Seeds – Part 1

Seeds are central to life on Earth:

1. Establish a new plant (propagation)
2. Food for humans and animals
3. Genetic repository
4. Some things are not possible without seeds …
Seeds – Part 1

• Seeds play a large part in the Rose Parade
Seeds – Part 1

• Imagine your world without seeds
Seeds – Part 1

• Imagine your world without seeds
Seeds – Part 1

- Imagine your world without seeds
Seeds – Part 1

• Imagine your world without seeds
Seeds are responsible for efficient and profitable agriculture
Perfect repository for genes
Seeds – Part 1

- Seeds are responsible for the success of angiosperms
  (seed-like structures ~ 360 million years bp, late Devonian period)
Seed plants began ~ 360 MYA exploded during Cenozoic era
Early land plants along the estuary margin, 400 million years ago
Painting by J. Pennanen for the New Brunswick Museum
Figure 21. Reconstruction of a tropical peat swamp of Middle Pennsylvanian age (about 300 million years ago). The taller plants were tree lycopsids (Lepidophloios), some of which grew to heights of 80 to 100 ft. Today, the lycopsids are represented by lowly club mosses. Other plants include cordaites (B), which were seed plants with strap-shaped leaves that are now extinct; tree ferns (C), which still live in warm, damp areas; calamites (D), which is a tree-size scouring rush; and pteridosperms (E), which were seed plants with fernlike leaves that are now extinct. The tree-like scouring rushes, which reached heights of 30 to 50 ft, are represented today by plants that grow in damp, but not necessarily warm, areas usually to only a few feet in height. From an illustration by Alice Pricket in GSA Today (Gastaldo et al., 1996); [http://pubs.usgs.gov/circ/c1143/html/fig21.html](http://pubs.usgs.gov/circ/c1143/html/fig21.html)

A. **lycopsids**; B. **Cordaites**; C. **Tree ferns**; D. **Calamites**; E. **Pteridosperms**
Seeds – Part 1

• Virtually all seeds are dormant at maturity
  ➢ The maintenance and release from dormancy is an unsolved biological mystery.
Vivipary is caused by a lack (or not enough) ABA

Viviparous maize
(McCarty et al 1989 Plant Cell)
Seeds of 17 tree species, all from the family Fabaceae, that cooccur in the Peruvian Amazon.
Botanically, a seed is a mature ovule.

- In most cases it results from fertilization (sperm nucleus + egg nucleus)
- Every seed consists of:
  - Embryo
  - Storage tissue (endosperm or cotyledon)
  - Protective outer covering (seed coat, pericarp)
  - Review Figure 4-1, morphological seed types to learn different parts of a seed.
1. Seeds represent the successful result of sexual reproduction

2. Therefore, seeds represent genetic variability

3. Unless you buy an F1 hybrid

4. Meiosis is the process by which genetic recombination occurs
   (meiosis is different from mitosis – see next slides)

5. Pollination occurs before fertilization
The cell cycle in a typical eukaryote

\[(G_1 \rightarrow S \rightarrow G_2 \rightarrow M)\]

(From Hartl and Jones 2002, Essential Genetics 3rd ed.)
Overview of Mitosis (From Hartl and Jones 2002, Essential Genetics 3rd ed.)
1. Production of haploid cells each containing complete genetic information.

2. Only in germ cells

3. Reduction division followed by equational division

4. chromatids, centromere, homologues,

5. Prophase I, Metaphase I, Anaphase I Telophase I; Prophase II, Metaphase II, Anaphase II Telophase II;

6. Chiasma forms during prophase I
Seeds – Part 1

• Sexual reproduction (Figure 4-5)
  • Pollination
    • Pollen tube
    • One tube nucleus
    • Two generative nuclei

• Fertilization
  • Embryo + one generative nucleus (zygote)
  • 2n

• Double fertilization
  • Two polar nuclei + one generative nucleus
  • 3n endosperm

• Review “Polygonum” type embryo sac (Figure 4.5)
  • Eight nuclei
    • 3 antipodal
    • 2 polar
    • 1 egg
    • 2 synergids
The remaining megaspore undergoes mitosis and asymmetric division

- Mitosis yields a seven-celled structure
  - One tube cell
  - One generative cell

In higher plants this structure differentiates into a pollen grain

- In most cases, three of the four megaspores degenerate

Mitosis yields a two-celled structure
- One tube cell
- One generative cell

Figure 3.15
(Brooker 2007)
Double fertilization

Figure 2.2

- Pollen grain
- Stigma
- Pollen tube
- Style
- Ovary
- Two sperm nuclei
- Central cell with 2 polar nuclei
- Ovule (containing embryo sac)
- Egg
- Micropyle
- Pollen tube grows into micropyle. One sperm nucleus unites with the egg and the other sperm nucleus unites with the 2 polar nuclei.
- Provides storage material for the developing embryo
- Endosperm nucleus (3n)
- Zygote (2n)

(c) Pollination and fertilization in angiosperms

(Brooker 2007) 3-66
Pollen grain = Po consisting of a Vegetative cell = VG and a Generative cell = GC, St = Stigma, St = Style, Pt = pollen tube, SC1 & SC2 = Sperm cell 1 and 2, O = ovule containing an embryo sac = ES (PRE = Before and POST = just after fertilization), E = egg cell, Sy = synergides, CC = Central cell, A = Antipodal cells, Zygote = zygote, fCC = fertilized Central Cell (forms the endosperm)

In animals, a single fertilization event between maternal and paternal gametes forms the zygote (not shown). Initially, the animal embryo is under predominant control of the maternal genome, and the zygotic genome is only gradually activated over the course of embryogenesis.

In plants, a double fertilization process generates the zygote and the endosperm tissue. Both the endosperm and the embryo are encased in maternal tissue that generates the seed coat. Chromosome symbols represent maternal (red) and paternal (blue) genomes. Nodine and Bartel show that, in contrast to the case for animals, the plant zygotic genome is activated almost immediately after fertilization.

Hale and Jacobsen 2012, Nature 482:42-44
Polygonum pattern of female gametophyte development.

### Abbreviations:
- AC = antipodal cell
- AN = antipodal cell nucleus
- CC = central cell
- CV = cell vacuole
- DM = degenerative megaspore
- EC = egg cell
- EN = egg nucleus
- EV = egg vacuole
- II = inner integument
- M = megaspore
- N = nucleus
- OI = outer integument
- PN = polar nuclei
- SC = synergid cell
- SN = synergid nucleus
- SV = synergid vacuole

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**Polygonum pattern common to 70% of all angiosperms.**

Buchanan, Gruissem and Jones, *Biochem & Mol Biol of Plants*. 2000
Seeds – Part 1

Seed Parts

• Embryo
  • Radicle
  • Cotyledon(s)

• Storage Tissue
  • Endosperm
  • Cotyledons
    • Monocotyledonous plants (monocots)
    • Dicotyledonous plants (dicots)

• Seed coat
  • Testa
  • Testa + Mucilaginous layer
  • Woody
  • Fibrous
Mature embryo – dicot
Dicot seed & seedling structure
Monocot seed structure
Capsicum annum

From: http://www.seedbiology.de/structure.asp#ricinus
Ricinus communis - castor bean (Euphorbiaceae)

Testa (seed coat)
Endosperm (E)
Embryo:
Cotyledons (C)
Radicle
Elaiosome = Caruncle

Hypocotyl (H)
Side roots
Primary root

© 2007 G. Leubner - The Seed Biology Place - http://www.seedbiology.de
*Pisum sativum*

- **Testa (seed coat)**
- **Plumula**
- **Hypocotyl**
- **Radicula**
- **Embryonic axis**

*Ethylene regulation of pea radicle growth*
Beta vulgaris: Sugar beet fruit and seed - The Seed Biology Place - http://www.seedbiology.de
Soybean life cycle

Le et al. 2007. Plant Physiol., 144:562-574
Soybean seed development

Le et al. 2007. Plant Physiol., 144:562-574
Transverse sections of soybean globular, heart, cotyledon and early maturation seed

a, Axis; al, aleurone; c, cotyledon; cu, cuticle; ep, embryo proper; es, endosperm; hg, hourglass cells; ii, inner integument; oi, outer integument; pa, palisade layer; pl, plumule; py, parenchyma; rm, root meristem; s, suspensor; sc, seed coat; sm, shoot meristem; v, vascular tissues; vb, vascular bundle.

Le et al. 2007. Plant Physiol., 144:562-574
Diversity of legume seed size

Scale: bar = 1 cm

Le et al. 2007. Plant Physiol., 144:562-574
Diversity of legume embryo morphology

B

Cicer arietinum
Lupinus luteus
Cytisus laburnum
Lotus corniculatus
Phaseolus coccineus
Medicago sativa
Glycine max
Lathyrus angustifolia

Cicereae
Genistaeae
Loteae
Phaseoleae
Trifoliaeae
Vicieae

Le et al. 2007. Plant Physiol., 144:562-574
Seeds – Part 1

![Diagram of a Zea mays seed](image)

*Ovary wall, Seed Coat, Root tip, Cotyledon, Shoot tip, Endosperm*  

Zea mays seed
Seeds – Part 1

Seed Development

1. Three stages of seed development (Figure 4.8)
   a) I. Histodifferentiation
   b) II. Cell Expansion
   c) III. Maturation / drying
      i. Orthodox Seeds
      ii. Recalcitrant Seeds

2. Seed quality develops over time
Stage I. Histodifferentiation

1. Dicot embryogenesis occurs in stages:
   a) Proembryo, globular, heart, torpedo, cotyledon

Friml et al 2003, Nature;
Stage I. Histodifferentiation

1. Dicot embryogenesis occurs in stages:
   a) Proembryo, globular, heart, torpedo, cotyledon

Nowack et al 2007, Nature;
Chlorophyll fluorescence at specific stages of Arabidopsis development

A, B – globular
C, I – heart
E, P – torpedo
G, W – walking-stick

Tejos et al. 2010; Biol Res. 43:99-111
Stage I. Histodifferentiation

1. Dicot embryogenesis occurs in stages:
   a) Proembryo, globular, heart, torpedo, cotyledon
2. Monocot embryogenesis:
   a) Proembryo, globular, scutellar, coleoptilar
3. Monocots have a scutellum, dicots have cotyledons)
4. Monocots have a plumule; dicots have a shoot
5. Monocots have a coleoptile to assist the plumule and a coleorhiza to protect the radicle during germination.
Fig. 2. A generalized overview of plant embryogenesis. Schematic representations of embryonic stages are based on light microscopy studies of Arabidopsis (33) and Capsella (30–32) embryo development. Torpedo and walking-stick refer to specific stages of embryogenesis in Arabidopsis and Capsella. Abbreviations: T, terminal cell; B, basal cell; EP, embryo proper; S, suspensor; Bc, suspensor basal cell; Pd, protoderm; u, upper tier; l, lower tier; Hs, hypophysis; Pc, procambium; Gm, ground meristem; C, cotyledon; A, axis; MPE, micropylar end; CE, chalazal end; SC, seed coat; En, endosperm; SM, shoot meristem; and RM, root meristem.
Seeds – Part 1

Soybeans (*Glycine max*)

(A) Late globular stage embryo
(B) Heart stage embryo

Abbreviations:
A – axis; CE – chalazal end; C – cotyledon;
EP – embryo proper; En – endosperm;
MPE – micropylar end; S – suspensor.
Capsella embryo
Stage II. Cell Expansion

1. Stage II is marked by rapid expansion of cells
2. Cotyledons or endosperm accumulate CH$_2$O, fats, oils, proteins.
   a) All seeds contain each component, but in characteristic amounts.
3. Dicots connection b/t mother plant and developing seed is through the funiculus.
   a) Assimilates reach the embryo via diffusion
   b) Excludes most viruses
4. Reserve accumulation is under genetic control:
   a) Plants have ~25,000 – 50,000 genes
   b) At least 50% are expressed during seed development
Stage III. Maturation Drying

1. Two types of seeds:
   a) Orthodox seeds can be dried down to ~5-7% moisture
   b) Recalcitrant seeds remain viable > 20 % moisture content
      • By comparison, humans can only withstand ~5% moisture loss
   c) Occurs when funiculus detaches from mother plant
2. Seeds develop ability to germinate before ability to withstand desiccation.
3. Maximum dry weight does not necessarily equate to physiological maturity.
4. Precocious germination (vivipary) is prevented by the plant hormone ABA, which accumulates during seed development.
5. Dry seeds can be stored a very long time, especially if kept very, very cold.
6. Maturation drying is under genetic control.
   a) Many different mRNA transcripts are produced which aid in preparing the seed to withstand extreme desiccation
Anhydrobiosis – life without water

Tardigrades (water bears) inhabit temporary ponds and films of water in soil and on moist plants. They can lose up to 98% of its body water and survive for decades. Add water, and within moments the water bear will become active.

From Campbell, 1996 Biology 4th ed.
How long can seeds survive?

*Nelumbo nucifera* Gaertn.

- Ancient lake bed at Pulantien, Liaoning Province, China
- Radiocarbon-dated to 1,350 ± 220 BCE
- Oldest confirmed germination

Photos from: http://flickr.com/photos/marc50/288174077
How long can seeds survive?

- Masada, an Herodian fortress overlooking the Dead Sea
- ~50 BCE to 70 CE
- date palm seed, *Phoenix dactylifera* L.

Sallon et al., 2008, Science
Dead for 32,000 Years, an Arctic Plant Is Revived
By NICHOLAS WADE
Published: February 20, 2012
New York Times

PNAS
Narrow-leaf campion, *Silene stenophylla* (Family Caryophyllaceae)
Fig. 4. Immature fruit of *Silene stenophylla* from burrow buried in permafrost more than 30,000 y ago. 
(A) Dissected fruit showing seeds and placenta (P).
(B) Fragment of placenta with seeds at different developmental stages. (Scale bars, 1 mm.)

Yashina et al. 2012. PNAS doi/10.1073/pnas.1118386109
Observations of seed viability in relation to environment show that their longevity increases as the seed storage temperature and moisture decrease. This same situation is seen for seed viability in the permafrost. First, at subzero temperatures the rates of biochemical reactions and biological processes become extremely slow and ensure preservation of the biological system. Second, in frozen ground, ice makes up 93–98% of total water volume; this frozen environment is effectively a “biologically dry” environment and favors conservation.
Seeds – Part 1

Biotechnology of Seed Reserves

1. Modifying F.A. content
   (omega-3-fatty acids; novel cooking/industrial oils)
2. Modifying amino acid content in maize
   (Brian Larkins’ work)
3. Adding to pathways
   (Golden rice)
Ploidy levels in plants

\[ n = \text{haploid number of chromosomes (germ cells)} \]
\[ 2n = \text{diploid number of chromosomes (somatic cells)} \]
\[ 3n = \text{triploid number of chromosomes (endosperm)} \]

Tetraploid species (e.g., potato)
\[ 2n=4x=48 \] (48 chromosomes in the tetraploid potato plant.)
Scheme of carotenoid biosynthesis in relation to Golden Rice

First committed step in carotenoid biosynthesis

PSY and CrtI are targeted by G.E.
(PSY - phytoene synthase
(CrtI - phytoene desaturase)
Golden Rice

I. Different types of “Golden Rice”
   A. 1. Untransformed
   2 - 4. single-transformant lines
   B. Co-transformant lines

II. Carotenoid content of (A) control seeds, (B) single transformant; (C) z11b co-transformant (D) z4b co-transformant

III. Structure of T-DNA region of pZPsC used in co-transformations.

Abbreviations:
LB-left border; RB-right border; “!” polyadenylation signal; p-promoters; psy – phytoene synthase; ctrl-bacterial phytoene desaturase; lcy-lycopene B-cylcase; tp transit peptide.

The making of golden rice

1. The genes that give golden rice its ability to make beta-carotene in its endosperm (the interior of the kernel) come from daffodils and a bacterium called Erwinia uredovora.

2. These genes, along with promoters (segments of DNA that activate genes), are inserted into plasmids (small loops of DNA) that occur inside a species of bacterium known as Agrobacterium tumefaciens.

3. These agrobacteria are then added to a Petri dish containing rice embryos. As they “infect” the embryos, they also transfer the genes that encode the instructions for making beta-carotene.

4. The transgenic rice plants must now be crossed with strains of rice that are grown locally and are suited to a particular region’s climate and growing conditions.
Cross section of lily ovary.
Megaspore mother cell
Megaspore tetrads.
Embryo sac showing polar nuclei and egg nucleus.