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Ankita
Department of Horticulture, School of Agriculture, Lovely Professional University, Punjab, India

Rupesh
Department of Horticulture, School of Agriculture, Lovely Professional University, Punjab, India

Harjinder Kaur
Department of Horticulture, School of Agriculture, Lovely Professional University, Punjab, India

RajKumari Asha Devi
Department of Horticulture, School of Agriculture, Lovely Professional University, Punjab, India

Corresponding Author:
Ankita
Department of Horticulture, School of Agriculture, Lovely Professional University, Punjab, India

Multifaceted perspective on mechanisms and environmental influences on seed germination: A review

Ankita, Rupesh, Harjinder Kaur and RajKumari Asha Devi

Abstract
A seed is a protective case that contains the early stages of a plant's development. This reproductive process is essential for seed plants, such as gymnosperms and angiosperms. Seed germination is the vital process through which a single seed transforms into a full-grown plant, significantly impacting both crop yield and quality. The development of a seedling from an angiosperm or gymnosperm seed is a common example of seed germination. Various factors influence seed germination, including external elements like water availability, suitable temperature, oxygen, and light exposure. Additionally, internal factors like the presence of auxin, stored nutrients, completion of dormancy, and seed viability also play a crucial role in the germination process.

Keywords: Seed, viability, temperature, processes, seedling emergence, environment

1. Introduction
Seed germination, the pivotal process by which a dormant seed transforms into a new, vibrant life, lies at the heart of plant reproduction and sustenance of terrestrial ecosystems. This biological phenomenon has been the focus of extensive research for decades, driven by its crucial role in agriculture, horticulture, and ecological restoration. Understanding the intricate mechanisms and environmental factors influencing seed germination is paramount to enhancing crop productivity, preserving biodiversity, and addressing global challenges such as food security and climate change. The generation of seeds and their germination are directly related to the persistence and spread of plant species. The seed's primary function is to safeguard the developing embryo and detect the surrounding environment in order to time germination with seasons that will allow the plant to complete its life cycle. The process of germination includes everything from imbibition through the emergence of the radicle through the seed coat. The mother plant's environment, as well as the form of the fruit and seed, affects the geographical pattern of seed distribution in the wild (Bewley *et al*., 2013) [43]. Additionally, the genetic make-up of the plant, which influences both inactivity and germination capacity, interacts with the environment to determine the timing of germination (Willis *et al*., 2014) [39]. A danger to agricultural output in the ensuing decades could be caused by rises in temperature, carbon dioxide, and precipitation during the 21st century
(Batley and Edwards 2016; Vogal *et al*., 2019; Wing *et al*., 2021) [3, 34, 40]. Research on enhancing agricultural productivity in the face of deteriorating climatic circumstances is required to secure global food security since climate change would adversely influence the world's food resources. Despite conventional breeding efforts, the blooming, the pollination process development of seeds, germination, and seedling growth stages of the crop life cycle continue to be highly vulnerable to climatic conditions. Genomic and enhanced phenotype are revolutionizing breeding techniques and the creation of new varieties of resilient crops due to decreased sequencing and genotyping costs (Batley and Edwards 2016; Voss-Fels and Snowdon 2016) [3, 35]. In particular circumstances that aren't ideal, seed vigor is a complicated feature that includes seed dormancy, viability, fast germination, and seedling growth. When seeds germinate, which takes place between imbibition and the appearance of its radicle from the seed, they gradually lose their vitality and become more vulnerable to stress (Bewley *et al*., 2013) [43]. In recent years, seed germination has emerged as an interdisciplinary field of study, attracting the attention of botanists, ecologists, agronomists, geneticists, and environmental scientists alike.

This growing interest stems from the realization that seed germination is not a simple, linear process but rather a multifaceted event influenced by a myriad of internal and external factors. While much progress has been made in unravelling the basic physiological and biochemical aspects of germination, there is a pressing need to integrate diverse perspectives to gain a comprehensive understanding of this vital phenomenon. This review paper aims to provide an in-depth exploration of the multifaceted nature of seed germination, shedding light on the intricate mechanisms underlying this process. We will delve into the complex interplay of physiological, genetic, and molecular factors that govern the germination process, with a focus on how these factors respond to various environmental cues. From light and temperature to soil conditions and water availability, environmental influences play a pivotal role in determining the fate of seeds and shaping plant communities. Moreover, we will delve into the recent advances in seed germination research, including cutting-edge techniques like omics approaches, which enable us to unravel the intricate gene regulatory networks that orchestrate germination. By synthesizing the latest findings and connecting different disciplines, we aim to provide readers with a comprehensive and up-to-date overview of the field. Ultimately, this review paper endeavours to not only deepen our understanding of seed germination but also underscore the importance of conservation efforts, sustainable agriculture practices, and environmental stewardship in safeguarding the delicate balance of life on our planet. By acknowledging the multifaceted nature of seed germination and the significant impact of environmental influences, we can pave the way for innovative solutions to address global challenges and ensure a greener, more sustainable future.

2. What is seed and germination of seed?

2.1 Seed

A seed is a young plant enclosed within a protective covering. Seed development is a crucial stage in the reproduction of seed plants, including gymnosperms and angiosperms (Geisinger, 2008) [13]. Once pollen fertilizes the ovule and undergoes some growth within the parent plant, matured ovules give rise to seeds. The zygote creates the embryo, and the integuments of the ovule create the seed coat (Koger *et al*., 2004) [17]. The evolution of seeds has played a significant role in the reproductive success of gymnosperms and angiosperms, distinguishing them from more primitive plant types like ferns, mosses, and liverworts, which do not have seeds and rely on water for propagation. Today, seed plants thrive in diverse environments, from hot to cold climates, and dominate various terrestrial habitats, including forests and grasslands.

2.2 Seed germination

Seed germination is the essential process through which a single seed transforms into a fully grown plant, influencing both crop yield and quality. The mature seed remains inactive with a dormant embryo until conditions become favourable for growth. (J. Wang *et al*., 2009) [37] Furthermore, multiple explanation of seed germination has been put forward, emphasizing the importance of understanding the distinctions. According to seed physiologists, the radicle emerging from the seed coat is what distinguishes germination. (Rajjou *et al.,* 2012) [22]. Germination, according to the seed analyst, is "the development and growth of essential structures from the seed embryo that indicate the potential to develop into a healthy plant under favourable conditions." On the other hand, other people view germination as the embryo's return to active growth, which results in the seed coat rupturing and the emergence of an embryonic plant. (Meyer & Pendleton, 2005) [19] This perspective makes the supposition that the embryo has lain dormant ever since it formed and matured. The seed is normally dormant and has a low rate of metabolism during this resting stage. It can stay in this form until something causes it to start growing. Irrespective of the specific terminology used, it is crucial to recognize that the germination process is not directly observable. Consequently, all definitions encompass some aspect of seedling development, which occurs after the germination event. Some seeds may germinate shortly after fertilization, well before their usual harvesting time, while others remain dormant for a prolonged period, necessitating additional time or specific conditions before they start to sprout. (Miransari & Smith, 2014) [2]. The duration of this phase varies significantly, ranging from a few days to several years, contingent upon the particular species. Seed germination can be described by various common stages, irrespective of the time span between maturity and the recommencement of growth. The water content of a seed typically falls within the range of ten to fifteen percent, and this relatively low level of water is considered a crucial factor contributing to the seed's dormancy. (Peng & Harberd, 2002) [21]. The dormant embryo initiates its active phase once the necessary external conditions are met. Seed germination, in essence, encompasses all the stages and events involved. It commences with the hydration of the seed and concludes with the emergence of the embryonic axis from the protective coat.

3. Morphology of Germination

There are two distinct forms of seed germination, neither of which appear to be related to seed structure and which depend on what happens to the embryonic cot or storage organs. The sprouting of bean and pea seeds provides a clear illustration of these two kinds. Although these seeds are structurally similar and come from the same phylogenetic relatives, their germination processes differ greatly from one another (Toole *et al*., 1956) [33].

3.1 Epigeal Germination

When compared to hypogeal germination, epigeal germination, which occurs in bean and pine seeds, is thought to be more primordial in terms of evolution. The cotyledons are elevated above the soil throughout this phase and continue to feed the plant's developing sections. As the root grows, the hypocotyl begins to expand in an arch, forcing the cotyledon and encased the plumule up into the air. The cotyledons then begin to expand, the plumule develops, and finally, the cotyledons eventually wither and fall to the ground.

3.2 Hypogeal Germination

Pea seeds exhibit hypogeal germination, as do those of other grasses, including maize, and several other plant species. The plumule develops upward and bursts above the soil's surface while the cotyledons or other storage organs stay below the soil's surface during this form of germination. The rapidly elongating epicotyl is a crucial component in hypogeal germination. No matter if the developing points are situated above or below the earth, the cotyledons or comparable organs for storage continue to sustain them nutritionally during germination (Rajjou *et al*., 2012) [22]. The coleoptile, a transient sheath covering the plumule that is most frequently seen in grasses, is connected to hypogeal germination in several species. The coleoptile provides defence and assistance while the plumule penetrates through the soil and emerges. The coleoptile finally disintegrates after its plumule breaks through its outermost layer and becomes accessible to light.

3.3 Seed formation

Plants, much like humans and animals, follow a similar reproductive process. They utilize sperms and eggs for reproduction as well. The male plants release pollen to fertilize the ovaries. As time passes, the ovaries undergo the reproductive process and transform into new seeds, eventually developing into new plants (Dumas & Rogowsky, 2008) [11]. During this growth process of the developing ovaries, the seeds accumulate a surplus of carbohydrates and proteins. Once the plant grows its leaves, these stored nutrients become the primary source of nutrition for the plant. (Thomson & El-Kassaby, 1993) [32]. Over time, the fertilized ovaries of plants undergo maturation, leading to the formation of a sturdy outer covering for the seed. This protective coat helps the seed shield itself from adverse weather conditions and other environmental factors. Additionally, the coat aids in seed dispersal through mechanisms such as wind, water splashing, or animals grazing, resulting in the establishment of new plants in different locations. A number of variables affect seed germination; the most important ones are listed below.

3.4 Water absorption

According to McDonald *et al*., 1988 [18], to initiate the germination process, water absorption is the first crucial step. During this initial stage, the seed absorbs water and undergoes expansion as the cellular contents rehydrate. The swelling exerts significant force, causing the seed coverings to rupture, allowing the radical to emerge as primary roots (Kikuzawa & Koyama, 1999) [16] Seeds can easily absorb water due to the rehydration of essential materials, including anatomical and storage macromolecules, repository polysaccharides, and cell wall components such as proteins. Following water absorption, rehydrated seeds undergo various metabolic processes (Zuo *et al*., 2017) [42]. In this state, certain plants utilize anaerobic respiration, which relies on energy from glycolysis. However, once the energy enters a living organism like a plant, respiration switches to aerobic. The intriguing question arises about how submerged plants manage this process. To address this, submerged plant seeds utilize the dissolved oxygen present in the water. While seed germination in terrestrial plants cannot occur underwater, submerged plants require additional oxygen to support their growth and development (Stalin *et al*., 2020) [29]. Have you ever pondered why soil ploughing holds such significance for fertility? The reason lies in its ability to facilitate better air penetration into the soil. Planting seeds closer to the ground ensures they receive the necessary oxygen from the air. If seeds are buried too deep in densely compacted soil without proper air circulation, they will fail to germinate as they cannot obtain adequate oxygen. According to G. Wang *et al*., 2022, for successful germination, the seed needs to experience the appropriate level of heat. Typically, germination occurs within a temperature range of 25 to 30 degrees Celsius. It's crucial to remember that various plant seeds require different temperatures for germination. The need for temperature as low as five degrees Celsius or as higher as 40 degrees may be a particular need for some seeds.

4. Seed Germination Mechanism:

It is common knowledge that plants need sunlight to thrive, and the same applies to seed germination. Light is crucial for the process of seed germination. Photoblastic seeds exhibit a significant response to light, influencing their ability to germinate. These photoblastic seeds are categorized into three main groups:

4.1 Positive photoblastic seeds

When there is no light, positive photoblastic seeds will never germinate.

4.2 Negatively photoblastic seeds

In the presence of light, negatively photoblastic seeds will not germinate.

4.3 Non-photoblastic seeds

Seeds that fall under the category of non-photoblastic can undergo germination regardless of the presence or absence of light. However, it's essential to understand why plants require sunlight (Rezvani *et al*., 2021) [23]. Their dependence on light is regulated by a pigment known as "Phytochrome."(Rezvani *et al*., 2021) [23]. The elements mentioned above exert diverse effects on seed germination. As the germination process unfolds, the embryo experiences rapid expansion and growth. Eventually, the radicle develops after the outer layers of the seed burst, marking the completion of germination.

5. Factors affecting the seed germination

5.1 Environmental Factors

The presence of water is crucial for germination to take place. It is essential for triggering enzymes, speeding up decomposition processes, permitting material translocation, and using reserves. Seeds are often low in dampness and metabolically inert while they are dormant. This dormancy ensures quiescent seeds' continued existence in the ground and during storage by allowing them to maintain a low degree of metabolic activity (P. Wang *et al*., 2016) [38]. Various expressions can indicate the availability of moisture. For germination, soil with a moisture level near field capacity is considered optimal, though this may differ depending on the plant species. In certain situations, high salt concentrations in the soil or semiarid regions can restrict water availability for seed germination. However, certain crops, like basin wild rye and tall wheatgrass, have the remarkable ability to germinate even under such limiting conditions when many other species cannot (Tabin & Shrivastava, 2014) [31]. High environmental humidity may occasionally provide sufficient moisture for the early stages of the germination process even if it might not be sufficient for the entire germination process. Precocious germination, also known as sprouting, occurs when seeds begin to grow inside the head of the seed or pod as a result of persistent rain or excessive humidity. Particularly in areas where soft white winter wheat is grown, such the Pacific Northwest, Michiga, the effects of premature germination can be severe and result in large crop output losses. As a result, scientists are actively looking into the physiological components that control the germination of precocious seeds. However, too much moisture might prevent germination.

5.1.1 Air (Oxygen and Carbon Dioxide)

Approximately 20% oxygen, 0.03% atmospheric carbon dioxide, and 80% nitrogen gas make up the majority of the air. It becomes clear through a variety of experimental settings that oxygen is essential for the majority of species to germinate. The presence of carbon dioxide (CO_2) levels above 0.3%, however, prevent germination, whereas nitrogen gas has little to no impact on the entire procedure (Zhou *et al*., 2005) [41]. The degree of respiration significantly increases when seed germination occurs. An adequate amount of oxygen is required for respiration because it is essentially an oxidative activity. Most seeds won't be able to germinate if the oxygen content is drastically lowered beyond that exists in the air (Zhou *et al*., 2005) [41].

5.1.2 Temperature

Temperature has an effect on every response and step of the complicated process of seed germination. Cardinal temperatures, which comprise the minimum, ideal, and maximum temperatures needed for germination to take place, may be used to discuss how temperature affects germination. It can be difficult to determine the minimum temperature since germination may be occurring, but at such a slow rate that it is frequently deemed completed before the process is totally completed. The ideal temperature, on the other hand, is the one that promotes the highest rate of sprouting in the least amount of time. The temperature at which vital germination proteins begin to denature establishes the optimal germination temperature. The germination process is extensive, therefore each step has a unique set of cardinal temperatures. As a result, different phases' cardinal temperatures have an impact on germination as a whole. As a result, the reaction of temperatures may change during the course of the germination period (Bai & Settles, 2015) [2]. The species, variety, growing environment, seed quality, and time since harvest are some of the variables that affect the temperature response during germination. Seeds from temperate regions typically require lower temperatures compared to seeds from tropical regions, and wild species generally need lower temperatures than domesticated plants. High-quality seeds have a broader temperature range for germination than lower-quality seeds. Most seeds tend to thrive in temperatures ranging from 15 to 30 degrees Celsius, while their maximum temperature for germination falls between 30 to 40 degrees Celsius. Low-temperature germination is typical of several floral, alpine, and rock garden species and some species may even sprout at temperatures that are very near to freezing. For instance, freezing soil or even ice has been seen to stimulate the germination of Russian pigweed seeds. Two sets of seeds, one that has lower gestation degrees and the other with greater germination temperatures (Bai & Settles, 2015) [2].

5.1.3 Alternating Temperature Germination

To achieve optimal germination, the seeds of numerous species require daily fluctuations in temperature. This diurnal periodicity is widespread, particularly in species that haven't undergone domestication for an extended period. For instance, under alternate temperature settings, numerous tree and natural grass seeds germinate most effectively. Although the need for fluctuating temperatures during germination appears to be related to dormancy, it also speeds up the germination of non-dormant seeds. Alternating temperatures are necessary and provide an adaptive advantage. As an example, vegetation protects the soil surface from considerable daily temperature variations by acting as a shield. Additionally, the soil serves as an insulator in open spaces, with deeper layers preserving more stable temperatures. The requirement for fluctuating temperatures guarantees that the bulk of seeds sprout on or near the soil surface when there isn't any surrounding vegetation. When alternate temperatures are required, it appears that the difference between the two extremes is more important than the particular temperature values. It is yet unknown what specifically causes the impact of varying temperatures on seeds that are germination. Their specific impact on the several phases of sprouting stands out among the often-highlighted consequences. There is evidence to support the theory that changes in temperature cause structural changes in the seed's constituent parts, impeding germination in its normal condition. Changing the temperature may also result in an equilibrium of intermediates products produced by respiration throughout the extreme temperatures process, which may be detrimental for germinating at that particular temperature but may be helpful for germination at lower temperatures as well. Alternating temperatures modify the ratio of inhibitors to promoters, which is thought to be the cause of this phenomenon. The promoter rises during high-temperature cycles whereas the inhibitor lowers during low-temperature cycles, ultimately leading to germination (Bai & Settles, 2015) [2].

5.1.4 Chilling Injury

Dry lima bean and cotton seeds are susceptible to chilling harm when ingested at temperatures between 5 and 15 degrees Celsius. However, the risk of damage might be reduced if imbibition occurs above twenty degrees Celsius and is then followed by lower temperatures. Stalin *et al.*, 2020 [29], other creature's exhibit damage of a comparable nature. Low-temperature imbibition damage has an unclear exact cause, but the first observable effect is that wounded seeds tend to bleed out more naturally occurring nutrients than unharmed seeds. It is thought that low temperatures cause the cell walls to become stressed, which increases leakage from the cell during imbibitional chilling. It is common practice to condition wet seeds in cold, moist settings to promote germination. The nursery business is where the idea of stratification first appeared. Propagating stocks are kept between layers of moist sand and ashes before they are planted in the ground the following spring. A combination of moisture and low (or occasionally high) temperature preconditioning is referred to as "stratification" in seed testing facilities is known as prechilling (Stalin *et al.*, 2020) [29]. A maximum of 56% of the non-prechilled seeds showed germination when exposed to a variable temperature of 40/30°C and a 12-hour photoperiod. Tetrazolium chloride testing showed that the bulk (about 97%) of the kernels were still alive. The length of stratification was closely correlated with the increased susceptibility of the seeds of Eastern white pine (*P. Strobus*) and loblolly pine (*P. Taeda*) to light after stratification. While there is a substantial amount of data regarding the impact of light and temperature on germination, creating a unified picture from this information is challenging. The response to each factor can be clearly influenced, increased, decreased, or qualitatively changed by the other, but this effect varies across different cases. Dock (*Rumex*) seed germination, on the other hand, can be replaced by low-temperature treatment instead of red light. Additionally, weak red light, which is insufficient to promote germination on its own, consistently facilitates germination when combined with high-temperature treatment.

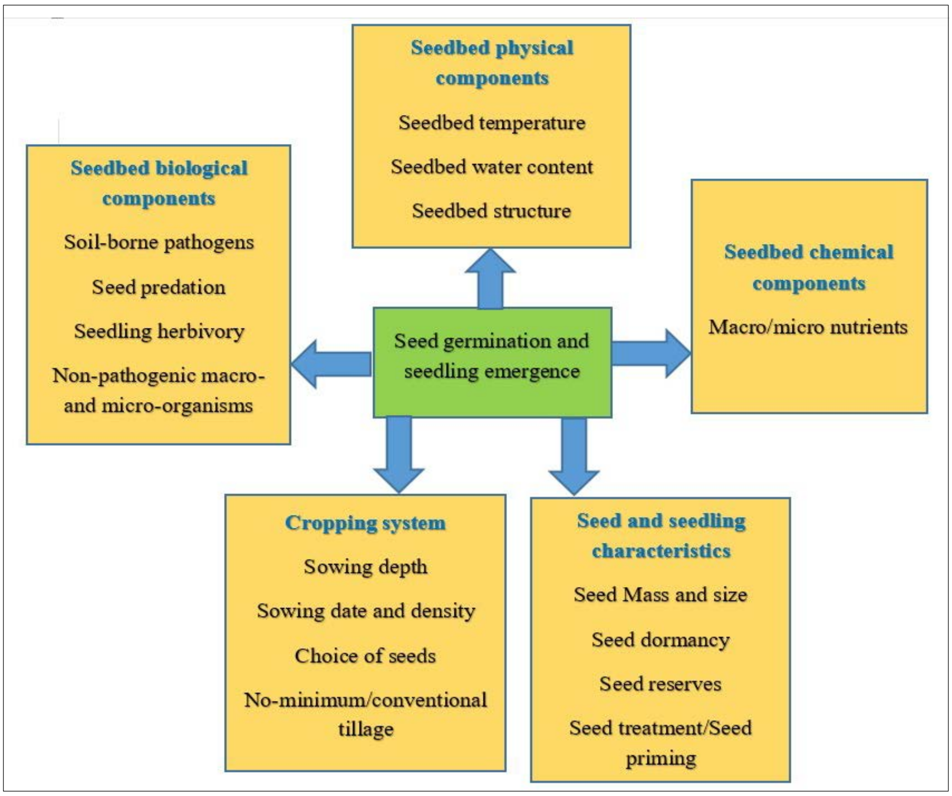

Fig 1: Factors affecting seed germination and seedling emergence

5.1.5 Light

Some species also need on light to start the process; other species need oxygen, moisture, and a warm atmosphere. Long ago, it was realized how important light is to seed germination. To ascertain if light, darkness, or apathy to light accelerates germination, researchers have thoroughly investigated the luminescence reaction of seeds from a variety of taxa. In approximately half of the species that have been investigated, light have been found to induce reactions. The mechanism that controls light during seed germination is comparable to those which controls stem lengthening, pigment production in some fruits and leaves, radicle growth in some seedlings, and epicotyl unfolding in bean seedlings. Germination is influenced by both light quality (colour or wavelength) and intensity (lux or candlepower). Understanding the quality of light is possible thanks to visible light, which is made up of many wavelengths of distinct colours. Visible light, which looks colourless to the human eye, may be divided into its individual hues with the use of a prism. These phenomena may be seen in a rainbow, when cloud water works as a prism to partition the spectrum's colours into distinct bands. The human eye is unable to distinguish between frequencies smaller than 400 nm (in the (UV) range) and higher than 700 nm (in the infrared spectrum or far-red region).

1. Light intensity

The effects of light intensity vary greatly amongst various species. Moonlight with a maximum brightness of 100 lux has reportedly been shown to help certain seeds that need light germination, although lettuce seeds require far greater light intensities. Light levels of between 1080 and 2160 lux (100 to 200 foot-candles) from indirect sources are probably sufficient for the germination of the majority of species in a typical seed testing facility. Seed germinators with light requirements sometimes have extra lighting that produces several thousand lux. Light intensity can range from 16,200 lux (1500 foot-candles) on a gloomy, overcast day to up to 108,000 lux (10,000 foot-candles) on a bright, sunny day.

2. Light quality

With a peak at 660 nm, the red light spectrum (660–700 nm) is the most effective in stimulating germination. Above 700 nm, a zone of suppression is seen. Germination is hindered below 290 nm, and a second inhibition zone may be identified in the blue area (440 nm), however between 290 and 400 nm, there is no noticeable impact. (Bai & Settles, 2015) [2] Photoperiod has an impact on how different species' seeds germination responses behave. Phytochrome activation appears to control this process, just like floral induction does. There are species that prefer long days, like Begonia and Betula, and those that prefer short days, such *Amaranthus retroflexus*. This is similar to the situation with floral induction (Stalin *et al.*, 2020) [29].

5.1.6 Various Elements that affect Light Sensitivity:

Species, variation, and pre-and post-germination environmental factors influence how sensitive seeds are to light during germination. The effect of light is greatest immediately upon harvest and subsequently lessens as the seed ages until it completely disappears. This may be one of the causes of inconsistent data in the literature about the amount of light needed by seeds of the same species.

1. **Period of Imbibition:** The Grand Rapids lettuce seeds were shown to exhibit a drop in light sensitivity during the first 10 hours of imbibition, then a period of continuous light sensitivity for the next 10 hours, and finally an enormous rise in light sensitivity.
2. **Temperature of imbibition:** When Lepidium seeds were soaked in water at 20 °C, only 31% of them responded to light by germinating. However, germination rose noticeably to 98% when the seeds were ingested at 35 °C. Intake of water was assisted by the elevated temperature during imbibition, which also speed up germination-related metabolic processes and increased sensitivity to light. In the southern parts of Australia, investigations on the annual sow thistle (*Sonchus oleraceus*) have been conducted. Each plant of this weed, a dicotyledonous winter annual, may produce up to 8,000 seeds, making it notable for its prolific seed output. In southern Australia, it has become a serious problem for winter crops. Furthermore, this weed has become resistant to chlorsulfuron in places like southern Queensland and northern New South Wales, making it harder to control (Chauhan *et al.*, 2006) [7].

Table 1: Effect of depth of sowing on germination of seeds and emergence of seedlings.

Name of crop	Seed width (in cm)	Type of soil	Depth of Sowing (in cm)	Influence drawn	References
Brassica napus	-	Compost and river soil (1:2 vol/vol)	3, 5 and 7	Negative relationship between germination of seeds and emergence and planting depth	(Singh *et al*. 2017) [27]
Zea mays	-	Silt loam, silty clay loam	2.5, 3.8, 5.1, and 6.4	The ideal seeding depth varied between locations and between years within sites.	(Cox and Cherney 2015) [9]
Glycine max	-	Silt loam, silty clay/silt loam, and gravelly loam	2.54, 3.81, 5.08, and 6.35	Highly reliant on interactions with the environment, particularly with the weather and the type of soil	(Cox and Cherney 2016) [10]
Legume species	0.24 to 0.36	Blonde peat (60%), sand (30%) and perlite (10%)	0 and 10	Depending on the species, many things can affect how seedlings emerge.	(Siles *et al*. 2017) [26]
Indian bay leaf	-	Compost and river sand (1:2 vol/vol)	3, 5 and 7	Negative relationship between seed germination and emergence and planting depth	(Singh *et al*. 2017) [27]

5.1.7 Temperature and light effects on germination

Freshly obtained annual sow thistle seeds did not exhibit any effect from the tested temperatures of 25/15, 20/12, and 15/9 C day/night. On the other hand, the presence of light significantly stimulated germination. At 25/15, 20/12, and 15/9 C day/night conditions, respectively, seed germination occurred at 80%, 93%, and 84% under light/dark circumstances vs 44%, 47%, and 40% under complete darkness. A modest amount of dormancy appears to exist in annual sowthistle, as shown by the 90% germination rate at seed maturity. The interaction with climate (17/7, 25/10, and 30/20 °C) and lighting (light/dark and dark) significantly affected the germination of feather fingergrass seeds. With a day/night temperature difference of 30/20 C and a light/dark cycle, the greatest germination rate (92%) was noted (Hartleb *et al.*, 1993) [14]. Both 12-hour daylight hours and a 24-hour period of darkness were necessary for the germination of Texas weed seeds, although the 12-hour daylight hours was more effective. The maximum rate of Texas weed seed germination under variable temperature circumstances took place at 40 °C/30 °C (54%), subsequently followed by 30 °C/20 °C (28%), and there was no sprouting at 20°C/10°C (0%) with a 12-hour daylight hours. Under 24-hour darkness, similar patterns in germination were seen with both continuous and changing temperature regimes (Scott *et al.*, 1984). Texas weed's sensitivity to temperature is comparable to that of other broadleaf weed species, such hairy beggarticks (*Bidens pilosa*) and redvine [*Brunnichia ovata* (Walt.) Shinners]. The recommended temperature for such plants is between 25 and 35 C. (Bai & Settles, 2015) [2] A maximum of 56% of the non-prechilled Texas weed seeds showed germination when subjected to a temperature range of 40 °C/30 °C with a 12-hour of day light. But the solution of chloride test showed that 97% of the seeds were viable. This indicates that at least 41% of Texas weed seeds display dormancy. Without any prechilling, 56% of Texas weed seeds could germinate, but prechilling significantly reduced seed germination. The results are presented individually due to the trial by treatment interaction for temperature effects. Tropical signal grass germination was lowest in both experiments at 15 °C and 20 °C and greatest at 25 °C (Solanki *et al.*, 2020) [28]. No significant differences ($p \leq 0.05$) in germination percentage were observed between seeds placed in darkness and those exposed to light during germination (data not presented). Tropical signal grass seeds exhibited an average germination rate of 70% in both trials (Bradford, 1990) [5]. Consequently, tropical signal grass seeds seem to exhibit no specific light requirement for germination. In contrast, goosegrass (*Eleusine indica*) and crabgrass (*Digitaria spp.)* can germinate in darkness, but their germination rates are enhanced with the presence of light (Fernando *et al.*, 2016) [12].

5.1.8 Impact of pH on Germination

Within a pH range of 5 to 8, annual sowthistle seed germination was continuously strong, topping 90%. Germination began to decrease when the pH rose from 8 to 10, although it still exceeded 77%. In northwest European soils that range from mildly acidic to alkaline, this species is reported to germinate well. The best germination was seen for the Canada thistle [*Cirsium arvense* (L.) Scop.] Seeds at pH values of 6 and 7. The robust seed germination of annual sowthistle throughout a broad pH range indicates that pH is not expected to be an obstacle for germinating in a wide range of soils (Chauhan *et al.*, 2006) [7]. The germination rate of feather fingergrass seeds ranged from 64% on average in the pH range between 6.4 to 8 and reached 76% at pH 8. (McDonald *et al.*, 1988) [18] When the pH went from 5 to 4, the germination rates showed a fall; when the pH went from 9 to 10, an increase was seen. These findings show that feathered finger grass seeds may not be pH-dependent in the majority of soil conditions since they have a high germinating potential throughout a wide pH range. The capability for producing seeds as well as the effects of environmental conditions on Texas weed sprouting, emergence, and survival were studied. In contrast to the stems and petioles, which are coarsely hairy, the cotyledons are smooth. Its alternating, widely lanceolate, serrated-margined leaves range in length from 3 to 15 cm. The seeds are 2.5 mm in width, dark brown, and have a surface that is somewhat pitted. The research included field, lab, and greenhouse tests to investigate these Texas weed characteristics (Koger *et al*., 2004) [17]. Since there was no discernible trial by treatment interactions, the data were pooled. In the pH range of 5 to 6, tropical signal grass showed germination rates of at least 61%. Given that most Florida soils have a pH between 5.0 and 6.5, this is favourable for the growth of St. Augustine grass sod as well as tropical signal grass (Analysts, 1959) [1].

6. Impact of cropping factors on seed germination

6.1 Impact of Seed Placement Depth on Seedling outbreak

Annual sowthistle seedling emergence reduced with planting depth. In contrast, no seedlings appeared from seeds buried 5 cm or deeper, which had the greatest seedling emergence rate (77%) of any location (Chauhan *et al*., 2006) [7].

6.2 Seed Fate Is Affected by Seed Age and Depth

90 days of first after-ripening on the soil's surface was provided to the seedlings. Due to the low soil moisture levels at the time, no seed sprouting was seen in the field. Two-thirds of the bags carrying seeds were dug into the ground at depths of 2 cm and 5 cm to imitate ploughing after the 90-day post-ripening period (in mid-April), and the other thirty percent of the bags were left on the earth's surface (Chauhan *et al*., 2006) [7]. In another study, done by (Chachalis *et al*., 2008) [6] they investigated the germination of Venice mallow, several factors influencing the germination.

7. Effect of pH on Seed Germination in Controlled Environments

In a pH range of 3 to 11, Venice mallow seeds showed germination percentages of between 18 and 58%. Germination was much lower at pH 3 as well as 11 with only 28% germination, whereas most effective germination (57%) was seen at pH values of 7 and 8. Earlier research has shown that different weed species might respond differently to pH on wild seed germination. Red vine (*Brunnichia ovata*), for example, showed germination over a wider pH range (Chachalis *et al*., 2008) [6].

7.1 Effects of Light and Temperature on Seed Germination in Controlled Environments.

Tetrazolium chloride testing revealed that scarified Venice mallow seeds were 89% viable. Regardless of light exposure, sprouting remained below 40% in circumstances of constant temperature (Shen & Cho, 2021) [25]. For the majority of temperature regimes, germination was considerably aided by a 12-hour photoperiod (P 0.05). At either the extremely high temperatures of 10 °C or 45 °C, no germination took place. Germination was induced by changing temperatures and a 12-hour photoperiod, with the maximum percentage (60%) found at 30/20 °C and the lowest proportion (40%) at 20/10 °C. Different weed species, like the small-seeded trumpet creeper (*Campsis radicans*), have been found to exhibit a similar improvement of germination with temperature fluctuations and light exposure (Chachalis *et al*., 2008) [6].

7.2 Hard Seed Burial's impact on hard seediness in controlled environments:

Seeds that stayed firm shortly after an eight-month burial revealed two unique traits through scanning electron microscope examination. First, numerous samples showed evidence of mycelia from fungi on the surface of the seed. The seed coat's appearance, however, did not change significantly, indicating the hyphae that had not yet had an impact on the hard seed's water permeability. (Clevenger *et al*., 2004) [8] These seeds stained similarly to the uncovered controls after being soaked in a calcofluor solution. This suggests that the physical dormancy of the silk tree is broken by soil fungus (Chachalis *et al*., 2008) [6].

7.3 Effect of Osmotic Stress on Seed Germination in Controlled Environments.

Even though seed germination significantly decreased as osmotic potential increased, 22% germination was still seen at potentials as high as 20.8 MPa. However, germination was fully prevented at osmotic potentials lower than 21.3 Mpa (Chachalis *et al*., 2008) [6]. In an another research, they studied the how different climatic conditions affected the germination of seeds of feather finger grass, a well-known emergent weed in warm climates all over the world (Fernando *et al*., 2016) [12].

8. Impact of stress on germination of seeds

8.1 Flooding's Impact on Germination

When the soil was continuously wet or flooded for 30 days, with water rising up to 10 cm over the soil surface, Texas weed germination was hampered. Throughout this 30-day wet or flooded soil situation, no seedlings sprouted. However, certain seeds did germinate once the water was removed. In each of the three flooding treatments, the percentage of viability for Texas weed seeds exposed to a thirty-day period of moist or drowned soil, which was followed by 30 days of six wetting-drying cycle’s equivalent to the untreated check, varied from 23% to 25%. (Bai & Settles, 2015) [2] Although Texas weed seeds did not sprout in moist or flooded soil, periodic flooding does not appear to be a workable pest management strategy because the seeds continued to sprout even after the water was removed (Steinbrecher & Leubner-Metzger, 2017) [30]. Tropical signal grass is a prevalent weed in the turfgrass industry of Florida and poses a potential threat to the turfgrass industry in the southeastern region (Fernando *et al*., 2016) [12].

8.2 Water Stress Impact

The effects of water stress interacted with trials and treatments, resulting in the display of distinct results. The sprouting reaction of tropical signal grass to higher negative water potential revealed a sigmoidal pattern in both cases, with a lag period followed by a significant drop in germination, despite the variations in trials being unexplained. At water strengths of 0 and 20.2 MPa, sprouting was at or below 5%, and at 20.4 to 21.0 MPa, sprouting was at or below 5%. According to the study, germination of blanket, big, seamless, and tropical crabgrass was reduced by up to 70% at water potentials between 20.4 and 20.8 MPa (Fernando *et al*., 2016) [12].

8.3 Osmotic stress and the impact of salt on germination
A NaCl dosage of 320 mM fully prevented the germination of annual sowthistle. 89.6 mM NaCl. These results indicate that certain annual sowthistle seeds may still be able to grow in soils with high salt, which are typical in several southern Australian locations. Additionally, Texas weed (*Caperonia palustris* St. Hil.) seeds displayed comparable germination to annual sowthistle at a NaCl concentration of 160 mM (27 percent), (Chauhan *et al*., 2006) [7].

9. Conclusion
Seeds are crucial planting materials in all crops, and their germination process plays a vital role in productivity. Epigeal and hypogeal seeds have different germination mechanisms. External elements including the availability of water, temperature, air, and light as well as within variables like the availability of auxin, reserves food, the end of inactivity, and seed viability all have an impact on seed germination. Creating a favourable environment that includes these essential elements can significantly improve germination rates and ultimately boost productivity.

10. References

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