Lecture 33
Agricultural Scientific Revolution: Genetic and Biological

Ancient Empirical Knowledge of Inheritance
- *Like begets Like*
- Beginning of genetic wisdom

Virgil's Georgics

When she has calved, then set the dam aside;
And for the tender progeny provide;
Distinguish all betimes with branding fire,
To note the tribe, the lineage, and the sire;
Whom to reserve for husband of the herd;
Or who shall be to sacrifice preferred;
Of whom thou shalt to turn thy glebe (soil) *allow,*
To smooth the furrows, and sustain the plough;
The rest, for whom no lot is yet decided,
May run in pastures, and at pleasure fed.

Shakespeare

My hounds are bred out of the Spartan kind,
So flew'd, so sanded, and their heads are hung
With ears that sweep away the morning dew;
Crook-knee'd, and dewlapp'd like Thessalian bulls;
Slow in pursuit, but match'd in mouth like bells,
Each under each

Midsummer's Nights Dream 4.1.119–124

Rudolph Camerarius (1665–1721)

Professor Botanic Gardens at Tübingen, 1688.

Through study of dioecious and monoecious plants explains function of pollen and egg; considered apices with pollen as male, first modern understanding of plant sexuality.

18th & 19th Century Experiments Hybridizing

Joseph Gottlieb Koelreuter (1733–1806)

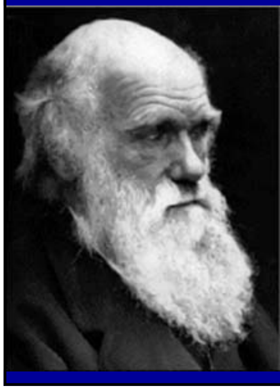
- First systematic experiments on plant hybridization using tobacco (*Nicotiana paniculata* × *N. rustica*)
- Demonstrated that hybrids resemble both parents
- Experimentally verified the genetic contribution of pollen
- First observed hybrid vigor (heterosis)

Thomas Andrew Knight (1759–1838)

Described dominance and segregation in the garden pea but failed to make the brilliant leap of Mendel

Initiated fruit breeding

Charles Darwin (1809–1882)



On the Origin of the Species (1859)
Discuses variability and evolution but does not have a rational genetic explanation

Gregor Mendel (1822–1884)
Father of Genetics

- Priest in Brünn, Austro-Hungarian Empire now Brno, Czech republic
- Crosses peas, intercrosses progeny, classifies and counts segregation of traits
- Paper formulates the "Laws of Genetics" concerning transmission of genetic information

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- Delivers 2 lectures at the Brünn Society for the Study of Natural History (1865)
- Famous paper, *Experiments on Plant Hybrids,* published in 1866; widely distributed, but basically unread or not fully understood
- The most famous paper in biology (up to Watson-Crick's paper on the structure of DNA) was written by a horticulturist

Classical Genetics (Transmission Genetics)

- Selected seven lines of peas with different traits
- tall and dwarf plant, round and wrinkled seeds, yellow or green seed, green or dark pods, smooth or constricted pods, axillary or terminal flowers)
- In these lines, traits were constant when self pollinated (bred true)
- Tall × tall (selfed or intercrossed) gave tall progeny
- Dwarf plants (selfed or intercrossed) gave dwarf progeny

- Crossing peas with certain contrasting traits (tall × dwarf) produced progeny with one of the two traits suggesting that one traits dominates the other
- Thus, when tall is crossed with dwarf (the source of the pollen is immaterial) the progeny was tall
- Thus, the factor responsible for tallness was dominant over dwarf
- Dwarf is said to be recessive to tall

- In the next generation, when the tall hybrids were selfed or intercrossed, the resulting offspring segregated for both traits (either tall plants or dwarf plants)
- The ratio of the two classes was predictable: 3 plants with the dominant trait (tallness) and one plant of the recessive trait (dwarf)
- The recessive plants bred true when selfed
- But the plants with the dominant trait (tall) show two types of segregation
- One third of them bred true for tallness and two thirds produced a 3:1 ratio of tall to dwarf

Furthermore, when the tall hybrid plant was crossed to the tall parent, all the offspring were tall

When the tall hybrid was crossed to the dwarf parent the offspring segregated in a ratio of 1 tall:1 dwarf

Segregation of plants with different traits (say tallness and seed color) segregated independently

These results could be explained by assuming each trait was controlled by a controlling element or factor (now known as a gene)

These results are explainable assuming true-breeding tall plants contained the gene *T* in a doubled form (*TT*) and that true-breeding dwarf plants contained the gene t in a doubled form (*tt*).

The gametes contain only 1 copy of each gene pair.

Tall (*TT*) × dwarf (*tt*) produced tall hybrids (*Tt*) because *T* dominated *t*.

Intercrossing the hybrids (*Tt*) produced progeny in a ratio of 3 tall to 1 dwarf

$Tt \times Tt \rightarrow$ 1 *TT* : 2 *Tt* : 1 *tt* (3 tall : 1 dwarf)

In the backcross of hybrids to parents

$Tt \times TT \rightarrow$ 1 *TT* : 1 *Tt* (all tall)
$Tt \times tt \rightarrow$ 1 *Tt* : 1 *tt* (1 tall : 1 dwarf)

The "gene" conditioning each trait can have different forms now called "alleles"

The mature plants had two alleles; the gametes had only one of each alleles

Thus, tall plants that bred true were *TT*; all gametes were *T*

Dwarf plants that bred true were *tt*; all gametes were *t*

The hybrid was *Tt*; it was tall indicating that *T* dominates *t* in expression; gametes had *T* or *t*

When hybrids were selfed or crossed (*Tt* × *Tt*) the *T* or *t* gametes combined at random, the offspring were either *TT*, *tT*, *Tt*, or *tt* or 1*TT* : 2*Tt* : 1*tt*. This is the F_2 generation

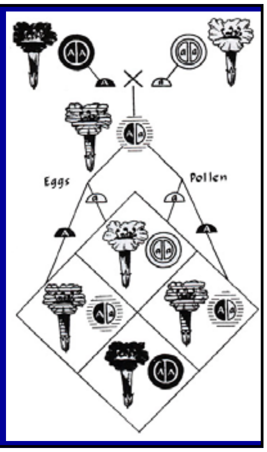
Because *Tt* is tall the "phenotypic" ratio was 3 tall to 1 dwarf

Of the tall progeny, 1/3 (*TT*) were true breeding for tallness while 2/3 (*Tt*) segregated in a ratio of 3 tall : 1 dwarf

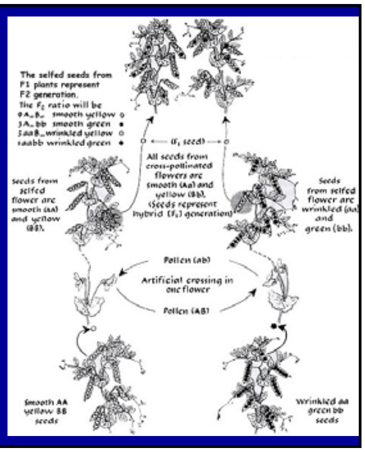
Backcross ratios (F_1 hybrid × parents)
Tt × *TT* gave all tall progeny;
Tt × *tt* produced 3 tall : 1 dwarf

Mendelian segregation illustrating incomplete dominance in the four o'clock (*Mirabilis jalapa*)

Note that the phenotypic ratio of 1 red:2 pink:1 white is also 3 colored:1 noncolored



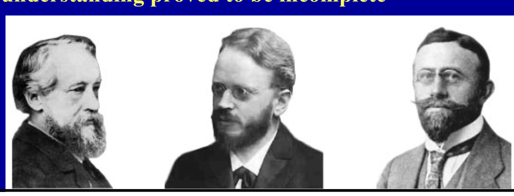
The independent assortment of two genes in peas



- What Mendel proved was that the traits are produced by factors (genes) that pass from one generation to the other
- Furthermore, the factors that control inheritance were not changed by their transmission
- Factors segregated in predictable patterns
- It was inferred that variability was due to the segregation and interaction of different genes

DeVries, Correns, and von Tschermak

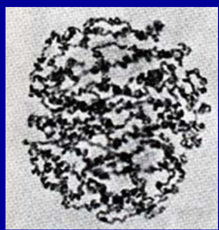
- No one paid much attention to Mendel's paper; although cited, it had no immediate impact
- However, in 1900 three investigators (Hugo DeVries, Carl Correns, and Erich von Tschermak) who were working on inheritance, discovered Mendel's paper
- They cited it to confirm their results, although their understanding proved to be incomplete



- During the interval between 1865 and 1900, the chromosome was discovered
- Chromosome segregation in cell division was studied and it was determined that gametes had half of the chromosomes of the mature organism
- This was to provide a physical mechanism to explain the genetic results of Mendel
- The rediscovery of Mendel had a profound affect on the study of inheritance
- Mendel's factors were renamed "genes" and the science of heredity was renamed "genetics"

Mitosis in the California coastal peony (2*n*=10)

Prophase

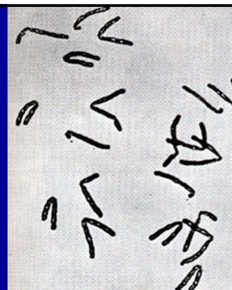


- During this stage the nucleus becomes less granular and the linear structure of the chromosomes can readily be discerned
- Note the chromosome coils

Metaphase

- The 10 chromosomes line up in the equatorial plate, which appear as an "equatorial line" due to the smearing process
- The chromosomes have reduplicated, and each appears visibly doubled

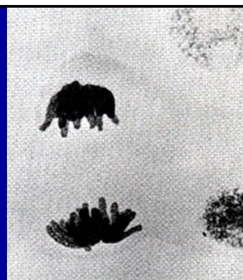
Anaphase



The chromosomes have separated, and approach the poles of the cell

It is possible to pick out the pairs in each group and to match the daughter chromosomes, which have just separated from each other

Telophase



During this stage the contracted chromosomes are pressed close together at each end of the cell

A wall subsequently forms across the cell, making two “daughter” cells with the same number and kind of chromosomes as exist in the original cell

Meiosis in pepper (*Capsicum*)

This species has 24 chromosomes in the vegetative cells (2*n* = 24). Note that there are two divisions.

(A) In the prophase of the first division, the chromosomes reduplicate and pair. A pair of visibly reduplicated chromosomes can be seen in the bottom of the cell.

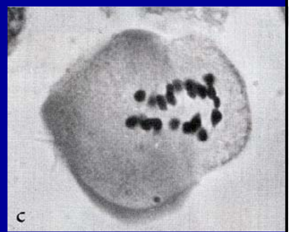
(B) At metaphase of the first division, the 12 chromosome pairs line up on the equatorial plate (face view). Each consists of 2 doubled chromosomes (4 chromatids).

(C) Anaphase of the first division

(D) Telophase of the first division

(E) Metaphase of the second division: One plate is a face view, the other is a side view

(F) Telophase of the second division. Walls will form four pollen grains, each containing 12 chromosomes, half as many as the original cell

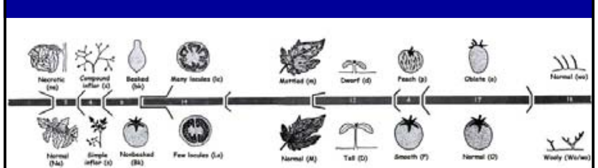


Chromosome Theory of Inheritance

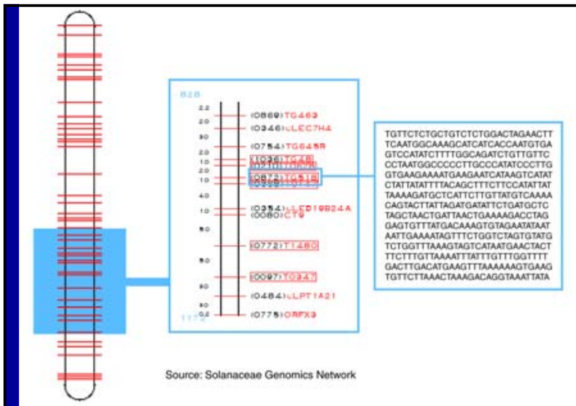
From 1900 to 1925, studies of Thomas Hunt Morgan and students (Bridges, Sturtevant, Muller) demonstrated with the fruit fly *Drosophila* that genes occurred on chromosomes in a linear pattern

Because the chromosomes exchanged segments the distance between the genes could be inferred, i.e. the chromosome could be mapped

Map of chromosome 2 (linkage group I) of tomato



Source: L. Butler, J. Hered. 43:25-35, 1952.



Chromosome 2 of tomato, 2003

Molecular Genetics: The Molecular Basis of Genetics

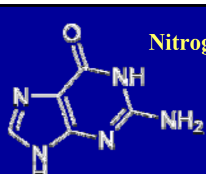
In the 1860s, at the same time that Mendel worked on the transmission of characters a young Swiss chemist, Johann Fredrich Miescher, described a substance he called nuclein derived from pus scraped from surgical bandages

Nuclein shown to contain protein + nucleic acid

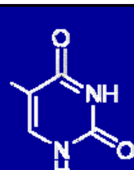
Nucleic acid composed of:
- Nitrogenous bases [adenine (A), guanine (G), cytosine (C), and thymine (T)] discovered by Ascoli (1900);
- Sugar (d-2 deoxyribose); Phosphoric acid

It was renamed deoxyribosenucleic acid (DNA)

Nitrogenous Bases

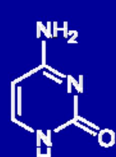


Guanine



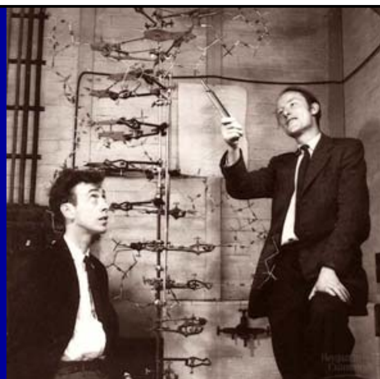
Thymine

Adenine



Cytosine

- A study of the nucleoproteins of bacteriophage (infectious virus infecting bacteria) demonstrated that the genetic material was due to DNA (not the protein)
- The problem was to determine the structure of DNA in order to explain the replication of DNA and how it transmitted genetic information
- In 1956, Watson and Crick demonstrate that DNA had the form of a double helix
- The "rungs" were the four bases ATGC that were distributed along the deoxyribose rails (backbone) of DNA

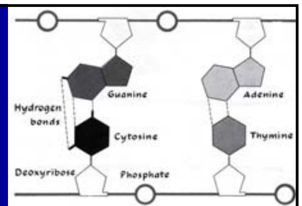


James Watson and Francis Crick

Rosalind Franklin (1920–1958)

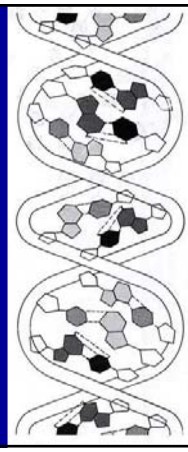
It was the work of Rosalind Franklin, her pictures of the structure of the DNA, the double helix, that revealed the puzzle to James Watson. Yet, he took credit for it. "*Compared with all previous B patterns that Franklin had obtained, these two pictures were vivid, No. 51 especially so. The overall pattern was a huge blurry diamond. The top and bottom points of the diamond were capped by heavily exposed, dark arcs. From the bull's-eye, a striking arrangement of short, horizontal smears stepped out along the diagonals in the shape of an X or a maltese cross. The pattern shouted helix.*"

A portion of the DNA molecule, shown untwisted



- The molecule consists of a long double chain of nucleotides made up of phosphate-linked deoxyribose sugar groups, each of which bears a side group of one of the four nitrogenous bases
- Hydrogen bonds (broken lines) link pairs of bases to form the double chain
- The bases are always paired as shown, although the sequence varies

The double-helix form of the DNA molecule

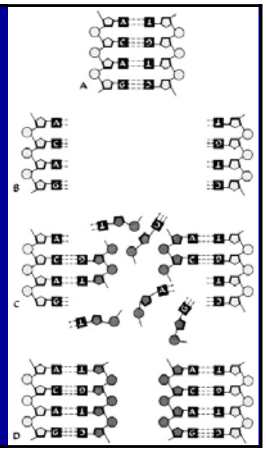


Replication

- Replication of DNA was explained by its structure and the precise base pairing
- Because there was a complementary paring of the bases (A-T, G-C) having one strand after separation could produce a complimentary strand

DNA replication
The linked DNA strands (A) separate in the region undergoing replication (B)

Free nucleotides (indicated by shading) pair with their appropriate partners (C), forming two complete DNA molecules (D)



Genetic Information (The Genetic Code)

The genetic information was shown to be a function of the sequence of three base pairs.

With 4 bases (ATCG), there were 64 different combinations possible, more than enough to account for 20 standard amino acids.

Note that the 26 letters of the alphabet can make up hundreds of three letter words, and these words strung together can make up sentences

The dog was not big.

Thus four letters of DNA (ATCG) in three letter sequences (triplets) can make up 64 combinations, more than enough to produce 20 amino acids

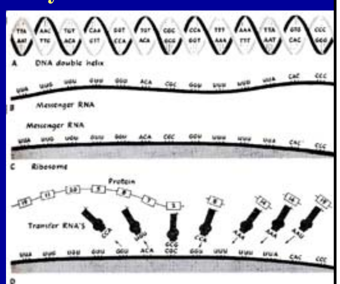
The amino acids depending on the sequence produce proteins

Thus a long sequence of bases can produce millions of proteins

	Second base				
First base	U	C	A	G	Third base
	Phenylalanine	Serine	Tyrosine	Cysteine	U
U	Phenylalanine	Serine	Tyrosine	Cysteine	C
(Uracil)	Leucine	Serine	*Nonsense*	*Nonsense*	A
	Leucine	Serine	*Nonsense*	Tryptophan	G
	Leucine	Proline	Histidine	Argenine	U
C	Leucine	Proline	Histidine	Argenine	C
(Cytosine)	Leucine	Proline	Glutamine	Argenine	A
	Leucine	Proline	Glutamine	Argenine	G
	Isoleucine	Threonine	Asparagine	Serine	U
A	Isoleucine	Threonine	Asparagine	Serine	C
(Adenine)	Isoleucine	Threonine	Lysine	Argenine	A
	Methionine	Threonine	Lysine	Argenine	G
	Valine	Alanine	Asparagine	Glycine	U
G	Valine	Alanine	Asparagine	Glycine	C
(Guanine)	Valine	Alanine	Glutamine	Glycine	A
	Valine	Alanine	Glutamine	Glycine	G

Protein Synthesis

- The complementary code, here derived from the dark-lettered strand of DNA (A), is transferred into RNA (B) and moves to the ribosome (C), the site of protein synthesis
- Amino acids (D, numbered rectangles) are presumably carried to the proper sites on messenger RNA by transfer RNA and are linked to form proteins



- Of course we have rules in English: Words can be any length, and each word consists of consonants & vowels
- There are similar complexities in the Genetic Code
- Proteins are shown to be folded and very complex
- The relation between protein structure and the genetic code is under intense investigation
- The proteins produced particular enzymes which catalyze biochemical reactions
- Molecular Genetics has completed the discovery of Mendel and brought genetics to a new level

Genetic Transformation

The tremendous advances in what is now known as molecular biology were brought about by a number of discoveries in the last half of the 20th century

DNA could be extracted and stored (Libraries are bacterial colonies containing bits of DNA)

DNA could be endless replicated by substances called endonucleases

DNA could be transferred from one organism to another either though a bacterial intermediary *Agrobacterum tumefaciens* or through a gene gun

The relationship and structure of genes produced a new science called genomics

A new science is now emerging on how the proteins actually work: proteinomics

Genetics and Plant Breeding

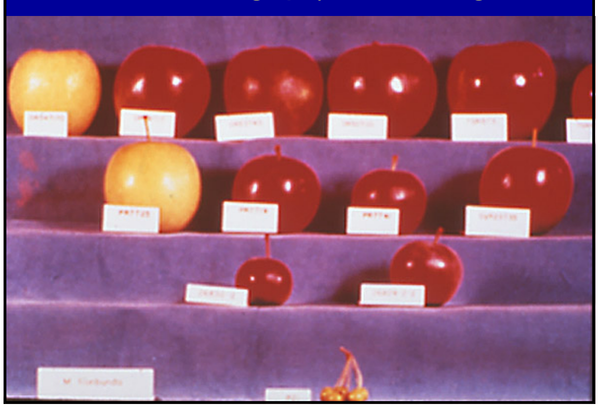
A knowledge of genetics has put plant breeding on a scientific basis

Classical genetics has demonstrated how segregation of different traits through sexual recombination can produce new combination of organisms

The key is genetic segregation plus selection

Science of genetics had a profound effect on plant breeding and horticulture
- Hybrid crops
- Pest resistance
- New traits (seedlessness, supersweet maize, sugarsnap peas)

Transferring *Vf* by Backcrossing



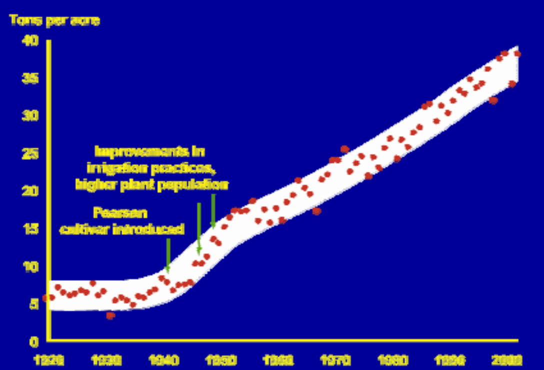
Henry Jones

Male sterility in hybrid onions, non-nuclear inheritance

Norman Borlaug

Green revolution, short stemmed wheat

Processing tomato production (tons/acre) 1920–2002



Plant Breeding

However, classical plant breeding is limited by the genetic variation available and the limits of genetic recombination

Molecular genetics has made possible a new level of plant breeding by making it possible to transmit genetic information between all organisms

(Genetic Engineering or Transgene Genetics)

We are truly entering a New World