Lecture-1

Propagation-need and potentialities, sexual and asexual methods of propagation and their advantages and disadvantages

Learning Objective

- Importance of plant propagation
- Modes of plant propagation
- Merits and demerits of different modes of propagation

Introduction

This progress in plant improvement would have been of little significance, without methods whereby improved forms could have been maintained in cultivation. Most cultivated plants either would have lost or reverted to less desirable forms unless they are propagated under controlled conditions that perceive the unique characteristic which make them useful.

Plant propagation means multiplication of plants with the aim to achieve increase in number and preserve the essential characteristics of the mother plant. It is essentially of two types:

A. **Sexual Propagation**

B. **Asexual Propagation**

A. Sexual Propagation

- Sexual reproduction refers to multiplication of plants by seeds. Seeds are formed after successful pollination and fertilization (Fig.1.1) by the union of male and female gametes.
- Meiosis division takes place in the course of fusion and the chromosome numbers are reduced to half, which after fertilization becomes normal.
- The plants raised through seed are called seedling plants.
- Propagation of plants by seeds offers many advantages however several have disadvantages too.

- Sexual propagation involves careful management of germination conditions and facilities and knowledge of the requirements of individual kind of seeds.

Success of seed propagation depends upon fulfilling the following conditions:

1. Using seed of proper genetic characteristics to produce the cultivar or species, of provenance desired. This can be accomplished by obtaining seed from a reliable source or dealer.
2. Using good quality seeds which germinate rapidly and vigorously to withstand possible adverse environmental conditions in the seed bed and provide a high percentage of usable seedlings.
3. Manipulating the seed dormancy by applying pre-germination treatments or proper timing of planting.
4. Providing proper environment for seed germination i.e., supplying sufficient water, proper temperature, adequate oxygen and either light or darkness (depending upon kind of seed) to the seeds and resulting seedlings until they are well established.

Advantages

Sexual method of propagation has several advantages, like

- Propagation by seeds is simple and easy.
- Seed propagation is only mean of diversity particularly in the selection of chance seedlings.
- Seedling plants are long lived, productive and have greater tolerance to adverse soil and climatic conditions and diseases.
- Seed propagation makes feasible to propagate plants like papaya and coconut in which asexual means of propagation is not common.
- Hybrids can only be developed by sexual means.
- Sexual propagation offers opportunities of polyembryony (citrus, mango or *jamun*) and apomixis (*Malus sikkimensis, Malus hupehensis, Malus sargentii*), which produces true- to - type plants.
- Seed is the source for production of rootstocks for asexual propagation
- Seeds, if stored properly can be kept for longer duration /period for future use.

Disadvantages

Sexual method of propagation has some disadvantages, like

- Seedling plants are not true to type to the mother plants due to heterozygous nature of fruit plants.
- Seedling plants have long juvenile phase (6-10 years) and hence flowering and fruiting commences very late in them.
- Sexually raised plants are generally tall and spreading type and thus are cumbersome for carrying out various management practices like pruning, spraying, harvesting etc.
- Seeds of many fruits are to be sown immediately after extraction from the fruits as they lose their viability very soon e.g. cashew nut, *jamun*, jackfruit, citrus, mango and papaya.
- The beneficial influences of rootstocks on scion variety cannot be exploited in sexual propagation.
- Seedling plants usually produce fruits inferior quality.

B. Asexual Propagation

- It is independent of sexual propagation process as there is no involvement of sex organs.
- It takes place due to mitotic division. Mitotic division continues in shoot tip, root tip and cambium.
- When some portion of plant is wounded, mitotic division takes place.
- Under mitotic division, chromosomes divide longitudinally to form two daughter cells. This forms the basis of asexual propagation.
- The plants raised through asexual process are identical to mother plants. Cutting, division, layering, budding and grafting are main techniques of asexual propagation.

Advantages

Propagation by asexual means has several advantages over sexual means, like

- Asexually propagated plants are true to type to their mother plants.
- Asexually propagated plants have short juvenile phase and bear flowers and fruits in the early age (3-4 years) than seedling plants.
- The vegetatively propagated plants are smaller in stature and hence management operations like spraying, pruning and harvesting etc. become easy.

- Plants in which seed setting does not take place (e.g. pineapple and banana), asexual propagation serves as a substitute for sexual propagation.
- Using asexual methods, desirable characters of a mother plant can be perpetuated/ multiplied easily.
- The benefits of rootstocks and scion are usually exploited through asexual propagation.
- Repairing of damaged portion of plant is possible through asexual propagation as in case of bridge grafting.
- It is possible to convert a non-productive local variety into productive improved variety by using asexual methods.
- It is possible to grow several varieties on one plant or change variety of existing plant by top working

Disadvantages

- Asexual propagated plants have shorter life-span.
- Asexual propagation restricts diversity.
- Sometimes asexual propagation disseminates diseases e.g. *Tristeza* virus in citrus.
- Technical skill is required.

Lecture-2

Seed Dormancy: Causes and Types

Learning Objectives

- Importance of dormancy
- Types of dormancy

Introduction

Dormancy is a condition where seeds will not germinate even when the environmental conditions such as water, temperature and air are favourable for germination.

- It is observed that seeds of some fruit plants (mango, citrus) germinate immediately after extraction from the fruit under favourable conditions of moisture, temperature and aeration.
- However, in others (apple, pear, cherry) germination does not take place even under favourable conditions. This phenomenon is called as 'dormancy'.
- This is an important survival mechanism for some species because these species do not germinate unless adverse climatic conditions end.
- In some species, chilling temperature for certain period helps in the termination of dormancy. Often dormancy is due to several factors and may persist indefinitely unless certain specific treatments are given.

Types of dormancy: Different types of dormancy include

1. Exogenous Dormancy

- This type of dormancy is imposed by factors outside the embryo.
- In exogenous dormancy, the tissues enclosing the embryo can affect germination by inhibiting water uptake, providing mechanical resistance to embryo expansion and radicle emergence, modifying gaseous exchange (limit oxygen to embryo), preventing leaching of inhibitor from the embryo and supplying inhibitor to the embryo. It is of three types:

a) Physical dormancy (seed coat dormancy): Seed coat or seed covering may become hard, fibrous or mucilaginous (adhesives gum) during dehydration and ripening as a result they become impermeable to water and gases, which prevents the physiological processes initiating germination This type of dormancy is very common in drupe fruits i.e. olive, peach, plum, apricot, cherry etc. (hardened endocarp), walnut and pecan nut (surrounding shell). In various plant families, such as, Leguminosae, the outer seed coat gets hardened and becomes suberized and impervious to water.

b) **Mechanical dormancy**: In some fruits seed covering restricts radicle growth, resulting in dormancy of seeds. Some seed covering structures, such as shells of walnut, pits of stone fruits and stones of olive are too strong to allow the dormant embryo to expand during germination. The water may be absorbed but the difficulty arises in the cementing material as in walnut. Germination in such seeds does not occur until and unless the seed coats are softened either by creating moist and warm conditions during storage or by microbial activity.

c) **Chemical dormancy**: In seeds of some fruits chemicals that accumulate in fruit and seed covering tissues during development and remain with the seed after harvest. It is quite common in fleshy fruits or fruits whose seeds remain in juice as in citrus, cucurbits, stone fruits, pear, grapes and tomatoes. Some of the substances associated with inhibition are various phenols, coumarin and abscisic acid. These substances can strongly inhibit seed germination.

2. Endogenous dormancy

This type of dormancy is imposed by rudimentary or undeveloped embryo at the time of ripening or maturity. This can be of different types such as morphological, physiological, double dormancy and secondary dormancy.

A. Morphological dormancy (Rudimentary and linear embryo): Dormancy occurs in some seeds in which the embryo is not fully developed at the time of seed dissemination. Such seeds do not germinate, if planted immediately after harvesting. Plants with rudimentary embryos produce seeds with little more than a pro-embryo embedded in a massive endosperm at the time of fruit maturation. Enlargement of the embryo occurs after the seeds have imbibed water but, before germination begins. Formation of rudimentary embryo is common in various plant families such as Ranunculaceae (Ranunculus), Papavaraceae (poppy). Some plants of temperate zone like holly and snowberry have also rudimentary embryos.

B. Physiological dormancy

a) Non-deep physiological dormancy: After ripening time is required for seeds in dry storage to lose dormancy. This type of dormancy is often transitory and disappears during dry storage. Temperate fruits such as apple, pear, cherry, peach, plum and apricot, cultivated cereals, vegetables and flower crops, have this type of physiological dormancy which may last for one to six months and disappears with dry storage.

b) Photo dormancy: Seeds that either require light or dark condition to germinate are termed as photo-dormant seeds. It is due to photo-chemically reactive pigment called phytochrome widely present in some plants. When imbibed seeds are exposed to red light (660-760 nm), the phytochrome changes to red form (P_{fr}), thereby substituting the germination process. However, when seeds are exposed to far-red light (760-800), P_{fr} is changed to P_f which inhibits germination process.

c) Thermo dormancy: Some seeds have specific temperature requirement for their germination, otherwise they remain dormant. Such seeds are called as thermo dormant .For example seeds of lettuce, celery and pansy do not germinate if the temperature is below 25^o C.

Physiological dormancy is of 3 types:

I) Intermediate physiological dormancy: The seeds of some species require a specific period of one-to-three months of chilling, while in an imbibed and aerated state, commonly called as moist chilling. For example, most of temperate fruit seeds require moist chilling to overcome seed dormancy. This requirement led to the standardization of world famous, horticultural practice of stratification. In this process, the seeds are placed between layers of moist sand in boxes and exposed to chilling temperatures (2 to 7^0C) for the period varying from 3-6 months to overcome dormancy.

II) Deep physiological dormancy: Seeds, which usually require a relatively long (>8 weeks) period of moist chilling stratification to relieve dormancy as in peach.

III) **Epicotyl dormancy**: Seeds having separate dormancy conditions for the radicle hypocotyl and epicotyl, is called as epicotyl dormancy e.g. *Lilium*, *Hepatica antiloba and trillium.*

C. Double dormancy

- In some species, seeds have dormancy due to hard seed coats and dormant embryos.
- For instance, some tree legumes seed coats are impervious and at the same time their embryo are also dormant.
- Such seeds require two years for breaking of dormancy in nature. In the first spring, the microorganisms act upon the seed making it weak and soft and then embryo dormancy is broken by chilling temperature in the winter next year.
- Combination of two or more types of dormancy is known as ‘double dormancy’. It can be morpho-physiological i.e. combination of under developed embryo and physiological dormancy or exo-endodormancy i.e. combination of exogenous and endogenous dormancy conditions i.e. hard seed coat (physical plus intermediate physiological dormancy).

D. Secondary dormancy

Secondary dormancy is due to germination conditions. It is a further adaptation to prevent germination of an imbibed seed if other environmental conditions are not favorable. These conditions can include unfavorably high or low temperature, prolonged darkness and water stress. It is of two types:

I) **Thermo dormancy**: High temperature induced dormancy.

II) **Conditional dormancy**: Change in ability to germinate related to time of the year.

Advantages

1. Permitting germination only when environmental conditions favour seedling survival as in fruit plants of temperate region.
2. Helpful in creation of a “seed bank”
3. Dormancy can also synchronize germination to a particular time of the year.
4. Seed disposal can be facilitated by specialized dormancy conditions. For example modification of seed covering through digestive tract of a bird or other animals.

Lecture-3

Seed Dormancy: Methods of breaking seed dormancy

Learning objectives

- To know about techniques for breaking different types of dormancy

Several methods are used for breaking seed dormancy of horticultural crops. These are briefly described hereunder:

1. **Softening seed coat and other seed coverings:** This helps in better absorption of water and gases, which ultimately leads to better germination of the seeds. This can be achieved by scarification.

a) Scarification: Scarification is the process of breaking, scratching, mechanically altering or softening the seed covering to make it permeable to water and gases. Three types of treatments are commonly used as scarification treatments. These include mechanical, chemical and hot water treatments.

i) Mechanical scarification

- It is simple and effective if suitable equipment is available.
- Chipping hard seed coat by rubbing with sand paper, cutting with a file or cracking with a hammer are simple methods useful for small amount of relatively large seeds.
- For large scale, mechanical scarifiers are used. Seeds can be tumbled in drums lined with sand paper or in concrete mixers containing coarse sand or gravel. The sand gravel should be of a different size than the seed to facilitate subsequent separation.
- Scarification should not proceed to the point at which the seeds are injured and inner parts of seed are exposed.

ii) Acid scarification

- Dry seeds are placed in containers and covered with concentrated Sulphuric acid (H_2SO_4) or HCl in the ratio of one part of seed to two parts of acid.
- The amount of seed treated at any time should be restricted to not more than 10kg to avoid uncontrollable heating.
- The containers should be of glass, earthenware or wood, non- metal or plastic. The mixture should be stirred cautiously at intervals during the treatment to produce uniform results.

- The time may vary from 10 minutes to 6 hours depending upon the species.
- With thick-coated seeds that require long periods, the process of scarification may be judged by drawing out samples at intervals and checking the thickness of the seed coat. When it becomes paper thin, the treatment should be terminated immediately.
- At the end of the treatment period, the acid is poured off and the seeds are washed to remove the acid.
- The acid treated seeds can either be planted immediately when wet or dried and stored for later planting. Large seeds of most legume species, brinjal and tomatoes are reported to respond simple sulphuric acid treatment.

iii) Hot water scarification

- Drop the seeds into 4-5 times their volume of hot water with temperature ranging from 77 to 100^{o}C.
- The heat source is immediately removed, and the seeds soaked in the gradually cooking water for 12 to 24 hours. Following this the unswollen seeds may be separated from the swollen seeds by suitable screens.
- The seed should be sown immediately after hot water treatment.

iv) Warm moist scarification

- The seeds are placed in moist warm medium for many months to soften the seed coat and other seed coverings through microbial activity. This treatment is highly beneficial in seeds having double seed dormancy.
- The hard seeds are planted in summer or early fall when the soil temperature is still higher, that usually facilitates germination.
- For instance the stone fruit including cherry, plum ,apricot and peaches) show increased germination if planted early enough in the summer or fall to provide one to two months of warm temperature prior to the onset of chilling.

b. Stratification

- Stratification is a method of handling dormant seed in which the imbibed seeds are subjected to a period of chilling to after ripen the embryo in alternate layers of sand or soil for a specific period. It is also known as moist chilling.
- However, temperate species displaying epicotyl dormancy (like fringed tree) or under developed embryo (like hollies) a warm stratification of several months followed by a moist chilling stratification is required.

- Several tropical and subtropical species (like palms) require a period of warm stratification prior to germination to allow the embryo to continue development after fruit drop.
- The seeds can be sown after fruit drop. The seeds can be sown immediately after stratification in the field.
- Seeds with a hard endocarp, such as *Prunus* spp. (the stone fruit including cherry, plum, apricot and peaches) show increased germination if planted early in the summer or fall to provide one to two months of warm temperature prior to the onset of chilling.

i)Outdoor stratification

- If refrigerated storage facilities are not available, outdoor stratification may be done either by storing seeds in open field conditions in deep pits or in raised beds enclosed on wooden frames.
- However it is likely that seeds are destroyed in outdoors by excessive rains, freezing, drying, or by rodents. Seeds are placed in alternate layers of sand to provide and low temperature and proper aeration in the stratification pit. The top is covered with Sphagnum moss to maintain moisture level.
- The pit or tray is irrigated at regular intervals to maintain appropriate moisture status.

ii) Refrigerated stratification

- An alternative to outdoor field stratification is refrigerated stratification.
- It is useful for small seed lots or valuable seeds that require special handling.
- Dry seeds should be fully imbibed with water prior to refrigerated stratification. Twelve to twenty four hours of soaking at warm temperature may be sufficient for seeds without hard seed coats.
- After soaking, seeds are usually placed in a convenient size box in alternate layers of well washed sand, peat moss or vermiculite(Plate 3.3).
- A good medium is a mixture of one part of coarse sand to one part of peat, moistened and allowed to stand for 24 hours before use. Seeds are placed in alternate layers of sand or medium.
- The usual stratification temperature is 4-7^{o}C. At higher temperature seeds sprout prematurity and low temperature delays sprouting.
- The medium should be remoistened. The stratified seed is separated from the medium prior to sowing in nursery beds.

- The stratification of seeds results in quick and uniform germination and therefore the seed should be subjected to stratification invariably under all conditions.

Table 3.1. Effect of seed stratification period on per cent germination of important temperate fruits

Kind of fruit	Stratification period (days)	% germination
Apple	70-75	70-75
Kainth (*Pyrus pashia*)	30-35	90-95
Peach	60-70	55-60
Apricot	45-50	75-80
Almond	45-50	85-90
Walnut	95-100	80-85
Pecan	70-75	75-80

iii) Leaching of inhibitors: It is established fact that some inhibitors and phenolic compounds are present in seed coverings of many species, which inhibit germination. Therefore, soaking of seeds in the running water for 12-24 hours or placing them in water for few hours help in leaching off the inhibitors and phenolic compounds, which help in easy seed germination.

iv) Pre-chilling: In seeds of certain plant species, dormancy can be overcome by pre-chilling treatment. In this treatment, the imbibed or soaked seeds are kept at a temperature of 5-10^{0}C for 5-7 days before sowing. After that seed can be sown in the field immediately.

v) Pre-drying: This is also a useful practice in some seeds to overcome seed dormancy. In this treatment, the dry seeds are subjected to a temperature of 37-40^{0}C for 5-7 days prior to sowing. After this, seed can be sown in the field.

vi) Seed priming: Seed priming refers to the procedures followed to overcome dormancy in freshly harvested fruits. Most widely used seed priming procedures are osmo- conditioning, infusion and fluid drilling.

- **In osmo-conditioning**, the seeds are placed in shallow layer in a container having 20-30 per cent solution of polyglycol (PEG). The seeds are then incubated at 15-20^{0}C for 7-21 days, depending upon seed size and plant species.

- Different hormones and fungicides can also be added to protect the seeds from pathogens. After this, the seeds are washed and dried at 25^0C and are stored until use.
- **In infusion**, the hormones, fungicides or insecticides and antidotes are infused into dormant seeds through organic solutions. In this process the seeds are placed in acetone or dichloromethane solution containing chemicals to be used for 1-4 hours.
- Afterwards, the solvent is allowed to evaporate and seeds are dried slowly in vacuum desiccators for 1-2 hours. The seeds absorb the infused chemical directly into the embryo when soaked in water.
- **In fluid drilling**, the seeds are suspended in a special type of gel before sowing. Now-a- days different types of gels are available in the market but sodium alginate, guar gum and synthetic clay are most widely used in fluid drilling.

vii) Treatment with chemicals: Some compounds other than hormones are also used to break dormancy but their role is not clear. Thiourea is one example known to stimulate germination in some kinds of dormant seeds. The seeds are soaked in 0.5 – 3 per cent solution of thiourea for 3-5 minutes. Afterwards seeds are rinsed with water and are sown in the field. Similarly, potassium nitrate and sodium hypochlorite also stimulate seed germination in many plant species.

viii) Hormonal treatment

- Among various hormones, GA_3 is commercially used for breaking seed dormancy in different types of seeds. The concentration of GA_3 depends upon the kind of seed but generally a concentration of 200-500 ppm is most widely used.
- Cytokinin is another group of hormones used for breaking physiological dormancy and stimulating germination in seeds of many species. Kinetin and BA(6-benzyle aminopurine) are commercial preparations of cytokinin used for breaking seed dormancy. Soaking seeds in 100 ppm solution of kinetin for 3-5 minutes is highly effective concentration for overcoming seed dormancy of many species. Etheral also stimulates germination in seeds of some species.

Table 3.2. Recommended concentrations of growth hormones in temperate fruits for increasing seed germination

Crop	Chemical/hormone	Concentration
Apple	Thiourea	5000ppm
	Kinetin	25ppm
	GA	50ppm
	Ethrel	100-200ppm

Pear	GA	150ppm
	Thiourea	5000ppm
Peach	Thiourea	5000ppm
	GA	400ppm
	BA	400ppm
Walnut	GA	250ppm
	Ethrel	1000ppm

Hormonal changes during stratification:

A triphasic change in endogenous hormones is many seeds is depicted in Fig.3.1.

- A reduction of ABA
- Increased synthesis of cytokinin and gibberellins
- Reduction in hormone synthesis in preparation for germination.

- In general, gibberellins promote germination in dormant seeds, while ABA inhibits germination.
- Pre-sowing treatments with certain seeds not only reduce the stratification requirement and improve the seed germination but also enhances seedling growth in a number of temperate fruits.

Role of hormones in seed dormancy:

Plant hormones affect seed germinations and dormancy by affecting different parts of the seed. Embryo dormancy is characterized by a high ABA/GA ratio, whereas the seed has a high ABA sensitivity and low GA sensitivity. To release the seed from this type of dormancy and initiate seed germination, an alteration in hormone biosynthesis and degradation towards a low ABA/GA ratio, along with a decrease in ABA sensitivity and an increase in GA sensitivity needs to occur.

- Plant regulators can be used to break or prolong the dormancy. Sprouting of potato tubers and onion bulbs is a common phenomenon in storage.
- Pre-harvest spray of maleic hydrazide (MH) at 2000 ppm applied 15 days before actual date of harvest prolongs dormancy in the above storage organs by inhibiting the sprouting.
- In fruit trees of apple, plums and figs, early flowering is induced by spraying Dinitro orthocresol at 0.1 % in oil emulsion.
- Seed treatment of tomato with GA at 1 00 ppm breaks the dormancy and increases the percentage of germination.

- ABA controls embryo dormancy, and GA enhances embryo germination. Seed coat dormancy involves the mechanical restriction of the seed coat, this along with a low embryo growth potential, effectively produces seed dormancy.
- GA releases this dormancy by increasing the embryo growth potential, and/or weakening the seed coat so the radical of the seedling can break through the seed coat. Different types of seed coats can be made up of living or dead cells and both types can be influenced by hormones; those composed of living cells are acted upon after seed formation while the seed coats composed of dead cells can be influenced by hormones during the formation of the seed coat.
- ABA affects testa or seed coat growth characteristics, including thickness, and effects the GA-mediated embryo growth potential. These conditions and effects occur during the formation of the seed, often in response to environmental conditions. Hormones also mediate endosperm dormancy.
- Endosperm in most seeds is composed of living tissue that can actively respond to hormones generated by the embryo. The endosperm often acts as a barrier to seed germination, playing a part in seed coat dormancy or in the germination process.
- Living cells respond to and also affect the ABA/GA ratio, and mediate cellular sensitivity; GA thus increases the embryo growth potential and can promote endosperm weakening. GA also affects both ABA-independent and ABA-inhibiting processes within the endosperm.

Lecture-4

Polyembryony, apomixis, chimeras and bud- sports

Learning objective

- To get acquainted with polyembryony, apomixis, chimeras and bud- sports
- Horticultural significance of polyembryony, apomixis, chimeras and bud- sports

Polyembryony

Polyembryony means that more than one embryo develops within a single seed. It is also known as adventitious embryony (Nucellar embryony or Nucellar budding).

- Polyembryony can develop from several distinct causes. Specific cells in the nucellus or sometimes with integument have embryos. Genetically, these embryos have the same genotype as the parental plant and are apomictic.
- Adventitious embryony occurs in many plant species but is most common in citrus and mango. In these species, both zygotic and apomictic embryos are produced. In other species (e.g. *Opuntia*), no pollination or fertilization is needed.
- Polyembryony is common in mango and citrus. In trifoliate orange (*Poincirus trifoliata)* several seedlings arise from one seed.
- Of these seedlings, one seedling, usually the weakest may be sexual, and the others arise apomictically from cells in the nucellus, which are diploid copies of the mother plant.

Horticultural significance of polyembryony

Nucellar seedlings in citrus are completely free from viruses, because the embryo sac and adjoining tissues are impregnated at flowering time with some unknown powerful substances which kills all the viruses. For immediate requirement of planting material, development of nucellar lines is the quickest and easiest method. The major possible horticultural applications of polyembryony are:

- Nucellar seedlings are true-to-type seedlings
- Such seedlings are genetically uniform and can be used as virus free rootstocks
- More vigorous seedlings – continuous vegetative propagation leads to decline in vigour in citrus
- Development of virus free seedlings and bud wood
- Significance in breeding programme

Apomixis

In some species of plants, an embryo develops from the diploid cells of the seed and not as a result of fertilization between ovule and pollen. This type of reproduction is known as **apomixis** and the seedlings produced in this manner are known as apomicts.

- Apomictic seedlings are identical to mother plant and similar to plants raised by other vegetative means, because such plants have the same genetic make-up as that of the mother plant.
- Such seedlings are completely free from viruses. Plants that produces only apomictic embryo and are known as **obligate apomicts** and those which produce both apomictic and sexual seedlings are called **facultative apomicts**.

Types of Apomixis: Maheshwari (1950) classified apomixis into four groups:

1. **Recurrent Apomixis**: In this type of apomixis, the embryo develops from the diploid egg cell or from the diploid cells of the embryo sac without fertilization. As a result, the egg has normal diploid number of chromosomes, just like the mother plant (Fig.4.1).The species, where recurrent apomixis commonly occur are, *Parthenium, Rubus, Malus, Allium , Rudbeckia, Poa, Taraxacum* ,etc.
2. **Non-Recurrent Apomixis**: In this case, the embryo develops either from the haploid egg cell or from some other haploid cells of the embryo sac. In this case, haploid plants are produced, which contain only one set of chromosome of the mother plant. Hence, the haploid plants are sterile in nature and cannot be normally perpetuated into the next generation. Non-recurrent apomixis occurs only in a few species such as *Solanum nigrum, Lilium* spp. etc.
3. **Nucellar Embryony or Adventitious Embryony**: In this type of apomixes, the embryos arise from diploid sporophytic cells outside the embryo sac i.e. cells of the nucellus, integuments etc. This type of apomixis is quite common in citrus and certain varieties of mango, where fertilization occurs normally and sexual plus a number of apomictic (nucellar) embryos develop.
4. **Vegetative apomixis or bulbils**: In some species of plants, such as *Allium* , *Agave, Poa* etc., the flowers in an inflorescence are replaced by bulbils or vegetative buds, which sprout, while still on the mother plant and turn into new daughter plants.

Advantages

- Assured reproduction in the absence of pollinators, such as in extreme environments
- Maternal energy not wasted in unfit offspring (cost of meiosis)

- Some apomictic plants (but not all) avoid the male energy cost of producing pollen

Disadvantages

- Can't control accumulation of deleterious genetic mutations
- Usually restricted to narrow ecological niches Lack ability to adapt to changing environments

Clone

The term clone may be defined as a group of genetically uniform individuals, derived originally from a sexually produced individual or from mutations and maintained exclusively by asexual means from one ancestor.

- The common examples are Bartlett pear, Delicious apples, Sultana grapes and Dashehari mango.
- The goal of vegetative propagation is to reproduce progeny plants identical in genotype to a single plant. The biological process is known as cloning and the resulting population of plants is called a clone.
- The uniformity of individual plants, within a clonal population is a major advantage of clonal cultivars of fruit and nut crops.
- Clonal propagation helps in fixing genotypes, uniformity of population, facilitates propagation and reduces juvenile phase, combine more than one genotype into single plant (grafting) and control phases of development.
- If environmental conditions are favourable and the clone is managed properly, its trueness-to-type can be maintained for hundreds of years.

Genetic variations in a clone

Mutation

Mutation is a single-step genetic change or sudden heritable change within cells of a clone. In general, these changes take place spontaneously, in the plants regular but rare intervals.

- A mutation is a genetic change involving some part of the DNA molecule. Genetic mutations result from structural changes in the nuclear DNA of the chromosome in the nucleus. DNA also occurs in mitochondria and chloroplasts and defects here can produce genetic changes.
- Chromosomal changes may be due to chance rearrangement of the four bases in the DNA molecule (point mutation) rearrangement of different parts of the chromosomes (deletion, duplication, translocations and inversions), addition or subtraction of

individual chromosome (aneuploidy), or the multiplication of entire set of chromosome (polyploidy).

- The rate of mutation can be increased by treatment with specific mutagenic agents e.g. X-ray, gamma rays and certain chemicals.

Bud- sports or bud mutations

When mutation occur and suddenly appear as a chance in the branch of a plant, is called **bud sport or bud mutations**, because they appear to have originated within a single bud.

- Detection of a new mutant within a clone may require a series of vegetative propagated generations and multiple propagations from many buds of the same plant.
- Many 'sports' have become commercial cultivars. Mutations may affect fruit (colour, shape, time of maturity), tree structure (spur type), time of bloom, and as a host of other traits. Sometimes these mutants have highly useful horticultural traits and have given rise to important new cultivars ('Ruby Red' grapefruit, red coloured sports of apple and pear.)
- On the other hand, mutations may be undesirable and give rise to misshapen fruits, low production and susceptibility to diseases.

Chimeras

When a mutation occurs within a single cell of a clone, it initially produces an '**island** 'of mutant cells within a growing point of a stem. The plant becomes a, mixture of two different genotypes. This structural arrangement is known as **chimeras**.

- It is the most important kind of genetic variant within clones typified by various kinds of variation. The name chimera was historically given to certain unique clonal variants now known to have arisen as graft chimeras.
- Chimeras develop because of the unique architecture of the apical meristem and the strategic location of the mutation in a dividing cell near the apex of the apical meristem.
- The three important types of chimeras are based upon the distribution patterns of mutated and non-mutated cells.
- Buds arising at different positions on a sectorial chimera may produce shoots consisting of mutated and non-mutated cells, entirely of mutated cells or entirely of non- mutated cells or sectorial (rarely), mericlinal or periclinal chimeras as described herewith.

- **Periclinal chimera:** The mutated tissues occupy layers of cells that completely surround an inner core of non mutated tissue. For examples in many red colored fruit cultivars in apple (Plate 4.2), the red pigment is located only in the epidermal layers; whereas the cells of the inner tissue have alleles for green or yellow colour. Similarly, some black berry (*Rubus spp.*) cultivars are thorn less; because the cells making up the epidermis do not have this allele. Periclinal chimeras are relatively stable if propagated stem or grafting.
  - **Mericlinal chimera:** This combination is similar to the periclinal expect that the cells carrying the mutant gene occupy only a part of the outer cell layer. In case of a red mutant on a yellow delicious fruit, the surface of the fruit may have longitudinal streaks or sectors of red on an otherwise yellow surface (Plate 4.3). This type is unstable and tends to change into periclinal chimeras, revert to the non-mutated form, or continue to produce mericlinal shoots.
  - **Sectorial chimera:** The mutated cells in this combination occupy an entire sector of the stem including all layers of the shoot apex. Sectorial chimeras appear if the mutation occurs in roots and very early stages of embryos where the cells of the growing point do not occur in layers. In general, this type is unstable and tends to revert to mericlinal and periclinal chimeras.
  - **Graft Chimera:** In horticulture, a **graft-chimera** may arise in grafting at the point of contact between rootstock and scion and will have properties intermediate to those of its **parents**. A graft-chimera is not a true hybrid but a mixture of cells, each with the genotype of one of its parents is a chimera. Hence, the once widely used term "graft-hybrid" is not descriptive; it is now frowned upon. In practice graft-chimaeras are not noted for their stability and may easily revert back to one of the parents.

SEED GERMINATION

James C. Delouche[1]

Germination is the crucial and final event in the life of a seed. It represents both the fulfillment and the completion of the basic function of seed - propagation. Seed - to be sure - have other functions in modern agriculture. They are the main mechanism by which improvements genetically engineered into plant populations are transmitted from one crop generation to another. They also function very efficiently as a convenient means of distributing plant populations throughout areas of adaptation. The latter two functions, however, are wholly dependent on germination. A seed that has lost its capacity for germination can neither transmit genetic improvements nor function in the distribution of desirable plant populations from one place to another.

Seed are produced to propagate crops and other desirable plant species. A substantial portion of the operations and activities involved in seed production and supply are designed to maintain, protect, and/or enhance the propagative value of seed, i.e., capacity to germinate. Seedsmen, therefore, should have a good understanding of the germination process and its vulnerabilities.

Germination is the resumption of active growth of the embryonic axis in seed. The meaning of this definition will be clearer after a brief review of the essential events involved in seed formation and development.

Seed Formation and Development

At some point in the life cycle of annual plants or the seasonal cycle of perennials, the balance of physiological processes shifts from growth to reproduction. Reproductive organs are initiated, develop and mature. Certain cells within the male and female organs undergo meiosis and produce male and female gametes with a reduced chromosome number, i.e., one chromosome from each pair. The stamen which is the male organ produces pollen grains which carry the sperm or male nuclei. The pistil or female organ consists of an ovary, style and stigma. The ovary contains ovules within which the female or egg cells are situated - one

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egg cell per ovule. In angiosperms two other cells - the polar nuclei - participate in the overall reproductive act. A pollen grain is transferred from the anther to the stigma of the pistil. It germinates and produces a tube which grows down through the style and into the ovary and to an ovule. One sperm nuclei from the pollen tube fuses with the egg cell while a second nuclei fuses with the two polar nuclei in the ovule. This double fertilization is characteristic of the angiosperms or flowering plants. (See Figure 1).

Following fertilization the ovary develops into the fruit (e.g., soybean pod) while the ovules develop into the seed (e.g., seed within the pod). The fertilized egg cell divides, multiplies, develops and differentiates into the embryo with 2N chromosome number (one of each pair from the female and male parents). The fertilized polar nuclei develop into the endosperm. The seed coat or covering is derived from maternal tissue - the integuments of the ovule, plus, in some cases, accessory tissues such as the pericarp (fruit coat) and hulls.

The embryo reaches full development and ceases to grow. Moisture content of the maturing seed continues to decrease and food reserves continue to accumulate. Physiological maturity of the seed is attained, i.e., maximum dry matter accumulation, and dehydration of the seed continues until an equilibrium is established between the seed and the relative humidity of the field or storage environment. During seed formation the endosperm develops and constitutes a major portion of the seed in some species, e.g., the starchy portion of a corn kernel. In other species the endosperm develops to a point and is then "reabsorbed" with its "food storage" function taken over by the cotyledons - organs of the embryo.

The events outlined above culminate in the formation of a mature seed. The seed is very dry - 10 to 14% moisture content. Dehydration of living plant tissue to this degree - and even lower - is unusual. The dehydrated condition of seed is a major factor involved its remarkable longevity and resistance to environmental stresses.

Components of Mature Seed and Their Functions

The mature "seed unit" consists of three essential components: a seed covering, storage or supporting tissue, and an embryonic axis in an "arrested" state of development (Figure 2). Each of the three components of the seed has essential roles and functions. The seed covering has two functions: a protective function and a regulatory function. The seed covering maintains a "sterile" condition inside the seed (ideally), and protects the seed against the invasion of external micro-organisms, and mechanical abuse. Seed with fractured seed coverings are much more susceptible to storage fungi and seed rotting organisms in the soil than those with intact seed coverings. In terms of protection against mechanical abuse, a seed with a thick, somewhat elastic seed covering withstands greater mechanical force than one with a thin, brittle seed covering.

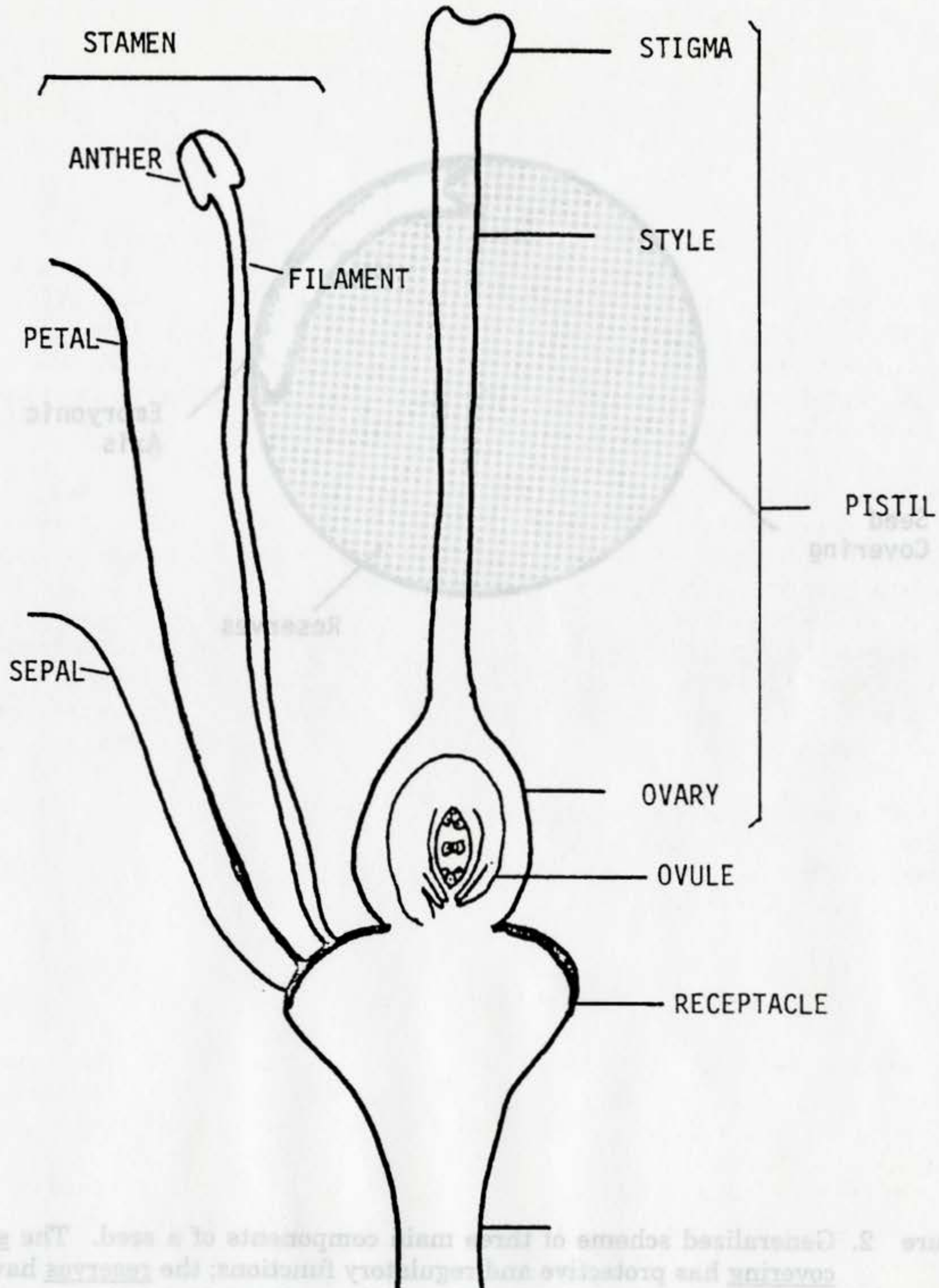


Figure 1. Cut-a-way view of a typical perfect flower.

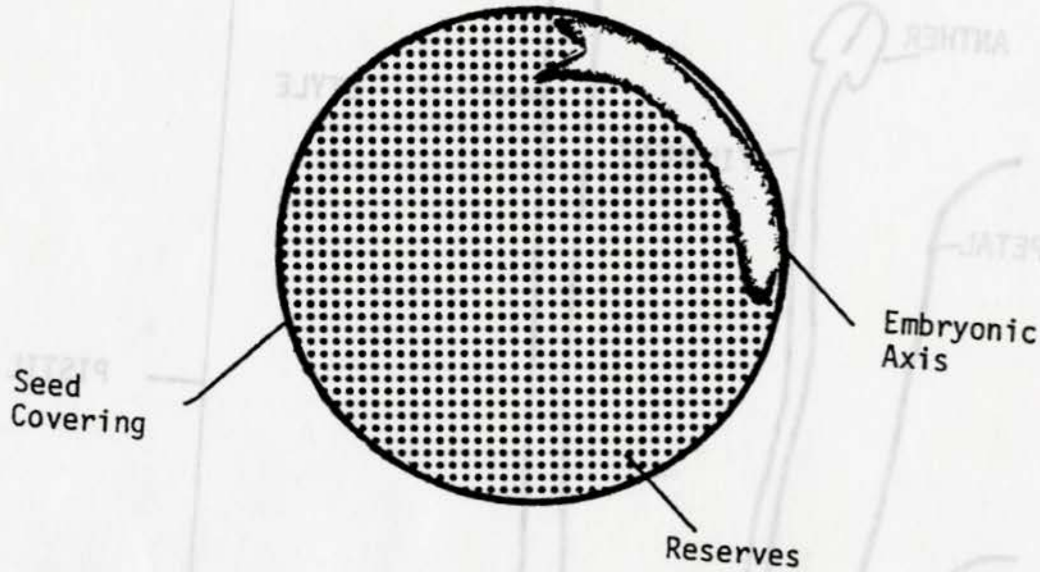


Figure 2. Generalized scheme of three main components of a seed. The seed covering has protective and regulatory functions; the reserves have a nutritive function; the function of the embryonic axis is to resume growth and develop into the plant.

The seed covering regulates the rate of absorption of water - vapor and liquid - and oxygen. Seed always absorb water more rapidly with the seed covering removed (or ruptured) than when it is intact. The reduction in rate of water absorption imposed by the seed covering reduces the magnitude of imbibitional stresses that develop as the "wetting front" moves into the embryonic tissue, thus minimizing tearing of the tissue. The water absorption regulatory function is also involved in dormancy mechanisms. In some species the regulation is extreme - the seed covering is completely impermeable to water (hard seed). In other cases regulation of the rate of water absorption by the seed covering slows the germination process which can be advantageous or disadvantageous depending on the circumstances. A restriction on rate of oxygen absorption imposed by the seed covering is believed to be involved in dormancy in many species, especially species of the grass family. The seed covering, therefore, ultimately regulates germination itself through its regulation of water and oxygen absorption.

The supporting or reserve tissue of seed - endosperm, cotyledons or perisperm - contains starch, proteins, fats and oils, minerals, and other substances. During germination these materials are broken down to provide the energy, "building blocks", and other nutritional materials required to support the resumption of active growth of the embryonic axis. *The function of the embryonic axis is, of course, resumption of active growth leading to the development of a seedling.*

The mature seed dries naturally or is dried artificially to a moisture content of 8-13%. This level of hydration (moisture content) is extremely low and can - at best - support only a maintenance level of activity, deteriorative processes, and physical-physiological changes involved in the "loss" of dormancy. Growth of the embryonic axis ceased prior to the time physiological maturity was attained which - it should be recalled - occurs while seed moisture content is still very high, 30 to 60% depending on the species.

Germination can be considered as a complex of physical and physiological processes which result in the resumption of active growth of the embryonic axis. Physiologists and biochemists usually consider germination as complete when the radicle or root tip ruptures the seed covering and becomes visible. Seed technologists and crop scientists, however, are interested in seedling development so their definition of germination encompasses both the resumption of active growth and early seedling development.

Resumption of active growth of the embryonic axis requires the availability of several environmental factors and conditions.

Requirements for Germination

The basic requirements for germination of seed are moisture, a favorable temperature, and oxygen.

Moisture

Moisture is required for rehydration of the seed to levels that can support greatly increased respiratory activity, the breakdown of complex reserve materials such as starch, fats and oils, and proteins into simple, mobile, and usable forms, and the synthesis of new materials for growth. The moisture or water must be available in the liquid phase. Seed cannot absorb enough water vapor to bring moisture content high enough to support completion of the germination process.

The liquid water required for germination is normally supplied by the media in or on which the seed are planted - soil, peat, blotters, etc. The absorption of water by a seed essentially involves a special type of diffusion called imbibition. Water - or other mobile material - move from a place or area where it is high in concentration (purer) to an area where it is lower in concentration (less pure) by diffusion until an equilibrium is established, assuming, of course, there are no barriers to such movement. The water in a seed at 10-13% moisture content is not very concentrated - it is very impure. It is much lower in concentration than the water in a moist blotter, damp peat, or even relatively "dry" soil. The net movement of water, therefore, is from the media (soil, peat, blotter, etc.) into the seed. As mentioned above the initial stages of water absorption by a seed are most physical. They are the same whether the seed is alive and germinable, alive and nongerminable (dormant), or dead.

As water continues to move into the seed, the cells rehydrate and begin to develop a pressure - a bit like the pressure which develops as a tire is inflated. Rate of water absorption slows down as the internal pressure - hydrostatic pressure - increases. A point is eventually reached where the hydrostatic pressure in the seed cancels out any remaining difference in diffusion pressure between water in the media and seed, and an equilibrium is established. The seed is "fully" imbibed. The "fully imbibed" condition roughly corresponds to the seed moisture content required for gemination.

The seed moisture content required for germination varies among the species. A seed of a species of the grass family - grasses, cereals, small grains, etc., must attain and maintain a moisture content of 30-40% in order for germination to proceed to the point where active growth is resumed. Other kinds of seed, because of differences in chemical composition, require higher moisture contents for germination - 50 to 60% for cotton, soybean, and peanut seed.

Earlier, the statement was made that water absorption by seed involves a special type of diffusion called imbibition. Imbibition is characterized by a swelling of the imbibing material (e.g., seed) and the intake of relatively great amounts of water in relation to the initial volume and dry weight of the imbibing material. The colloidal materials in seed have a great affinity for water and swell as they become hydrated. Imbibition is also characterized by the production of heat.

The rate of water absorption by seed is affected by several factors: the permeability of the seed covering to water; initial moisture content of the seed; temperature; the relative concentration or purity of water in the seed and in the media; the extent of forces binding water to the media; the extent of contact of the seed with the water supply; and the chemical composition of the seed. The coat or covering of a seed generally restricts the rate of water absorption to some degree, which is desirable. In some cases, however, the seed covering is impermeable to water, and no water can be absorbed. This condition is certainly undesirable at planting time.

Other factors being equal, the rate of water absorption by a seed increases as temperature increases (within a "biological" range), the initial moisture content is lower, the area of the seed in contact with water is larger, and the difference in concentration of water in the media (high) and seed (low) is wider.

Although seed have a great "capacity" for absorption of water, several field conditions can reduce the availability of water to the extent that the critical seed moisture content for germination cannot be attained. Lack of rain or evaporation during seed bed preparation can result in a low supply of moisture in the soil through the planting depth. Under such conditions rate of water absorption, hence, germination can be slowed down considerably. If the soil moisture is still lower, the seed might be able to absorb only enough water to increase moisture content to 20 to 25%, which is not enough for germination. Until the soil is resupplied with moisture by rain or irrigation, the seed are in effect "stored" in the soil at a high moisture content and often at high temperatures. If this "storage" period is sufficiently long, the seed will deteriorate, be attacked by seed rotting organisms, and die. Situations such as this are often responsible for stand failures in late planted soybeans. The soil is too dry to supply enough water for the seed to germinate but they do increase in moisture content and swell. The soil temperature at planting depth can in Mississippi range from 80°F during the night to over 100°F during the day. Soybean seed do not live long under such conditions.

Planting seed in the fertilizer band reduces the availability of water to the seed because the fertilizer reduces the concentration of water in the band zone.

Oxygen

A second general requirement for germination of seed is a supply of oxygen. Oxygen is needed for a great increase in respiratory activity to provide energy to drive the germination process. Since the atmosphere has an abundance of oxygen, it becomes limiting for germination only when its availability to the seed is blocked or impeded by some environmental factor or seed condition. Excessive moisture in the soil or other media displaces oxygen in the pore spaces and can reduce its availability to the seed below the threshold level. Many kinds of seed die and ferment in soil that is water logged for more than 2 or 3 days. The covering or coat of some kinds of seed imposes dormancy on the seed because it restricts absorption of oxygen.

A few kinds of seed such as those of rice and some aquatic plants can germinate submerged in water - a condition that severely limits or excludes oxygen.

Favorable Temperature

For each kind of seed there is a range of temperature within which the germination process can proceed to completion in a reasonable period of time if it is not blocked by dormancy. The classical work on seed germination defines three cardinal points along the temperature range for germination of a species. These cardinal points are the minimum or base, optimum, and maximum or ceiling temperatures. They differ among the different kinds of seed.

The minimum or base temperature is the temperature below which the processes of germination do not proceed to the point of visible growth of the embryonic axis within a "reasonable" period of time. For many seed kinds the minimum temperature is difficult to establish because of its dependence on time. Since the main effect of a lower temperature on germination is - up to a point - a slowing down of the germination process, the minimum temperature established in a 10 day germination period is usually higher than when a 15 or 20 day period is allowed. Temperatures below the minimum but above freezing are usually not lethal to imbibed seed and do not cause death unless exposure is very prolonged, there is an interaction with seed rotting micro-organisms, or the seed are susceptible to imbibitional chilling injury. The seed generally germinate rather rapidly when the temperature is raised from the sub-minimal level to near the optimum.

The maximum or ceiling temperature is the temperature above which the germination mechanisms fail and visible growth does not occur. In contrast to the minimum temperature, the maximum temperature is rather specific and relatively easy to establish. Further, a temperature above the maximum is usually lethal. Imbibed seed exposed to temperatures above the maximum die and rot within a few days.

The optimum temperature for germination is the temperature at which the maximum percentage of seed germinate in the shortest period.

The cardinal temperatures for germination and their interrelationships can be illustrated by using a line to represent the temperature range within which germination takes place:

A. Minimum — Optimum — Maximum

Vigorous Seed

B. Minimum — Optimum — Maximum

Fresh or Low Vigor Seed

The optimum temperature for germination is generally closer to the maximum than to the minimum. The major effect of reducing temperature from the optimum to the minimum is on the rate of germination. The germination process and early seedling growth become progressively slower as temperature decreases from the optimum. If enough time is allowed, the percentage of germination is about the same. On the other hand, increasing the temperature above the optimum decreases both the rate and percentage of germination regardless of the time period allowed.

The effect of temperature on germination is strongly influenced by the physiological condition of the seed. Newly harvested seed, which are often residually dormant, are usually rather specific in their requirements for germination. This is related to the dormancy condition. Newly harvested rice seed, for example, germinate best at about 32ºC, while newly harvested wheat seed do best at 16-18ºC. As seed lose their residual dormancy, the optimum temperature shifts to a slightly warmer level and the temperature range for germination increases. The seed become less specific in their requirements for germination. (See diagrams A and B above).

There is another shift in the temperature requirement as seeds deteriorate. The seed again becomes more sensitive to temperature, the temperature range for germination shortens, and the optimum temperature shifts to a cooler level.

Much of the research on temperature relations of germination has been done using constant temperatures. In nature, of course, seed seldom germinate under constant temperatures. In most climatic areas there is a daily fluctuation of temperature from "higher" during the day to "lower" at night. It is not surprising, therefore, that many species germinate better under alternating temperatures than at a constant temperature. Most kinds of forage grass seed, for example, germinate best under such daily alternations of temperature as 15 to 25ºC, 20 to 30ºC, and 20 to 35ºC.

Temperature affects the gemination process in several ways. In general, the rate of germination increases as temperature increases from the minimum to the optimum and even slightly above the optimum. Temperature has a pronounced effect on rate of respiration and the many other processes involved in germination including rate of water absorption. As the temperature approaches the maximum, the detrimental effects of excessive heat on the living system and biological materials become obvious. There is an increase in the percentage of abnormal seedlings and decayed seed. When the temperature exceeds the maximum, all of the seed die within a few days.

Knowledge of the temperature requirements for germination and the range within which germination occurs is not just of academic interest. It is important in establishing the most favorable planting dates and in unraveling many stand establishment problems.

Mobilization of Energy and Food Reserves

The absorption of water by seed "turns on" and/or accelerates metabolic processes which lead to the resumption of active growth of the embryonic axis in the seed and support early seedling development. One of the basic processes accelerated is respiration.

Energy is required for the resumption of active growth of the embryonic axis - for germination and many of the processes that support germination. The energy required is provided by respiration. An air dry seed at 10-13% moisture content respires but at a very low rate. During the water absorption phase of the germination process, the rate of respiration increases dramatically. Some of the energy released during respiration is in the form of heat, but most is converted from some chemical forms to others.

The process of respiration requires a readily available substrata - an organic compound which can be oxidized to release energy. The basic respiratory substrate is a simple sugar called glucose. During respiration glucose is oxidized by complicated processes to carbon dioxide and water with the release of a substantial quantity of energy. In green plants the organic compounds required for respiration are formed by the process of photosynthesis, thus the sun is the ultimate source of energy for plant growth and the production of seed and the other plant materials that man harvests.

Since photosynthesis is not re-established until after germination is complete and the seedling has developed to a certain extent, the germination process is dependent on reserve organic compounds stored in the seed for energy and other materials. Some of those organic compounds are in the embryonic axis in readily usable forms, e.g., sucrose, and serve as respiratory substrata for the early phase of the germination process. The bulk of the reserve materials, however, are in the form of complex, non-mobile (non-translocatable) forms located in specialized tissue within the seed. These compounds must be broken down to simple, translocatable forms to make them available for germination.

The reserve materials in seed occur in three major forms: starch and other complex carbohydrates, fats and oils, and proteins. The processes which transform these materials into usable, translocatable forms are termed "mobilization of reserves." (See Figure 3).

Starch is the principal reserve in cereals and other species of the grass family. It is stored in the endosperm. During the early phase of gemination, gibberellin, a hormone present in the scutellum (part of the embryo or gem), moves into the outermost layer of the endosperm and stimulates the activity of hydrolytic enzymes which catalyze the breakdown of starch into glucose. One of the steps involved in the breakdown of starch is the production of maltose, which is, of course, important in the brewing industry. Glucose is a simple sugar and easily translocated. It moves from the endosperm into the scutellum where it is converted into sucrose. Sucrose is then translocated to the active sites in the embryonic axis for use. The mobilization of stored starch and other complex carbohydrates in non-grass species such as peas is somewhat different but the end result is the same - respiratory substrata is made available to the active sites of the embryonic axis.

When all plant species are considered, the most frequent reserve material is fats and oils. The evolutionary significance of this situation is that fats and oils - or lipids - have a higher energy value than starch or proteins. Fats and oils are broken down by enzymic activity to fatty acids and glycerol. Glycerol is further broken down to simple compounds which can enter into the respiratory process, or it can be incorporated in "new" fats and oils. Likewise, the fatty acids are further degraded into fragments that are readily usable in the respiratory process or for re-conversion into other materials.

The proteins stored in seed are broken down by enzymic activity into amino acids. The amino acids liberated are translocatable and are used for synthesis of the new proteins required for other enzymes, and new plant material, i.e., for growth. Or, they can be oxidized to provide energy.

The reserve materials stored in seed provide the energy and "building blocks" needed for resumption of active growth of the embryonic axis and growth and development of the young seedlings. These materials are made available to the embryonic axis by "mobilization" processes. As the seedling develops, photosynthesis is re-established and it becomes independent of the reserves stored in the endosperm or cotyledons which decay or shrivel and drop from the seedling.

Man cultivates many species of plants for the reserve materials stored in seed for his own consumption or for animal feed. Wheat and other cereals are milled to produce flour for bread and pastries or for brewing. Rice is consumed directly.

STARCH

Starch $\xrightarrow{\text{amylases}}$ Maltose + Glucose

Maltose $\xrightarrow{\text{maltase}}$ Glucose

PROTEINS

Proteins $\xrightarrow{\text{proteinases}}$ Amino Acids

FATS AND OILS
(Lipids)

Lipids $\xrightarrow{\text{lipases}}$ Glycerol + Fatty Acids

Glycerol $\longrightarrow$ Respiratory Substrata

Fatty Acids $\longrightarrow$ Acetyl-CoA

Figure 3. Mobilization of food reserves in seed during germination.

Corn and sorghum are used as human and animal feeds, or for other products such as edible oil. All of these kinds of seed store primarily starch. The legumes such as beans, soybeans, peanuts, etc., and species from other families are consumed directly or milled to produce vegetable oils and protein residues. Man is fortunate indeed that the seed habit in higher plants evolved with an abundance of reserves to support the process of germination.

Resumption of Active Growth

The acceleration of respiration during imbibition and the mobilization of organic reserves provide the energy, fuel and building materials needed for gemination - the resumption of active growth of the embryonic axis. Growth involves cell elongation and expansion and cell division, i.e., the production of new cells.

Although the data and observations are not entirely in agreement, it appears that the first manifestations of resumed growth are the result of the elongation or expansion of existing cells. And, for most kinds of seed, cell elongation and expansion begins in the "embryonic" radicle or root. Cell division is initiated later - a few hours or even days after the onset of cell elongation.

In some species, cell elongation is sufficient to cause the radicle to emerge through the seed coat. Both cell elongation and division are involved in emergence of the radicle in other species. The time of radicle emergence is variable among seed kinds and greatly influenced by temperature. At a constant temperature of 30°C (86°F) radicle emergence in corn, soybean, sorghum and cotton seed can occur between 30-38 hrs.

The resumption of active growth begins in the radicle part of the embryonic axis then "spreads" to the plumule or epicotyl which will develop into the stem, leaves, branches, etc., of the plant.

During the germination process, some organic materials are "consumed", while others are synthesized. Since there is no input of new materials into a germinated seed, an overall decrease in dry weight occurs along with a redistribution of dry weight. Dry weight is "transferred" from the storage tissue (cotyledons, endosperm) to the growing embryonic axis, i.e., the seedling. The rate and degree of this transfer of "dry weight" from storage tissue to the seedling has been shown to be related to vigor in some kinds of seed.

In the soil the developing radicle or root responds positively to gravity and grows downward. The plumule or epicotyl responds negatively to gravity and begins to grow upward. Most seedlings can be classified into two groups on the basis of the "movement" of the storage tissue (or cotyledons). The storage tissue (endosperm) and one-cotyledon of seed of members of the grass family - corn, wheat, sorghum, etc. - remain in place in the soil, and the plumule emerges. Emergence of the plumule is facilitated by a conical sheath - the coleoptile - which encloses the leaves and growing point. The germination mode that maintains the storage tissue and cotyledons in place in the soil is called hypogeal germination. True peas have a hypogeal mode of germination - the cotyledons remain in the soil while the epicotyl or short emerges. (Figure 4).

The germination mode in cotton, beans, soybeans, sunflower, and peanuts is epigeal. The cotyledons or storage tissue are raised out of the soil. This is accomplished by growth of the hypocotyl - the portion of the seedling between the cotyledons and radicle. In soybeans, the hypocotyl emerges above ground in a sort of "doubled" position. It then straightens and pulls the cotyledons out of the soil. The seed coat is usually shucked during this process.

During emergence and seedling establishment, reserves are continually drawn from the storage tissue. Cotyledons that emerge above the soil generally become green and photosynthetic. Later, they shrivel and are dropped from the developing plant. Storage tissue and cotyledons that remain below the soil do not, of course, become green and photosynthetic. They serve in a nutritive role until the reserves are exhausted and then decay.

As the seedlings develops, a photosynthetic capability is established and it becomes autotropic - i.e., independent of stored food reserves for its nutrition. And, the growth and development cycle of the plant continues.

The term germination is properly associated with the resumption of active growth of the embryonic axis in a seed. However, it is also applied to the resumption of active growth of the buds and other meristemic areas in vegetative structures used for propagation of plants. A potato is not a seed but has many similarities in structure and function. A potato tuber has a covering, stored food, and a bud. When exposed to favorable conditions, the stored food is mobilized, and the bud resumes active growth - the potato germinates and a "seedling" develops. A joint of sugar cane, a tulip bulb, an iris rhizome also function in many ways like a seed.

Germination is a basic process in plants. Only in recent years have we begun to understand its complexity and some of the intricate mechanisms involved. As our knowledge grows and the mechanisms involved become clearer, greater control of the germination process should be possible for the benefit of crop production.

Considering the complexity of germination and the many mechanisms involved, it is not surprising that the process can and does fail. Nature compensates for germination failures by a general abundance in seed production. Man has followed this same route in crop production. Traditionally, a relative abundance of seed is planted to compensate for gemination failures. Although this tradition is still followed, it is becoming increasingly inappropriate in modern crop production.

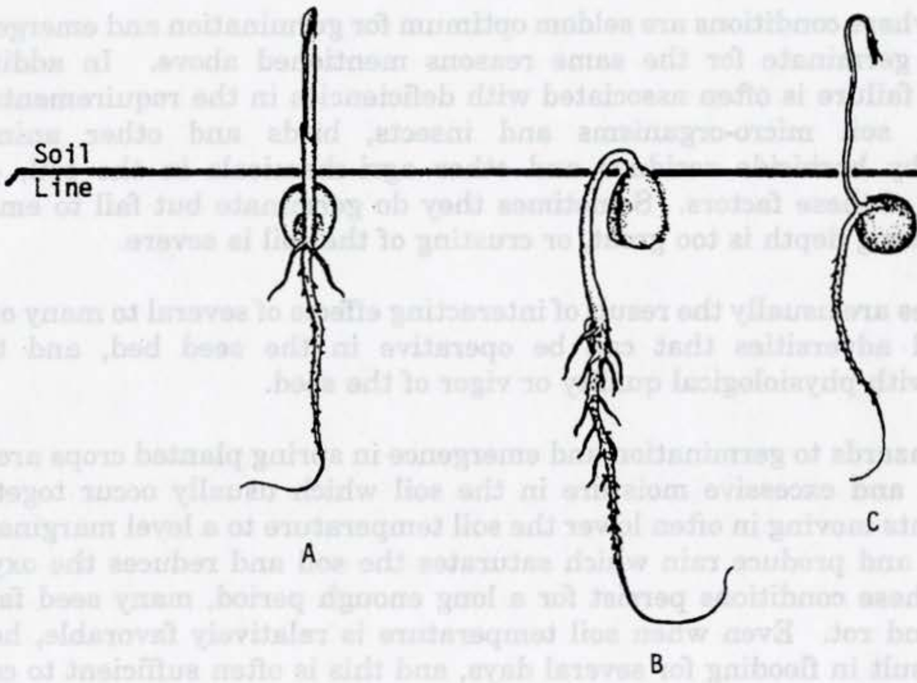


Figure 4. Emerging seedlings of: sorghum, A; soybeans, B; and peas, C.

Germination Failure

Seed fail to germinate and develop into seedlings for many reasons. Under the optimum conditions in the laboratory, germination failure is usually associated with dormancy, severe mechanical damage, or deterioration that has progressed to the point of loss of the capacity to germinate.

In the field where conditions are seldom optimum for germination and emergence, seed fail to germinate for the same reasons mentioned above. In addition, germination failure is often associated with deficiencies in the requirements for germination, soil micro-organisms and insects, birds and other animals, toxification by herbicide residues and other agri-chemicals in the soil, or a combination of these factors. Sometimes they do germinate but fail to emerge because planting depth is too great, or crusting of the soil is severe.

Stand failures are usually the result of interacting effects of several to many of the hazards and adversities that can be operative in the seed bed, and their interaction with physiological quality or vigor of the seed.

The major hazards to germination and emergence in spring planted crops are low temperature and excessive moisture in the soil which usually occur together. Weather fronts moving in often lower the soil temperature to a level marginal for germination and produce rain which saturates the soil and reduces the oxygen supply. If these conditions persist for a long enough period, many seed fail to germinate and rot. Even when soil temperature is relatively favorable, heavy rains can result in flooding for several days, and this is often sufficient to cause germination failure. The oxygen supply required for germination is cut off.

Preparation of the seed bed often dries the soil to a level marginal for germination, especially in the top two inches. Under such conditions some farmers plant deep to get the seed "into the moisture", while other plant shallow and hope for a rain. A heavy rain on deep planted seed can produce a thick compact zone and crust which defies emergence of many kinds of seed. A shallow planting depth would produce better results. However, shallow planting in anticipation of rain can also be disastrous when the rain doesn't come. The seed absorb some moisture and increase in moisture content, but not enough for germination. Sunny weather warms the top few inches of soil. The combination of elevated seed moisture content and warm temperatures causes rapid deterioration so that the seed weaken and die if rain is delayed long enough.

Although cold or cool soil temperatures are usually the most adverse for spring planted, warm season crops, high soil temperatures can also be detrimental. Germination failure of soybean seed begins at a temperature of about 100°F even when other conditions are good. Soil temperatures in the South - toward the end of the soybean planting period in late June and early July - can rise well above

100°F during the day, and not drop lower than 90°F during the night. Treated seed usually survive such conditions - until the temperature moderates - better than untreated seed.

Treatment of seed with fungicides also indirectly protects them against other adversities such as low temperature, excessive moisture and so on. The fungicides don't cause the seed to germinate at lower temperatures or reduced oxygen. Rather, they protect the seed from soil micro-organisms which attack and destroy seed when conditions are not favorable for rapid germination and emergence.

The interaction of seed vigor and stresses in the seed bed in stand failures is well established. Vigorous seed are less sensitive to conditions in the seed bed than seed low in vigor. Therefore, they germinate and emerge under a wider range of temperatures, soil moisture levels, and are most resistant to attack by soil micro-organisms. When conditions are extremely adverse, however, even high vigor seed fail to germinate and/or emerge.

Over-planting is the traditional response to the unpredictability of field conditions, hence, uncertainty regarding emergence. Many more seed are planted than required to produce a desirable plant population when conditions are favorable: "one for the crow, one for the snow, and one to grow". When the crows don't come around and the snow falls elsewhere, the excessive plants need to be thinned. Cotton seed, for example, used to be drilled thickly to ensure an adequate stand. When conditions favored a more than adequate stand, a lot of "cotton chopping" had to be done.

The modern trend in crop production is planting to a stand. A certain number of seed are planted per acre at specific in-row and between-row spacings with the expectation that a certain number of plants will be produced. The requirements for planting to a stand are high quality seed, and close monitoring of weather conditions so that planting is done when the probability of favorable conditions for germination and emergence is high. Presently, planting to a stand is standard practice in corn production and the production of many kinds of vegetables. Yield and quality of yield in these crops is closely associated with plant population and/or spacing and thinning is prohibitively expensive. There is no doubt that the practice of planting to a stand will be extended to other crops. When it is, germination failure will become even more important than it is now.

Summary

Germination is the crucial and final event in the life of a seed. It can be defined as the resumption of active growth of the embryonic axis. A seed requires moisture, a favorable temperature and oxygen for germination. Rehydration of the seed sets in motion a chain of reactions which provide the energy and building blocks for the resumption of active growth and development of the young seedling.

Germination failure is caused by many factors and conditions. These range from deterioration of the seed and loss of the geminative capacity to the mechanical impedance to emergence from soil crusts formed after sowing.

The Life Cycle of a Plant

New plant life

All living things pass through stages from birth to adult called a life cycle. For many living things, the cycle of life follows the four seasons of the year. For some living things, the cycle of life is short and is completed in just days, months, or a single year. For other living things, the cycle of life continues for many, many years.

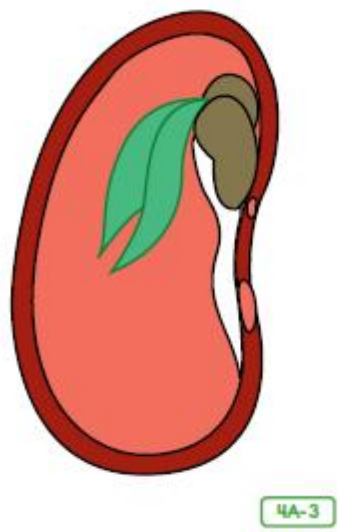
Flowering plants

Today you will learn about the life cycle of a flowering plant. Just think about all the flowering plants you see in the parks, yards, gardens, fields, and meadows. Our world is awash with colorful, vibrant flowering plants. How do these plants grow and **reproduce,** or make seeds for new plants? Let's find out.

Germination

A flowering plant begins its life cycle as a seed. Seeds need special conditions to germinate, or begin to grow. Spring provides seeds with the right conditions to grow. Therefore, the life cycle of a flowering plant begins in spring.

In spring, there is more sunlight and temperatures are warmer. Seeds need just the right amount of light from the sun, nutrients from the soil, and water in order to grow. Once the seed germinates, or sprouts, it grows and develops into a young plant with roots, a stem, and leaves. The first leaves unfold to allow photosynthesis to begin. Photosynthesis is the process by which plants make their own food, as well as oxygen. Plants use sunlight and water to make food in the form of glucose, a type of sugar.



Interior of flower

In the warmth of spring and summer, plants continue to grow. The young plant is called a seedling. Gradually, a plant's stem will grow taller and true leaves will **emerge**. Once the plant matures, or become an adult plant, flowers appear.

In order for a flowering plant to reproduce, or produce seeds that will make new flowering plants, it must be pollinated. Pollination is when pollen from one flower mixes with the pollen of another flower so that the plant can make seeds. But how is pollen transferred from one place to another? In other words, how does pollination occur? Flowering plants need **pollinators** to help them with pollination. Pollinators are insects, birds, and other animals that are **attracted** to the shape, fragrance, or color of a flower. Without pollinators, most flowering plants would not produce seeds and fruit.

Insect pollinators

There are many types of pollinators, such as birds and small mammals, but insects are the number-one pollinators of flowering plants. The flowers of a flowering plant are designed to attract various pollinators, especially insects. The shape, fragrance, and color of the flower, as well as the sweet-tasting nectar contained within the flower itself, attract many different kinds of insects. As insects move from flower to flower, the sticky substance called pollen clings to their bodies and is transferred, not only within a flower, but from flower to flower.

Honeybees are the most common pollinators. They carry out more pollination than any other insect. Some scientists think that bees are attracted to bright blue and violet-colored flowers, whereas butterflies like fragrant yellow, pink, red, and orange flowers. Butterflies also like wide petals so that they can settle on them while they drink the sweet nectar.

Mammal and bird pollinators

Birds are important pollinators, too, especially of wildflowers. For example, hummingbirds have perfectly designed beaks that can reach the nectar inside long, tubular-shaped flowers. There are more than 2,000 different kinds of birds in the world that feed on nectar. Birds have a poor sense of smell and help to pollinate unscented flowering plants because they are attracted by the color and shape of the flowers.

A variety of small mammals pollinate flowering plants. Mice, shrews, and rats—even tree-dwelling animals such as lemurs and small monkeys—can help to transfer pollen. People also help the pollination process. Often, when people are working in their flower gardens, the sticky pollen is accidently carried from flower to flower.

For some plants, pollination does not just occur during the daytime. Some scented flowers attract nighttime pollinators such as bats and moths.

Although ninety percent of flowering plants are pollinated by animals, especially insects, the wind and even water can play a part, too. Pollen is carried by the wind. Flowering plants that live in water, such as lilies, can be pollinated as the water carries the pollen from one plant to another.

Once pollen has been transferred and reaches the new plant, the flower produces seeds. The next part of the process is called seed dispersal. This is the process of carrying the seeds away from the parent plant so that the flowering plant life cycle can begin all over again.

Seed dispersal

Just like pollination, there are various ways that seeds can be dispersed, or spread apart in different directions. Many flowering plant seeds are carried away from the parent plant by the wind. As the wind blows, the seeds are carried up into the air. Some flowering plants have pods, or capsules, that explode, sending forth a burst of tiny seeds into the air. Other flowering plants drop their seeds into rivers and streams, and the seeds are carried along to their new home.

Sometimes animals carry seeds from place to place without knowing it. Some seeds contained within a **protective** casing can attach themselves to the fur of passing animals. The protective casing will eventually fall off the animal and rest in the soil, ready to begin the life cycle process.

Some seeds are contained within a fruit that animals like to eat. Animals either spit the seeds out, or they eat them, and the seeds reach the earth in the animal droppings that are left behind. Once on the ground, they rest in the soil until the germination process can begin again the following spring.

Seed to seed

All of this is happening around us in spring, summer, and early autumn. The potential for new life is being created as flowering plants are pollinated and seeds are dispersed. Across the world, the life cycle of flowering plants is renewed, or happens again, each year.