**SEED DORMANCY AND GERMINATION**

 Many seeds fail to germinate after processing and placement in favourable growing conditions - such seeds are said to be **dormant**. In some dormant seeds morphological changes must take place before germination can start. For others, parts of the seed must undergo physiological changes before germination can occur. Under natural conditions necessary changes take place gradually under varying combinations of aeration, moisture, temperature, and light. By duplicating key conditions of the natural environment in the laboratory or nursery, dormant seeds can be induced to germinate with a reasonable length of time.

 In general, there are two types of seed dormancy: **seed coat dormancy** and **internal dormancy**. Seeds with **seed coat dormancy** usually have a seed coat that is impermeable to oxygen and/or water. Occasionally the dormancy is caused by an inhibiting chemical in the epidermis or adjacent interior membranes. Under natural conditions these seeds remain on or in the ground without germinating until they have weathered sufficiently, to allow penetration of water, exchange of gases, or neutralization of inhibiting chemicals. Seeds of some species germinate only after being subjected to fire. The length of time involved—it can be several years or more—depends upon the species and the environmental conditions. Seed coat dormancy is common in California lilac (*Ceanothus*), Manzanita (*Arctostaphylos*), sumac (*Rhus*), and members of the legume family. If seeds of such plants are harvested when slightly green or immature and sown immediately before they dry out, germination problems may be reduced; however, once the seeds have dried out, the dormancy factor is present and must be counteracted to obtain prompt germination. Methods of breaking seed coat dormancy include scarification, hot water, dry heat, fire, charate, acid and other chemicals, mulch, water, cold and warm stratification, and light.

 **Internal dormancy** is a general term encompassing a number of physiological conditions that delay germination. Not all of these conditions are fully understood or easy to counteract. The most common one is called **after-ripening**. Seeds that require an after-ripening period, even though harvested when mature, germinate poorly or not at all until they have been subjected to moisture and either high or low temperatures or both in sequence; sometimes, however, a period of dry storage is sufficient to break dormancy. As might be expected, internal dormancy is most often found among species that grow in the high mountains or deserts. The more common method for breaking internal dormancy is cold stratification. In some cases, the use of chemicals can be substituted for part or all of the stratification requirement.

 Multiple dormancy factors also occur. In one general type there is seed coat dormancy plus internal dormancy. Seeds with this dormancy combination must be treated for the impermeable seed coat first, then for internal dormancy. In another type there are two or more distinct internal dormancy factors, which unlock sequentially at different temperatures. One group requires warm temperatures first for a small amount of primary root growth, then cold to break shoot bud dormancy, then warm again to initiate shoot growth and complete germination. Another group needs cold temperatures first to break primary root dormancy, and then warm to initiate a small amount of root growth, then cold again to break shoot bud dormancy, then warm again to initiate shoot growth and complete germination. In the wild, seedlings of plants with these dormancy types would not appear until the first or second spring after the seeds had matured and dropped from the parent plant.

 A general summary of methods that can be used to break seed dormancy are as follows:

**SCARIFICATION**: used for the members of legume family. Mechanical scarification is a technique for overcoming the effect of an impermeable seedcoat. Mechanical scarification can be done by rubbing seeds between two pieces of sandpaper, or using a file, a pin, or a knife to rupture the seed coat. Seed may also be mixed with coarse sand and shaken vigorously in a jar. Care must be taken not to injure the embryo. It may be necessary to open a couple of seeds to see where the embryo is located in relation to the micropyle, the former point of attachment to the fruit. Large seeds like those of the bush lupine (*Lupinus*) are easily scarified with a knife; the hot water treatment is easier for small seeds.

**HOT WATER**: Also used for the members of legume family. For small to medium-sized seeds or large quantities of seeds, the hot water treatment is more practical than scarification. For this treatment seeds should be dropped into about six times their volume of 180º-200ºF pre-heated water. They should be left to cool and soak in the water for 12 to 24 hours, after which they are ready for sowing. The container used for this treatment should not be made of aluminum as it may be toxic to the seeds.

**DRY HEAT:** Oven or dry heat is not often recommended, and the temperatures requiredare more suitable to an incubator than a kitchen oven. For this seed coat treatment the seeds should be placed in shallow containers in a preheated incubator or oven. The specific temperature and duration depend on the species. After the treatment, the seeds should be cooled immediately and sown.

**CHARATE:** The char from burned plant stems has been shown to be a good neutralizerof germination inhibitors in the seeds of several herbaceous species associated with chaparral fires. Golden yarrow (*Eriophyllum*), and *Phacelia* species have enhanced germination with the addition of a small amount of chamise (*Adenostoma fasciculatum*) charate to the sown seeds. Charate can be prepared by burning chamise stems of 3/8-inch or less in diameter with a propane torch until they are blackened through and then grinding the charred stems in a Wiley mill to produce a uniform powder.

**FIRE**: Seeds of some genera have tough, thick seed coats and germinate best when subjected to the heat of fire. For this treatment the seeds should be sown in the fall in a slightly moist medium but not watered. A layer of dry pine needles or excelsior, four to six inches deep, should be placed over the top of the seedbed. A few small pieces of wadded paper will help to ignite the material. One or two strips of aluminum foil placed over the exposed edges of the wood container will prevent it from burning; plastic containers should not be used. After the seedbed has cooled following burning, it should be thoroughly watered and then treated as any other batch of sown seeds. Since the small flash fire produced by this treatment is quite hot, this method should be used outdoors in the open, away from combustible material, and on a calm day. The seeded container should be left outdoors for germination, since seeds of many plants also have internal dormancy factors and therefore need a cold, moist period for germination. This fire treatment is not exact, and the results obtained may not be consistent because the amount and duration of heat actually reaching the seeds is governed by several variable factors.

**ACID:** Acid treatments are often used to break down especially thick impermeableseed coats. Since seeds placed in concentrated sulfuric acid (H2SO4) will become charcoal in time, the temperature of the acid and the length of time the seeds are soaked are very important. The acid should be used at room temperature for a period of a few minutes to several hours depending on the species. The seeds should be immersed in acid in a glass, china, or earthenware container, and should be stirred occasionally with a glass rod; however, too much stirring will cause the acid to heat undesirably. The seeds must be removed from the acid just before any acid penetrates the seed coats. When the allotted time is finished, the seeds should be removed promptly and washed thoroughly in several changes of water to neutralize completely all remaining acid. Since sulfuric acid is caustic and dangerous to handle, its use is recommended only for those familiar with the use of caustic chemicals. Water must not be splashed into the acid, as a violent reaction will occur. All workers should wear suitable safety clothing, gloves, and goggles or other eye protection.

**OTHER CHEMICALS:** About 50 years ago researchers in various agencies and private industry began experimenting with chemicals to neutralize dormancy conditions present in seeds. Results have shown that inhibiting chemicals can be present in one or more parts of the seed; other dormancy-causing factors (i.e., immature embryos or impermeable seed coats) may also be present in a given seed. Three chemicals that have proven very helpful in breaking certain types of dormancy are gibberellic acid (GA3), potassium nitrate, and thiourea. The aqueous solutions of these chemicals should be used at room temperature. The concentration and length of treatment depends on the species to be treated. Seeds soaked in GA3, or thiourea should be stirred occasionally and not rinsed afterwards, unless specified, but sown immediately. After this soaking they can also be air-dried and stored for short periods and then sown or given a subsequent treatment. The no-rinse-afterwards also applies to the use of potassium nitrate and hydrogen peroxide, other chemicals occasionally recommended as aids to germination.

**MULCH**: The mulch treatment hastens the microbial breakdown or softening of the seed coats. It is a slow method but is what often occurs in the wild. For this treatment, fill a six- to eight-inch deep container half full with seedbed medium. Then the sown seeds should be covered with a mulch of wood shavings. A one-inch thick layer of old composted shavings is best; but if not available, a three-inch layer of fresh shavings is satisfactory. If fresh shavings are to be used, they should be soaked a few hours in a bucket of water first and mixed with a compost starter of microbial inoculant. Neither the seeds nor the medium should be treated with a fungicide. If this treatment is initiated in early spring or early summer and if the shavings are kept moist all summer, germination will require three to four months or longer, depending on the species. This mulching technique also works well in a ground bed; however, transplanting may be a bit more difficult.

**WATER**: For the occasional species whose seed coats contain a readily water-soluble, germination-inhibiting chemical, this substance can be removed by soaking the seeds in tap water or by leaching the seeds in slowly running tap water for various lengths of time just prior to soaking. The length of time depends on the species. With the water bath, changing the water every 12 to 24 hours will hasten thisleaching process. Softened water should not be used for this treatment.

**COLD STRATIFICATION or PRECHILLING:** Cold stratification, or prechilling, for seeds with internal dormancy simulate cold winter conditions. The embryo of many seeds fails to germinate because oxygen does not diffuse through the seed coat. At cold temperatures, more oxygen is soluble in water, so the oxygen requirements of the embryo are better satisfied. Cold-moist stratification imitates overwintering in a field seedbed. For small quantities of seeds, mix a ratio of 1:3 or more with moist peat moss or moist vermiculite, place in a tightly sealed polyethylene bag or glass jar, and store in the refrigerator at a temperature of 35º- 41º F. With a few species, freezing the seeds at 28º - 32º F is required. For bulk seeds, soak in water for a few hours first, then place wet in a sealed container. Containers can be boxes, tanks, trays, cans, or barrels, as long as they have perforated bottoms to allow drainage of excess water and to facilitate gas exchange between the seeds and the storage room. Of course, polyethylene bags can be used as well. In any case, the seeds must be kept moist during the entire length of the treatment. This will require periodic checking and the addition of water if necessary. Another reason for periodically checking the stratifying seeds is to see if they have started to germinate.

**WARM STRATIFICATION:** The exposure of seeds to moist, warm conditions at room temperature (65ºF) or above is called warm stratification. Sometimes this treatment is necessary for seeds with internal dormancy to facilitate after-ripening of the embryos, in which case it is followed by cold stratification. Occasionally it is used in lieu of the acid treatment for seed coat dormancy. It also may be an intermediate stage in a multiple dormancy treatment. For warm stratification, the seeds should be mixed with moist peat moss or moist vermiculite and sealed in a polyethylene bag or glass jar. Possible places for warm stratification include desk tops, kitchen cupboards, the top of a refrigerator, or perhaps near the furnace—anywhere that stays warm night and day for the prescribed period of time.

**PHOTOCHEMICAL DORMANCY:** Seeds of some species are light-sensitive, and must receive light during germination. The intensity and duration of the light, as received by seed photoreceptors, interact with the available moisture and temperature to control germination. When light and temperature are each partially inhibitory, the effect can be synergistic. The first 36 to 72 hours of germination is the critical period. Photochemical dormancy is most pronounced in freshly harvested seeds and usually disappears naturally with age.

**SEED GERMINATION**

 Seed germination is defined as the sum of events that begin with hydration of the seed and culminate in emergence of the embryonic axis (usually the radicle) from the seed coat. Simple though this definition is, the details of radicle emergence from the seed coat or, its obverse, lack of radicle emergence despite favourable conditions (i.e., dormancy) are still not fully clear. Moreover, this definition applies mostly to seeds with well-developed embryos (e.g., pea, bean), where the breakdown of reserves to support seedling growth is primarily a postgermination phenomenon. In several species, seed is shed when the embryo is still small and undeveloped (e.g., *Fraxinus).* The embryo continues to grow and differentiate within the seed, utilizing the food reserves in the endosperm, and protrusion of the radicle does not occur until much later. These seeds do not germinate while immature.

 Seed germination in any species follows a strict pre determined programme that clearly played out in discrete steps as follows:

**1. IMBIBITION OF WATER**:

For seed germination to occur, the dry, quiescent seed must imbibe water and become hydrated; in addition, there is a requirement for oxygen. The temperature requirements are more flexible. Germination occurs over a wide range of temperatures, although for each species there is an optimal temperature and the rate of germination drops off at both above and below that temperature. Assuming no barriers to hydration (e.g., the presence of an impervious seed coat), the initial uptake of water is rapid (phase I) and is followed by a plateau (phase II). Metabolic reactivation of seeds starts immediately on imbibition and is closely associated with the rise in respiration rate and production of ATP.



**Figure**: Time course of major events associated with seed germination and seedling growth. The uptake of water by the dry, quiescent seed is shown in three phases: rapid at first (phase I) and then a plateau (phase II), followed by a second rise coincident with the beginning of seedling growth (phase III). The time for events to be completed varies from hours to many weeks, depending on the plant species and the germination conditions. The respiration rate generally parallels the rate of water uptake.

 Almost all seeds are capable of some anaerobic respiration in the early hours of imbibition, but the seeds of some plants that grow in flooded soils with low oxygen tension [e.g., rice *{Oryza sativa),* barnyard grass *{Echinocloa phyllopogon), Typha latifolia, Juncea effusus)]* are capable of germination, even some seedling growth, under anaerobic conditions. These seeds show considerable activities of alcohol dehydrogenase (ADH) and lactate dehydrogenase (LDH), enzymes involved in the fermentation of pyruvate produced during glycolysis to ethanol or lactate, respectively. For continued growth and development, however, an oxygen supply is necessary, and, with its provision, pyruvate is shunted toward oxidative decarboxylation in mitochondria and the activities of ADH and LDH decline.

 In dry seeds, the respiration rate and metabolism are both extremely low, and membranes and various cell organelles are structurally ill-defined and biochemically inefficient. In the early hours of imbibition, membranes are leaky (the leakiness may be induced by the rushing in of water), and various low molecular weight substances, ions, sugars, and amino acids, leach out into the surrounding medium. Within a few hours of hydration, however, the membranes are restored to their normal liquid-crystalline structure and selective permeability. Other changes include restoration of organelles, such as mitochondria and nuclei, to their functions and replacement of single ribosomes by populations of polyribosomes as protein synthesis begins. Hydration, while allowing some loss of solutes (which may cause fungal growth), also Results in loss of many inhibitors of germination, e.g., some phenolics and abscisic acid (ABA).

 The rise in water content is paralleled by a rise in the respiration rate and O2 consumption. Enzymes of the Krebs' cycle and the terminal oxidases are usually present in the dry seed and are reactivated, but new enzymes are also synthesized, as shown by the expression of both mitochondrial and nuclear genes encoding the subunits of cytochrome c oxidases. Such new synthesis of enzymes signifies biogenesis of new mitochondria, or repair to extant ones, which may occur almost exclusively in some species.

 Protein synthesis in the early hours of imbibitions generally involves translation of messages left over from development. These messages include transcripts for some LEA proteins and other stress-related proteins, such as heat shock proteins (HSPs) and antioxidants. If the water supply continues, these transcripts are gradually lost, but if it is interrupted, their genes may be reactivated. Other leftover transcripts include those for ribosomal proteins. Genes for these proteins become transcriptionally activated as germination proceeds.

 Hydration of seeds not only restores metabolic activity of quiescent embryos, it also activates the embryonic machinery such that it can receive signals, such as light, chilling, and alternating warm and cold temperatures, signals that are involved in breaking certain types of seed dormancy. Activated forms of hormones are also synthesized or converted from inactive precursors or conjugates on hydration.

**2.** **RADICLE GROWTH AND PENETRATION OF TESTA**

 Elongation of the radicle and its emergence from the seed coat complete phase II of imbibition and germination. The elongation growth of stems and roots is driven by a combination of wall loosening and turgor pressure of constituent cells, and there is no reason to doubt that the same combination also applies to growth of the young radicle.

 The rupture of the seed coat (or tissues surrounding the embryo) in most cases occurs with pressure from the growing radicle tip. It is not known whether the hydrolysis of wall polysaccharides of the surrounding tissues (e.g., endosperm or perisperm) is required, although it probably occurs. In some species, which show coat-enhanced dormancy (e.g., tomato. *Datura* sp.), synthesis of cell wall hydrolyzing enzymes is reported. Typically, cell division is not necessary for radical emergence, but there are obvious exceptions in seeds with immature embryos. For subsequent growth, however, it is necessary.