بسم الله الرحمن الرحيم

وأنتكم من الأرض نباتا

صدق الله العظيم
Seed Physiology

For 2nd Year Biology Students

Prof. Dr. Heshmat Aldesuquy
Seeds are considered a major source of food therefore, all information concerning their nutritive value, chemical composition during storage, retention of viability are very important. Plant physiologists have used seeds to study the influence of various environmental factors e.g. temperature, moisture, oxygen, light and other factors on germination and seedling emergence. Due to their necessity in human life, also farmers and horticulturists are interested in the factors related to seed germination.

Much emphasis is laid upon high-quality seed having excellent genetic potential and good germination and vigorous seedling growth. Recently techniques are employed to raise healthy and vigorous seeds to obtain vigorous seedlings. Several hormones and chemicals are used to improve the oil, protein, and other economic attributes of seeds.

To give students who are interested in studying seed sciences broad background related to the importance, physiology, and biochemistry of seed germination and dormancy. To relate these processes to problems with seed vigor and stand establishment.
Seeds and Seed Germination

1- Seed Structure

Keep in mind that the ovule in the ovary is what becomes the seed. The integument of the ovule becomes the seed coat. Inside the integument of the ovule was the embryo sac. The antipodals and synergids senesce and disintegrate. The central cell united with one sperm cell to make endosperm... a nutritive tissue that accumulates starch, protein and fats to provide for the growth of the embryo. The egg cell of the embryo sac united with the other sperm to make a zygote. The zygote grows and becomes a true embryo inside the integument.

We will recall that seed developing in the carpel produces hormones that make the carpel develop into a fruit. The mother plant also produces abscisic acid to make the embryo inside the seed become dormant. The mother plant also produces abscisic acid to make the embryo inside the seed become dormant.
When you have a dormant embryo, a storage tissue, and a seed coat, then you have a seed. In some seeds, the endosperm is retained as the storage tissue. In other seeds the endosperm is more or less used up to put storage chemical into the embryo itself (commonly in the cotyledons). Below are diagrams and a photo of some seeds.

This first example above, is a longitudinal section through a *Capsella* seed. You may observe several layers of seed coat (integument) on the outside.
Seed Structure and Anatomy

The structure, anatomy and morphology of mature seeds: an overview
The structure, anatomy and morphology of mature seeds: model species in seed biology

Endospermic seed structure: Brassicaceae - Arabidopsis thaliana
Endospermic seed structure: Brassicaceae - Lepidium sativum

Endospermic seed structure: Cestroidae subgroup of Solanaceae - tobacco and other Nicotiana-species
Endospermic seed structure: Solanoidae subgroup of Solanaceae - tomato and pepper

Non-endospermic seed structure: Fabaceae - pea and other leguminosae
The structure, anatomy and morphology of mature seeds: an overview

More general seed structural features:

**Spermatophyta** *(seed plants)*: Seeds are the dispersal and propagation units of the **Angiosperms** (flowers and related clades) and **Gymnosperms** *(plants)*, flowering plants. A comparison of these to major groups is presented on the webpage. Several seed-related issues differ between "Seed evolution" gymnosperms (750 species) and angiosperms (250000 species). If not otherwise stated, the information given in this website refers to typical Angiosperm seeds:

Ovules are structures of seed plants. **Seeds are mature, fertilized ovules** containing the female gametophyte with the egg cell, all being surrounded by **double fertilization** the nucellus and 1-2 integuments. In angiosperms the results in formation of the diploid embryo and the triploid endosperm:

Young sporophyte, diploid (2n), result of fertilization. The mature **Embryo** stem-like) **cotyledons** *(seed leaves)*, **hypocotyl** embryo consists of **radicle** *(embryonic root)* *(embryonic axis below the cotyledons)* were defined by Martin (1946). These and the **Seed and embryo types** webpage "seed evolution" resulting evolutionary trends are found on the Food storage tissue, triploid (3n), result of double fertilization, 2/3 **Endosperm** of the genome is of maternal origin.
* Testa (seed coat): Outer protective layer of the seed, developed from the integuments of the ovule, diploid maternal tissue. Fruits are mature, ripened ovaries containing seeds. The pericarp ("fruit coat") is diploid maternal tissue.

* Perisperm: Diploid maternal food storage tissue originates from the nucellus. Only in some species, e.g. *Beta vulgaris, Piper nigrum, Coffea arabica*, many Caryophyllales.

* Endospermic seeds: The endosperm is present in the mature seed and serves as food storage organ. Testa and endosperm are the two covering layers of the embryo. The amount of endosperm in mature seeds is highly species-dependent and varies from an abundant endosperm layer (*Nicotiana tabaccum*) to a single layer (*Arabidopsis thaliana*).

* Non-endospermic seeds: The cotyledons serve as sole food storage organs as in the case of pea (*Pisum sativum*). During embryo development the cotyledons absorb the food reserves from the endosperm. The endosperm is almost degraded in the mature seed and the embryo is enclosed by the testa.
More special seed structural features:

* **Hilum and funiculus:** Funicular scar on seed coat that marks the point at which the seed was attached via the funiculus to the ovary tissue.

* **Micropyle:** The Micropyle is a canal or hole in the coverings (seed coat) of the nucellus through which the pollen tube usually passes during fertilization. Later, when the seed matures and starts to germinate, the micropyle serves as a minute pore through which water enters. The micropylar seed end has been demonstrated to be the major entry point for water during tobacco seed imbibition and germination. During germination the tobacco testa ruptures at the micropylar end and the radicle protrudes through the micropylar endosperm.

* **Chalaza:** Non-micropylar end of the seed. The base of an ovule, bearing an embryo sac surrounded by integuments.

* **Raphe:** Ridge on seed coat formed from adnate funiculus.

* **Arillate:** General term for an outgrowth from the funiculus, seed coat or chalaza; or a fleshy seed coat.

* **Aril:** Outgrowth of funiculus, raphe, or integuments; or fleshy integuments or seed coat, a sarcotesta. Arils probably often aid seed dispersal, by drawing attention to the seed after the fruit has dehisced, and by providing food as an attractant reward to the disperser. The aril of the nutmeg produces the spice mace and the seed itself is the nutmeg.
* **Strophiole:** Outgrowth of the hilum region which restricts water movement into and out of some seeds. In some hard-coated legume seeds, e.g. *Melilotus alba* and *Trigonella arabica*, a plug covering a special opening - the strophiolar cleft - must be loosened or removed before water can enter, and then only through this region.

Operculum: A little seed lid. It refers to a dehiscent cap of a seed or a fruit that opens during germination.

* **Carunculate:** Seed with an excrescent outgrowth from integuments near the hilum, as in Euphorbia.

* **Fibrous:** Seed with stringy or cord-like seed coat, as mace in Myristica.

* **Funicular:** Seed with a persistent elongate funiculus attached to seed coat, as in Magnolia.

* **Strophiolate:** Seed with elongate aril or strophiole in the hilum region.

* **Fruit:** Strictly, the ripened ovary of a plant and its contents. More loosely, the term is extended to the ripened ovary and seeds together with any structure with they are combined, e.g. the apple (a pome) in which the fruit (core) is surrounded by flesh derived from the floral receptacle.

* **Achene:** A small, usually single-seeded, dry indehiscent fruit, e.g. lettuce.

* **Caryopsis:** A dry, nut-like fruit typical of grasses, e.g. a cereal grain. It is an achene with the ovary wall united with the seed coat.
* **Elaiosomes:** A specialty in the dispersal through animals is that through ants (myrmecochory). Such seeds or fruits bear attachments, the elaiosomes that contain lures and nutriments. Myrmecochory is common with plants that live at the forest soil like violets (*Viola*).

* **Caruncle:** A reduced aril, in the form of a fleshy, often waxy or oily, outgrowth near the hilum of some seeds. Usually it is brightly colored. It acts as an aid to dispersal. Viola seeds have an oily caruncle and are sought and dispersed by ants.

* **Mucilage:** A layer of polysaccharide slime produced by some seeds upon imbibition. Serves in water uptake during imbibition and germination.
<table>
<thead>
<tr>
<th>Family(clade)</th>
<th>Examples</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Endospermic seeds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucurbitaceae</td>
<td>muskmelon (Cucumis melo)</td>
<td>In the muskmelon seed the embryo is surrounded by a perisperm/endosperm envelope. Callose (β-1,3-glucan deposition in this envelope is responsible for the apoplastic semipermeability of muskmelon seeds. The perisperm/endosperm envelope is weakened prior to the completion of germination.</td>
</tr>
<tr>
<td>Core Eudicots - Rosid clade -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fenugreek</td>
<td>(Trigonella foenum-graecum)</td>
<td>Only some legume (Fabaceae) seeds are endospermic, most legume seeds are non-endospermic</td>
</tr>
<tr>
<td>Crimson clover</td>
<td>(Trifolium incarnatum)</td>
<td></td>
</tr>
<tr>
<td>Lucerne</td>
<td>(Medicago Sativa)</td>
<td></td>
</tr>
</tbody>
</table>
Brassicaceae
Core Eudicots -
Rosid clade -

- garden cress
  \textit{(Lepidium sativum)}
- mouse-ear cress
  \textit{(Arabidopsis thaliana)}

Only some Brassicaceae seeds are endospermic, most Brassicaceae seeds are non-endospermic. Mature seeds have 1-2 cell layers of endosperm, while \textit{Lepidium} of has a single endosperm cell layer. These \textit{Arabidopsis two-step germination} two species exhibit, as tobacco, a \textit{distinct testa rupture and endosperm rupture} is a promising model system for \textit{Lepidium} found that .\textit{(Müller et al. 2006 endosperm weakening)}

Euphorbiaceae
Core Eudicots -
Rosid clade -

- castor bean
  \textit{(Ricinus communis)}

Castor bean seeds (Malpighiales) are a classical seed system to study endosperm reserve breakdown.
Mature seeds of the Solanaceae family usually have an abundant endosperm layer. Well investigated examples are tobacco and tomato, which are model systems for seed biology for the study of endosperm weakening and the regulation of germination by plant hormones and environmental factors. The Solanaceae family can be divided into two large subgroups:

**Cestroideae** subgroup of Solanaceae (tobacco, *Nicotiana tabacum*, other *Nicotiana* species, *Petunia hybrida*)

- Straight or slightly bent embryos and prismatic to subglobose seeds
- Typically capsules as fruits

**Solanoideae** subgroup of Solanaceae (pepper, tomato, *Capsicum annuum*, *Lycopersicon esculentum*, *Datura* (*Datura ferox*), *Datura* (*Datura ferox*))

Curved embryos and flattened, discoid seeds, no visible distinction between testa rupture and endosperm rupture, often berries as fruits.

---

**Solanaceae**

- Core Eudicots
- Asterid clade
<table>
<thead>
<tr>
<th>Family</th>
<th>Genus</th>
<th>Common Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubiaceae</td>
<td>Lactuca</td>
<td>Lettuce</td>
<td>&quot;Seeds&quot; are actually fruits and have 2-3 cell layers of endosperm below the pericarp. Endosperm weakening has been demonstrated and the hormonal regulation of lettuce seed germination is similar to tobacco.</td>
</tr>
<tr>
<td>Oleaceae</td>
<td>Syringa</td>
<td></td>
<td>Seeds are mainly imposed by the mechanical resistance of the endosperm layer. Low temperature dormancy is imposed by the mechanical resistance of the endosperm layer.</td>
</tr>
<tr>
<td>Asteraceae</td>
<td>Coffea</td>
<td>Coffee</td>
<td>The coffee embryo is enveloped by an endosperm tissue. The fully differentiated embryo lies inside an embryo cavity. The endosperm is surrounded by endocarp, which resembles a seed coat. Endosperm weakening of coffee is inhibited by abscisic acid (ABA) and promoted by gibberellins (GA).</td>
</tr>
<tr>
<td></td>
<td>arabica</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Coffee**

*Coffea arabica*

**Syringa**

*Syringa species*

**Lettuce**

*Lactuca sativa*
<table>
<thead>
<tr>
<th>Family</th>
<th>Example Species</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apiaceae</td>
<td>Celery</td>
<td>A typical monocot seed with endosperm is onion Alliaceae family.</td>
</tr>
<tr>
<td>Core Eudicots -</td>
<td>Apium graveolens</td>
<td>In the highly specialized cereal grains/caryopses (wheat, barley,</td>
</tr>
<tr>
<td>Asterid clade -</td>
<td></td>
<td>maize) the endosperm can be divided in the starchy endosperm (starch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>grains, food storage, dead cells, flour) and the aleurone layer (</td>
</tr>
<tr>
<td></td>
<td></td>
<td>living cell layer surrounding the starchy endosperm). The cereal</td>
</tr>
<tr>
<td>Ranunculaceae</td>
<td>Trollius species</td>
<td>The seeds of basal angiosperms often have underdeveloped embryos</td>
</tr>
<tr>
<td>Basal Eudicots -</td>
<td></td>
<td>that are embedded in abundant endosperm tissue. Two-step germination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>process with distinct testa rupture and endosperm rupture.</td>
</tr>
<tr>
<td>Poaceae and other</td>
<td>Wheat</td>
<td>A typical monocot seed with endosperm is onion Alliaceae family.</td>
</tr>
<tr>
<td>monocot families</td>
<td>Triticum aestival</td>
<td>In the highly specialized cereal grains/caryopses (wheat, barley,</td>
</tr>
<tr>
<td>Basal -</td>
<td></td>
<td>maize) the endosperm can be divided in the starchy endosperm (starch</td>
</tr>
<tr>
<td>Angiosperms</td>
<td>barley</td>
<td>grains, food storage, dead cells, flour) and the aleurone layer (</td>
</tr>
<tr>
<td>Monocots -</td>
<td>Hordeum vulgare</td>
<td>living cell layer surrounding the starchy endosperm). The cereal</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>embryos are highly specialized in their structure.</td>
</tr>
<tr>
<td></td>
<td>(Zea mays)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>onion</td>
<td></td>
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<tr>
<td></td>
<td>Allium cepa</td>
<td></td>
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</tbody>
</table>
Most species of the mustard family (Brassicaceae) including several Brassica species have non-endospermic seeds. The cotyledons serve as sole food storage organs as described for the non-endospermic Fabaceae seeds.

Rape (Brassica napus) wild mustard (Sinapis alba) wild radish (Raphanus sativus)

Most species of the legume family (Fabaceae) including pea (Pisum sativum) and diverse beans have non-endospermic seeds. The cotyledons serve as sole food storage organs as in the case of pea seed development. During embryo development the cotyledons absorb the food reserves from the endosperm completely. In the mature seed the embryo is enclosed solely by the testa as the only seed covering layer. The regulation by ethylene of pea seed germination and seedling emergence has been studied in detail.

Pea (Pisum sativum) garden bean (Phaseolus vulgaris) soybean (Glycine max)
Perisperm is diploid maternal food storage tissue that originates from the nucellus. It is present in mature seeds of many Caryophyllales including the (Centrospermae Betas, ) Amaranthaceae among the (Chenopodium eudicots, but also in basal angiosperms like black pepper. (Piper nigrum)
Endospermic seed structure: Brassicaceae as model system in seed biology *Lepidium sativum*

In mature seeds of garden cress, the embryo is surrounded by 1-2 cell layers of endosperm.

*Lepidium sativum*

Two-step germination process with seeds exhibit, as tobacco, a *Lepidium*.

We found that distinct testa rupture and endosperm rupture.

The experimental excellent model system for seeds provide an *Lepidium*.

We found that investigation of endosperm weakening.

*Lepidium* and *Arabidopsis* are closely related species and exhibit, except for the size, highly most *Lepidium* and *Arabidopsis*.

Besides, *Müller et al. (2006)* similar seed structure.

Brassicaceae seeds are non-endospermic.
Bright field microscopy of *Lepidium sativum*. Structure of a mature seed of longitudinal sections of 2-3 h imbibed seeds stained with toluidine blue. (A) Entire seed, showing the mature and fully differentiated embryo, the endosperm, and the testa (seed coat). The boxed letters refer to the positions of the close-up sections.
B) Structure of the seed covering. *Lepidium sativum*. Structure of a mature seed of layers: Endosperm, a single cell layer; and testa (seed coat), composed of inner and outer integument. Note that the mucilage is generated from the outer testa upon imbibition. (C) Structure of the micropylar cap enclosing the radicle tip
- Endospermic seed structure: Brassicaceae as model system in seed biology

Arabidopsis thaliana

G) Drawing of a mature Arabidopsis seed; the seed anatomy that is very similar to that of Lepidium. (H-J) Arabidopsis seeds also germinate with testa rupture (H) preceding endosperm rupture (I). Also during the two-step germination process of Arabidopsis, ABA specifically inhibits endosperm rupture (J). Seeds were incubated in continuous light without (control) or with 10 μM ABA added to the medium.
Endospermic seed structure: Cestroidae subgroup of Solanaceae - species as model systems in seed biology. *Nicotiana* tobacco and other

Micropscopscopic picture of a sectioned dry mature Nicotiana tabacum seed: nuclei in the DAPI stain. The swap image "upon mouseover" shows the corresponding brightfield picture. Note that the testa has been removed except for the labeled testa remnant. © 2003 G. Leubner
Publication and tobacco seed drawings by Avery (1933)

The two drawings below are a redesign by me of Fig. 3K, L, M from Avery (1933).

(K) Transverse section through seed at the cotyledonary level (x70).

(L) Longitudinal-median section through seed just prior to endosperm rupture, showing ruptered testa (x50).

(M) Longitudinal-median section through seedling at 9 days (x50).
Endospermic seed structure: Solanoidae subgroup of Solanaceae
tomato and pepper as model systems in seed biology

- Non-micropylar endosperm
- Cotyledons
- Micropylar endosperm (cap)
- Embryo Endosperm
- Radicle
- Testa (seed coat)

Color image by Katrin) Capsicum annum. Drawing showing a mature seed of
Hermann based on a EM image by Watkins and Cantliffe, Plant Physiol 72: 146-150,
Non-endospermic seed structure: Fabaceae - pea as model system in seed biology

seed, a typical non-endospermic (*Pisum sativum*) Drawing of a mature pea seed with storage cotyledons and the testa as sole covering letters. Color .(Finch-Savage and Leubner-Metzger (2006) drawing published in
for information about ethylene and pea seed  "Plant hormones" See the web page germination and seedling radicle growth
In the interior is an embryo. There is a root apex, a radical that transitions into a hypocotyls terminating as the attachment node for two cotyledons between which we can see the shoot apex. The embryo may be bent, but it has all the parts of a typical embryo. Having two cotyledons means that *Capsella* is a dicot plant. Between the radical and the two bent cotyledons, more is found at the lower end of the seed. The structure of dicot and monocot seeds is illustrated below.

**2- Structure of the Seed Coat**

The seed coat is a structure of considerable importance because it forms the barrier between the embryo and its immediate environment. The seed coat is formed from the integuments, but in most seeds many layer of tissue forming integuments are destroyed and only the residual parts make up the seed coat.
The most important property of the seed coat is its permeability to water and sometimes to gases. Impermeable seed coats confer seed dormancy. As long as water entry is blocked, no germination can occur. In Pisum seeds a continuous layer of palisade cells is present. The caps of these cells are very hard and are impregnated with pectinaceous material. In these cells, or in the layer of cells immediately below the palisade. The osteosclereid cells, quinones are laid down. It is the combination of these two features which renders the seeds impermeable to water. Coat impermeability was found to be due to accumulation of insoluble lignin-like polymers.
3. Variability between Seeds

The size and shape of seeds is extremely variable. It depends on the form of the ovary, the condition under which the parent plant is growing during seed formation and on species. Other factors may also affect these character such as the size of the embryo, and the amount of the endosperm and to what extent other tissue participate in the seed structure. Variability in seed shape also exists within a given species and is referred to as seed polymorphism. Characteristic of polymorphic seeds is that they differ not only in shape or colour, but also in their germination behaviour and dormancy.
4. Chemical Composition of Seeds

Seeds may be divided into those whose main storage materials is carbohydrates and those whose main storage material is lipid. Seed containing proteins can belong to either group. Almost no seeds are known in which the predominant storage material is protein, although there are exceptions, such as soybean or *Macharium acutifolium* that has been reported to contain 66% protein.
1-Carbohydrates

Starch is the most dominant storage material in most field crops – wheat, rice, maize and sorghum. Starch is a polysaccharide composed of $\alpha$-1,4 glucan with $\alpha$-1,6 glucan side chains and serves as a source of glucose for the germinating seed. It is not the only storage carbohydrate, other poly- and oligosaccharides are often found in many seeds. Some seeds like those of date palm have the main storage material polysaccharides with a (1→4)$\beta$ mannan core. Other seeds contain compounds referred to as hemi-celluloses which are heteropolysaccharides in nature.
Lipids are generally present in the form of the glycerides of fatty acids: CHB2BO-RB1B-CHO.RB2B.CHORB3B, where RB-1B, RB2B & RB3 B may be the same or different fatty oleic, linoleic and linolenic acids.

The lipids are founding the seeds both as fats and as oils, depending on the relative amounts of saturated and unsaturated fatty acids occurring in the glycerides.

Other lipid materials found in seeds are esters of higher alcohols, sterols, phospholipids and glycolipids.
According to their solubility in water and salt solutions protein were classified as follows:

<table>
<thead>
<tr>
<th>Protein type</th>
<th>Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Albumins</td>
<td>* In water and salt solution</td>
</tr>
<tr>
<td>2. Globulins</td>
<td>* In salt solution but very slightly soluble in H₂O</td>
</tr>
<tr>
<td>3. Prolamins</td>
<td>*Soluble in 70-80% ethanol but not soluble in water or absolute alcohol.</td>
</tr>
<tr>
<td>4. Glutelins</td>
<td>* Soluble only in acids and alkaline</td>
</tr>
</tbody>
</table>
Germination of Seeds

Seed Germination
There are several factors affecting seed germination. First and foremost, seed must be viable meaning it must be capable of germination.
After their maturation the seeds do not remain viable indefinitely. They have a particular life span during which they must germinate otherwise they lose their viability (or capacity to germinate) first gradually and finally completely. The life span of seeds which may from few weeks to many years depends upon (i) species and (ii) the environmental conditions prevailing during seed storage.
Various environmental factors can affect germination. The following factors will be considered:

1. Water
2. Oxygen
3. Temperature
4. Light

Germination test
Stages of Germination

1- Phase of Activation

Germinating Corn Seed
2- Phase of Digestion and Translocations

Germinating Pea Seed
Epicotyl and Hypocotyl Germination
Mechanism of Germinating Seeds

SEED GERMINATION = radicle emergence

Seeds Lacking Dormancy: Moisture, Warmth

Dormant Seeds need more than this:
- Thick Seed Coat: Scarification
- Thin Seed Coat: Light or Darkness
- Insufficient Development: After-ripening with Fungi
- Inhibitors: Abscisic Acid, Phenolic

Vernalization, Repeated Leaching

Barley Seed Germination

Cotyledon

Epicyotyl

Radicle

H₂O

Immobilization

Hydrolysis

Starch

Sugar

Amylase

RNA

DNA

GA₂

Seed Coat

Endosperm

Aleurone Cells

Storage Protein

Amino Acids

Photoactivation

Emutation

α-Enterolactone-phosphoraleanosty

Photoactivation

Emutation

α-Enterolactone-phosphoraleanosty

Pr

Pr

730 µm

dark

Lettuce Seed Germination
Basal Metabolism of Germinating Seeds

I - Changes in Storage Products During Germination

C = Pair of cotyledons
P = Plumule
E = Epicotyl
R = Radical
H = Hypocotyl
II - Metabolism of Storage Products

The metabolic changes occurring in the early stages of germination are the result of the activity of various enzymes, which are either present in the dry seed or very rapidly become active as the seed imbibes water.

1 - Carbohydrates

Sucrose biosynthesis

\[
\begin{align*}
(1) & \quad \text{Glucose} + \text{ATP} \rightarrow \text{G-6-P} \\
(2) & \quad \text{one portion converts to F-6-P} \rightarrow \text{other portion converts to G-6-P} \\
(3) & \quad \text{G-6-P} + \text{UTP} \rightarrow \text{UDP-G} \\
(4) & \quad \text{UDP-G} + \text{F-6-Psynthetase} \rightarrow \text{UDP} + \text{sucrose P} \\
& \quad \text{Sucrose} + \text{iP} 
\end{align*}
\]
Sucrose hydrolysis:

Sucrose + H2O $\xrightarrow{\text{invertase}}$ Glucose + Fructose
Figure: The relationship between the TCA (solid line) and the glyoxylate cycle (broken line) and the possible interconversion of lipid to carbohydrates.

3- Proteins

\[
\text{COOH} \quad \text{CH-NH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CO(NH}_2) \\
\text{Glutamine}
\]

\[\alpha\text{-keto glutaric acid} + (2\text{H}) \xrightarrow{\text{glutamic acid synthetase}} 2\text{glutamic acid}\]
Glutamine + aspartic acid + ATP

synthetase

asparagine

COOH

CHNH₂

CH₂

CO-NH₂

Asparagine

PPI + AMP + glutamic acid +
## 4-Metabolism of Phosphorus Containing Compounds

<table>
<thead>
<tr>
<th>Time of germination in days</th>
<th>Dry seeds</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytin</td>
<td>8.6</td>
<td>8.5</td>
<td>7.2</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Inorganic-P</td>
<td>0.4</td>
<td>0.3</td>
<td>1.9</td>
<td>4.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Total lipid</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
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<td>Ester</td>
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<td>0.4</td>
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<tr>
<td>RNA</td>
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<td>0.11</td>
<td>0.15</td>
<td>0.25</td>
<td>0.39</td>
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<tr>
<td>DNA</td>
<td>0.11</td>
<td>0.11</td>
<td>0.12</td>
<td>0.21</td>
<td>0.44</td>
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<tr>
<td>Protein</td>
<td>0.11</td>
<td>0.10</td>
<td>0.16</td>
<td>0.28</td>
<td>0.26</td>
</tr>
</tbody>
</table>
Germination is an energy-requiring process and is therefore dependent on the respiration of the seed. The level of the gas exchange of dry seeds depends on the moisture content in dry seeds, it rises as the latter rises.
Hydrolysis

Proteases

Nitrogen source of synthesizing other nitrogenous components. (Amido nitrogen).

1

Transamination

Oxidative deamination

2

NH$_3$ utilized for amide formation

Keto acids Kerb's cycle

3 75%

Precursors for protein formation

Proteins

Amino Acids

Nitrogen source of synthesizing other nitrogenous components. (Amido nitrogen).
Synthesis of Amino Acids:

A- Reductive Animation

\[ \alpha \text{-ketoglutarate} + \text{NH}_3 \xrightarrow{\text{Glutamic dehydrogenase}} \text{Glutamate} + \text{NAD} \]
B-Transamination

Glutamic acid + Oxaloacetate → α-ketoglutaric acid + Aspartic acid

(glutamic aspartic transaminase)
C-Amide synthesis

Glutamic acid + NH$_3$ + ATP $\overset{\text{Mg}^{2+}}{\rightleftharpoons}$ glutamine + ADP + Pi

Glutamine synthetases

Glutaminase

glutamine $\overset{\text{H}.\text{OH}}{\rightarrow}$ amino acid + NH$_4$ (Utilized in amino acid synthesis)
Although hormones have been shown to promote germination, it is by no means clear-cut. Endogenous and exogenous levels of hormones were shown to affect the germination of seeds. The role of endogenous levels or exogenously applied hormones e.g. indole acetic acid (IAA) gibberellic acid (GAB3B) and kinetin on germination has been widely investigated.
1-Auxins

The relative concentrations of auxins, their precursors and other hormonal regulators of growth are known to control the development of different plant parts. There was a rapid and sharp increase in the endogenous IAA content of lupin, bean, maize, wheat and pine seeds in response to water imbibition, especially during the time of radical emergence.
Gibberellic acid (GAB3B) stimulates the germination of seeds. Furthermore, some of the known gibberellins occur in bound forms in fruits and seeds; these being converted to free gibberellins during germination of seeds.
Kinetin promotes the germination of seeds. Zeatin, its riboside and ribotide are natural cytokinins and were shown to stimulate germination, with lower activity in case of the derivatives than zeatin itself. The cytokinins are actively metabolized in germinating seeds. A large number of derivatives of kinetin, where the furfuryl group is replaced by other groups, also stimulates germination, for example benzyladenine.
It was found that applied cytokinin, could partly be substituted for the endosperm, and that the levels of the endogenous cytokinins in the endosperm decreased during imbibition and clearly germination. These results suggested that cytokinins present within the endosperm of the seed were either exported to the embryonic axins or utilized within the endosperm itself.
Abscisic acid (ABA) was detected just prior to germination of hyoscyamus seeds. It soon disappeared after the emergence of radicle. Xanthophylls and xanthoxin present in the extract of many seedlings, may be precursors in the biosynthesis of (+) – abscisic acid. In Loblolly pine a high level of promoter but no inhibitors was detected in germinating seeds. This activity greatly increased up to a period of 28 days. In Zea mays root tip extracts, ABA and xanthoxin were confirmed to the root cap.
When exogenously applied it stimulates germination. Germinating seeds are able to produce ethylene. Some ethylene effects are gene activation and formation of some mRNA and membrane integrity, changes in the level of hydrolytic enzymes, endogenous auxins.
Seed treatment with coumarin resulted in reduction in % germination, while thiourea stimulated % germination. Coumarins interfere with various metabolic process during germination. Coumarin prevents the rise of lipases in fatty seeds. Nitrogen metabolism was also affected by coumarin where it prevented any rise in soluble nitrogen during germination. It inhibits breakdown of proteins due to inhibition of proteases.
Most seed does not germinate immediately but rather undergoes or is under the influence of some type of primary dormancy present to delay initial seed germination.
Position of dormancy in a plant’s life cycle
Dormancy in Annuals

Annual Rhythm of Growth & Dormancy

Moderately Humid Climate

Shoot growth

Bud break

Berry development

Leaf Abscission

Growth

high Readiness for bud break
low

Correlative predormancy
Endogenous dormancy
Exogenous postdormancy

Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb
A schematic representation of inhibition of budbreak during dormancy. Dormancy begins with paradormancy and it deepens during endodormancy. The depth and duration of ecodormancy is environment dependent.
Fig. 4 Seasonal changes in freezing tolerance (LT50, °C) of the lateral buds in 3-year-old field-grown seedlings of three ecotypes of *B. pendula* (triangle the southern ecotype, square the central ecotype, circle the northern ecotype) from January to December. Values are the means±SE of 5 replicates.
Dormancy Induction  

Dormancy release  

Germination

- Immature seed  
- Mature seed  
- Imbibed mature seed + light  
- Radicle protrusion  
- Seeding
Seed Dormancy

Primary dormancy
- Seed coat
  - Prevention of water uptake
  - Mechanical constraints
  - Gas exchange
- Chemical
  - Inhibitors or
  - Inhibitor production
- Developmental
  - Immature embryo
- Physiological
  - Brief exposure to light, dehydration or chilling
- Deep dormancy
- Double dormancy

Secondary dormancy
- Post-imbibition conditions
  - Water stress
  - Prolonged dark or light
  - Anoxia or hypoxia
  - Drought

Scarification
Stratification
Seed Dormancy

Interplay of hormones
Seed Dormancy

Interplay of hormones

- Decrease in ABA level and sensitivity
- Increase in GA sensitivity or loss of GA requirement

- After-ripening
- Testa rupture
- Endosperm rupture

- Dormant seed
- Non-dormant seed
- Micropylar endosperm
- Germinated seed

- Light
- GA
- BR
- ABA
- Ethylene

- βGlu I
- EREBP
Untreated  + gibberellin  + abscisic acid

Figure 3: Light-induced germination of lettuce seeds
The seeds in the top row were placed in darkness, and the seeds in the bottom row were placed in light.
Release of Dormancy - Chilling Requirement

A measurable period of cold temperatures (0-10 degC) required by plants to break out of endodormancy

POINT TO NOTE
• Measured as bud break

• Different for different species

• Geographical distribution of plants based on chilling requirement

• Ecodormancy can override chilling requirement

• Intensity of dormancy proportional to chilling requirement

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of chill hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almonds</td>
<td>0-800</td>
</tr>
<tr>
<td>Peaches</td>
<td>100-1250</td>
</tr>
<tr>
<td>Japanese plums</td>
<td>100-300</td>
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<tr>
<td>Apples and pears</td>
<td>200-1400</td>
</tr>
<tr>
<td>European plums</td>
<td>800-1500</td>
</tr>
<tr>
<td>Cherries</td>
<td>800-1700</td>
</tr>
</tbody>
</table>


Doesn’t cold temperature signal onset of dormancy?
Modification of chilling requirement

1. Intermittent warm periods during chilling
2. Light
3. Presence of leaves

Fig. 1. The influence of diurnal temperature cycles on bud break in 'Redhaven' peach. (Exposure to 4°C in the cyclic treatments for 16 hr a day.) Mean Separation by Duncan's multiple range test, 0.05 level.

As time progresses chilling becomes irreversible
**Presence of leaves inhibits bud break but not chilling accumulation**

<table>
<thead>
<tr>
<th>Trt</th>
<th>Prechil</th>
<th>Postchill</th>
<th>Prechill</th>
<th>Postchill</th>
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<tr>
<td></td>
<td>D</td>
<td>G</td>
<td>D</td>
<td>G</td>
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<tr>
<td>1A</td>
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<td>+</td>
</tr>
<tr>
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<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4B</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>5A</td>
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<tr>
<td>5B</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
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</tbody>
</table>

D-Defoliated
G-Girdled

Bud break inhibitor moves through the phloem
Chilling models
Predict status of dormancy cycle and/or completion of endodormancy

1. Chill hour model
   Weinberger, 1950
   No. of hrs between 0-7 degC

2. Chill unit model
   Richardson et al., 1974
   Chilling effectiveness units assigned to various temps.
   1 CU = 1 hr at optimum Temp
   Fractional CUs at non-optimum Temps

3. Mean Temperature Model
   Uses mean winter (December and/or January) monthly temperatures to estimate accumulated chilling units (FL & GA)

<table>
<thead>
<tr>
<th>Chill unit values</th>
<th>Corresponding temperatures (°C)</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
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<tr>
<td>0</td>
<td>&lt;1.4</td>
</tr>
<tr>
<td>0.5</td>
<td>1.5-2.4</td>
</tr>
<tr>
<td>1.0</td>
<td>2.5-9.1</td>
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<tr>
<td>0.5</td>
<td>9.2-12.4</td>
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<tr>
<td>0</td>
<td>12.5-15.9</td>
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<tr>
<td>-0.5</td>
<td>16.0-18.0</td>
</tr>
<tr>
<td>-1.0</td>
<td>&gt;18</td>
</tr>
<tr>
<td>-1.5</td>
<td>—</td>
</tr>
<tr>
<td>-2.0</td>
<td>—</td>
</tr>
</tbody>
</table>

A- Richardson et al., 1974, high chilling peaches
B-Gilreath and Buchanan, 1981, low chilling nectarine
C-Shaitout and Unrath, 1983, high chilling apples
Types of Primary Dormancy

Seed treatment using a file
Seed treatment using a sand paper
The result of treatments
Germination of seed after seed coat treatment (left), no germination of control (right).
2- Chemicals

3- Morphological

4- Physiological or Intermediate

5- Deep Dormancy
Secondary Dormancy

Secondary dormancy factors can also influence seed dormancy. Secondary dormancy prevents germination of a seed after imbibitions of water have occurred. The activation phase has started but doesn't progress. Causes of secondary dormancy include temperature extremes, prolonged darkness, or prolonged light. Water stress, dry conditions, or oxygen extremes – anoxia or hypoxia (too much or too little oxygen) – can also induce secondary dormancy.
Causes of Dormancy

1- Permeability of Seed Coats

2- Temperature Requirements

3- Light Requirements and Thin Interaction with Temperature

4- Germination Inhibitors
Seed Longevity and Deterioration

Seeds are uniquely equipped to survive as viable regenerative organisms until the time and place are right for the beginning of a new generation; however, like any other form of life, they can not retain their viability indefinitely and eventually deteriorate and die.
The Life Span of Seed

1-Long-Lived Seeds

2-Short-Lived Seeds

Concepts of Seed Deterioration

Seed deterioration can be characterized by the following three general concepts:
1. Seed deterioration is an inexorable process:

All living thing eventually deteriorate and die. It is possible to retard the rate of deterioration through optimum storage practices.

2- Seed deterioration is an irreversible process:

Once seed deterioration occurred, this can not be reversed.

3- Seed deterioration varies among seed populations:

It is now will established that certain varieties exhibit less deterioration than others.
Factors Influencing the Life Span of Seeds

1- Internal Factors

2- Relative Humidity and Temperature

3- Seed Moisture
Symptoms of Seed Deterioration

- Seed symptoms.

- Morphological changes:

Seed coat colour often provides an indication of seed deterioration, particularly for legumes. Darkening of the seed coat in deteriorating clover, peanut and soybean seeds have been reported.

Color changes are presumably due to oxidative reactions in the seed coat which are accelerated under high temperature and relative humidity conditions. Other morphological changes have been reported in deteriorating lettuce seeds which develop red necrotic lesions in the cotyledons (Cotyledonary necrosis).
- Ultrastructure Changes

The ultrastructure changes using electron microscopy and two general patterns of coalescence of lipid bodies and plasma lemma withdrawal with deterioration have been observed. Coalescence of lipid bodies in the embryo has been founding broad group of species. Withdrawal of the plasma lemma also has been detected in these species (wheat, peas and pine). It is significant that both of these events influence cell membrane integrity.
-Cell Membranes

Deteriorating seeds are characterized by inability to retain cellular constituents which leak out during imbibition. Many of these cellular constituents are essential for normal, vigorous germination. Some of these compounds are necessary for maintenance of internal osmotic potential which is responsible for normal water uptake and provides the turgor pressure required for radical protrusion. The external leakage of these substances encourages the growth of pathogenic microflora.

The increased leakage was attributed for membrane disruptions, associated with loss of membrane phospholipids. This loss may be due to either phospholipase enzyme activity or lipid peroxidation.
- Loss of Enzyme Activity

Among the biochemical tests that have been used to measure loss of enzyme activity are the tetrazolium test (dehydrogenase), catalase, peroxidase, amylase and cytochrome oxidase.
- Reduced Respiration

As seeds deteriorate, respiration becomes progressively weaker, and leads to loss of germination.
Viability means that a seed is capable of germinating and producing a normal seedling. Therefore, a given seed is either viable or nonviable, depending on its ability to germinate and produce a normal seedling.

The another sense, viability denotes the degree to which a seed is alive, metabolically active, and possesses enzymes capable of catalyzing metabolic reactions needed for germination and seedling growth.

Numerous tests exist for determining seed viability, these are discussed in the following.
- Germination Test

This is most commonly used to determine seed viability. It is a useful viability index. It is considered as indicative of the ability to produce a normal plant under favourable conditions. Seeds of certain species require special treatment for maximum germination or breaking dormancy. Such requirements include light and KNOB3B. Eight hours of light per day is usually sufficient. KNOB3B (0.2%) is used to promote germination of some dormant seeds.
Tetrazolium Test-

This is an accurate means of estimating seed viability. It is often referred to as “quick test” since it can be completed in only a few hours (as compared to regular germination tests that require as long as two months for some species).
Principle:

The tetrazolium test distinguishes between viable and dead tissues of the embryo on the basis of their relative respiration rate in the hydrated state. Although many enzymes are active during respiration, the test utilizes the activity of dehydrogenase enzymes as an index to the respiration rate and seed viability.

Dehydrogenase enzymes react with substrates and release hydrogen ions to the oxidized, colorless, tetrazolium salt solution, which is changed into red formazan. Seed viability is interpreted according to the staining pattern of the embryo and the intensity of the coloration.
**Procedure**

Seeds are first imbibed on a wet substratum to allow complete hydration of all tissues. For many species, the tetrazolium solution can be added to the intact seed. Other seeds must be prepared by cutting and puncturing in various ways to permit access of tetrazolium–solution to all parts of seed. After hydration, the seeds are placed in a tetrazolium salt solution at 35PoPC. Two hrin usually adequate for seeds that are bisected through the embryo, but others require longer periods of staining.

Tests focus on seed membrane and embryo integrity
1- Conducting Test

Conductivity tests are based on the fact that as seed deterioration progresses, the cell membranes become less rigid and more water–permeable, allowing the cell contents to escape into solution with the water and increasing its electrical conductivity.
2- Excised Embryo Tests

It is a way of recessing seed viability in dormant seeds, especially in woody species. If the embryos of dormant seeds are carefully removed without injury and placed on a moist filter paper under favourable conditions they will readily grow and turn green. This will happen much more rapid than in the intact seed.
3- Hydrogen peroxide (HB2BOB2B) Test

The test is conducted by cutting the seed coat at the radical and allowing a 1% solution of HB2BOB2B to permeate the interior of the seed. This treatment results in more rapid root protrusion compared to the standard germiantion test. This stimulation might occur from the degradation of HB2BOB2B into HB2BO & 1/2OB2B which enhances the environment surrounding the seeds and thus stimulates germination.

Other tests focus on the integrity of the seed coat which can have an influence on imbibition damage, seed leakage, and susceptibility to invasion by pathogens. They include the following:
A- Ferric Chloride Test
Mechanically injured legume seeds turn black when placed in a solution of FeCl₃ (20%) for 15 min. It is a very rapid test and gives a quick estimate of the % of abnormal seedlings which expected from a crop.

B- Fast Green Test
This test also reveals physical fractures in the seed coat of light – colored seeds such as corn. Seeds are soaked in a 0.1% fast green solution for 15-30 seconds. During this period, the fast green penetrates any area of the seed coat which has been fractured and stains the endosperm green. After the soak period, the seeds are washed and the fractures then become apparent in the seed coat.
Questions

- What is the seed?
- Mention the significance values of seeds.
- Explain in details the structure of seed.
- Discuss the types of seeds in concerning with their chemical structure.
- Define the germination and explain in details the internal and external factors affecting germination.
- Write a brief account on germination stages.
- Explain why gibberellic acid plays an important role in accelerating the germination of monocot and dicot.
- What is the structure of seed coat? Contain small amount seeds. Discuss why the scutellum in Zea mays contain high percentage of hexoses and high percentage of sucrose during its germination.
- Mention the changes in storage materials during the germination of seeds.
- Discuss the metabolism of phytin in concerning its function in seeds.

Discuss the following:

a- Germination is an energy requiring process.
b- Mode of action of gibberellic acid during germination of seeds.
c- Hydrolases play an important role in germination of seeds.
d- Changes in nucleic acid and respiration during germination.
- Mention the physiological aspects of quiescent “dry” seed.
- Explain the metabolism of hormones during germination of seeds.
- Explain why the growth bioregulators play an essential role in germination process.
- What is seed viability?
- Mention in details the types of seed deterioration.
- Discuss the chemical tests used in detection of seed deterioration.
• What are the two major types of seed dormancy?
• Which type of seed dormancy manifests itself after imbibition?
• How can seed coat based dormancy be broken?
• How can deep dormancy be overcome?
• Relative amounts of what hormones determine dormancy of a seed?

• What is the importance of chilling requirement?
• What does the presence of leaves inhibit?
• Bud break inhibitor moves through which conducting tissue?
• Name the two models for chilling?
• Do you think these models are applicable in present commercial production environments?
• What do you suggest as an alternative?
Thank You
With My Best Wishes
Prof. Dr.
H.S. Aldesuquy