: 1white-long

Punnett square: 4 × 4 = 16 types

♂♂/♀♀	BS	Bs	bS	bs
BS	BBSS	BBSs	BbSS	BbSs
Bs	BBSs	BBss	BbSs	Bbss
bS	BbSS	BbSs	bbSS	bbSs
bs	BbSs	Bbss	bbSs	bbss

P:  × 

Black-Short (BBSS) white-long (bbss)

F_1: Black-Short (BbSs)

$F_1 \times F_1$:

BbSs x BbSs

	BS	Bs	bS	bs
BS	BBSS	BBSs	BbSS	BbSs
Bs	BBSs	BBss	BbSs	Bbss
bS	BbSS	BbSs	bbSS	bbSs
bs	BbSs	Bbss	bbSs	bbss

Fig 2.4 Dihybrid cross in guinea pigs and its phenotypes in F_2

A dihybrid cross in *D. melanogaster*

P: ♂♂Grey-Long (++++) × ♀♀black-vestigial (bbvgvg)

G: ++ bvg

F_1: +b+vg (all Grey-Long)

$F_1 \times F_1$: +b+vg × +b+vg

G: ++, +vg, b+, bvg ++, +vg, b+, bvg

F_2: 9+-+-: 3+-vgvg: 3bb+-: 1bbvgvg

Phenotypes: 9Grey-Long: 3Grey-vestigial: 3black-Long: 1black-vestigial

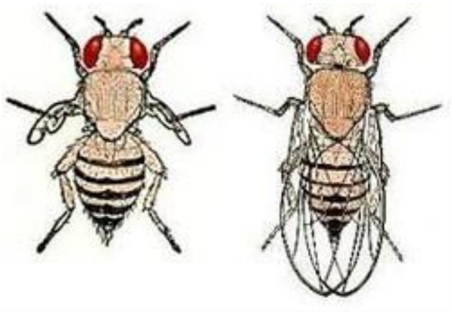


Fig 2.4 Black-vestigial (left) and grey-long parents of *Drosophila*

Punnett square for a dihybrid cross in *Drosophila* showing 16 types of progenies in F_2.

♂♂/♀♀	++	+vg	b+	bvg
++	++++	+++vg	+b++	+b+vg
+vg	+++vg	++vgvg	+b+vg	+bvgvg
b+	+b++	+b+vg	bb++	bb+vg
bvg	+b+vg	+bvgvg	bb+vg	bbvgvg

Trihybrid cross: A cross between individuals differing in *three contrasting heritable characters* under consideration, *e.g*. TTRRYY × ttrryy. Example of a trihybrid cross in garden peas is described below.

A trihybrid cross in garden peas

P: ♂♂Tall-Round-Yellow (TTRRYY) × ♀♀dwarf-wrinkled-green (ttrryy)

G: TRY try

F_1: TtRr Yy (all Tall-Round-Yellow)

$F_1 \times F_1$: TtRrYy × TtRrYy

G: TRY, TRy, TrY, Try, tRY, tRy, trY, try;TRY, TRy, TrY, Try, tRY, tRy, trY, try

Punnett square: 8 × 8 = 64 types

♂♂/♀♀	TRY	TRy	TrY	Try	tRY	tRy	trY	try
TRY	TTRRYY	TTRRYy	TTRrYY	TTRrYy	TtRRYY	TtRRYy	TtRrYY	TtRrYy
TRy	TTRRYy	TTRRyy	TTRrYy	TTRryy	TtRRYy	TtRRyy	TtRrYy	TtRrYy
TrY	TTRrYY	TTRrYy	TTrrYY	TTrrYy	TtRrYY	TtRrYy	TtrrYY	TtrrYy
Try	TtRRYy	TTRrYy	TTrrYy	TTrryy	TtRrYy	TtRryy	TtrrYy	Ttrryy
tRY	TtRRYY	TtRRYy	TtRrYY	TtRrYy	ttRRYY	ttRRYy	ttRrYY	ttRrYy
tRy	TtRRYy	TtRRyy	TtRrYy	TtRryy	ttRRYy	ttRRyy	ttRrYy	ttRryy
trY	TtRrYY	TtRrYy	TtrrYY	TtrrYy	ttRrYY	ttRrYy	ttrrYY	ttrrYy
try	TtRrYy	TtRryy	TtrrYy	Ttrryy	ttRrYy	ttRryy	ttrrYy	ttrryy

F_2: 27T-R-Y-: 9T-R-yy: 9T-rr-Yy: 3T-rryy: 9ttR-Y-: 3ttR-yy: 3ttrrY-: 1ttrryy

Phenotypes: 27 Tall-Round-Yellow; 9 Tall-Round-green; 9 Tall-wrinkled-Yellow; 3 Tall-wrinkled-green; 9 short-Round-Yellow; 3 short-Round-green; 3 short-wrinkled-Yellow; 1 short-wrinkled-green =64 types of offspring.

Mendelian crosses: Methods of Analyses

There are two common methods of analyses for Mendelian crosses. These include:

1. **Punnett square method** (examples in Burns, 1980)
2. **Forked-line method** (examples in Gardner *et al*., 1991)

The Punnett square method has been described in earlier examples. Here, the forked-line method of analysis is shown below.

Forked-line method (dihybrid cross):

P: TTRR × ttrr

F_1: TtRr

$F_1 \times F_1$: TtRr × TtRr

F_2: 3 Tall< 3 Round =9 Tall-Round

1 wrinkled =3 Tall-wrinkled

1 short< 3 Round =3 short-Round

1 wrinkled =1 short-wrinkled

=16 types of offspring

Forked-line method (trihybrid cross):

$F_1 \times F_1$: TtRrYy × TtRrYy

F_2:	3 Tall<	3 Round <	3 Yellow	=27Tall-Round-Yellow
			1 green	=9Tall-Round-green
		1wrinkled <	3 Yellow	=9Tall-wrinkled-yellow
			1 green	=3Tall-wrinkled-green
	1 short<	3 Round <	3 Yellow	=9short-Round-Yellow
			1 green	=3short-Round-green
	1wrinkled <	3 Yellow		=3short-wrinkled-Yellow
			1 green	=1short-wrinkled-green
				= 64 types of offspring

Determination of phenotypic and genotypic ratios

Phenotypic ratios

Monohybrid crosses: 3: 1 = 4 types of offspring

Dihybrid crosses: 3: 1 × 3: 1= 9: 3: 3: 1 = 16 types of offspring

Trihybrid crosses: 3: 1 × 3: 1 × 3: 1 = 27: 9: 9: 3: 9: 3: 3: 1 = 64 types of offspring

Genotypic ratios

Monohybrid crosses: 1: 2: 1 = 4 types of offspring

Dihybrid crosses: 1: 2: 1 × 1: 2: 1 = 1: 2: 1: 2: 4: 2: 1: 2: 1 = 16 types of offspring

Trihybrid crosses: 1: 2: 1 × 1: 2: 1 × 1: 2: 1= 1: 2: 1: 2: 4: 2: 1: 2: 1: 2: 4: 2: 4: 8: 4: 2: 4: 2: 1: 2: 1: 2: 4: 2: 1: 2: 1 = 64 types of offspring

Formulae for calculating different parameters in Mendelian crosses

Parameters like number of gamete genotypes, numbers of progeny phenotypes and genotypes and total number of progeny types are calculated by simple formulae shown in the table below:

Pairs of contrasting characters	Number of gamete genotypes	Number of progeny phenotypes	Number of progeny genotypes	Total number of Progeny types
1 (TT×tt)	2	2 (3: 1)	3 (1: 2: 1)	4 (3+1)
2 (TTRR×ttrr)	4	4 (9: 3: 3: 1)	9 (1:2:1:2:4:2:1:2:1)	16 (9+3+3+1)
3 (TTRRYY×ttrryy)	8	8 (27:9:9:3:9:3:3:1)	27 (1:2:1:2:4:2:1:2:1…:1)	64 (27+9+....+1)
n	2n	2n	3n	4n

Ref: G. W. Burns (1980)

Suggested reading:

Ayala & Kiger, 1980. *Modern Genetics*.
Burns, GW. 1980. *The Science of Genetics*.
Gardner *et al*. 1991. *Principles of Genetics* (8th edn)
Islam, MS. 2018. Selected Lectures on Genetics. LAP Lambert Academic Publishing, Germany.
Sinnott *et al.* 1973. *Principles of Genetics* (5th edn)
Stansfield, WD. 1991. *Theory and Problems of Genetics* (3rd edn)
Strickberger, MW. 1976. *Introduction to Genetics.*
Winchester, AM. 1966. *Genetics*.
ইসলাম, ম.সা., খান, হা.সা. ও রানা, ম.হা.তা. ২০১৭। *জেনেটিক্স: মিল ও অমিলের বিজ্ঞান*। অন্যপ্রকাশ, ঢাকা।