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Chemical Solutions for Seed Dormancy: A Comprehensive Review on Strategy to Combat Pre-harvest Sprouting in Mung Bean

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ABSTRACT

The mung bean, or *Vigna radiata* (L.) Wilczek, is a significant grain legume with enormous global economic value. *Kharif* is the most significant of the three seasons and during this time pre-harvest sprouting (PHS) is a major issue that results in significant production losses. Due to PHS, yield losses in green gram have been estimated to be between 60 and 70 per cent. Chemical treatments that induce seed dormancy may prevent premature germination and enable a timely harvest. This study covers the effectiveness of inducing dormancy in mung bean plants with various chemicals at critical developmental stages before harvest. Treatment with various chemicals like maleic hydrazide, sodium azide and plant growth regulators (abscisic acid, ethylene, gibberellins) following chemical administration at pre-arranged intervals, physiological parameters such as seed moisture content, germination rates and antioxidant enzyme activities can be considered to prevent PHS. Mitigating pre-harvest sprouting losses and increasing mung bean output can be achieved by optimising dormancy induction by prudent chemical use. To increase mung bean output, PHS-tolerant cultivars must be developed due to the significant losses incurred by PHS. This review discusses various aspects, including how different traits affect pre-harvest sprouting.

Key words: Dormancy, Hormones, PHS, Plant growth regulators.

The green gram or mung bean (*Vigna radiata* L.) is a significant legume crop that is grown and widely consumed mostly in Asia, Africa and Middle East. It is an important part of a vegetarian diet since it contains a rich source of dietary fibres, vitamins, minerals and the plant-based proteins (Keatinge, 2011). Millions of people, especially in underdeveloped nations, rely heavily on mung beans for nutrition and food security (Nair *et al.,* 2013). Apart from its high nutrient content, mung beans have various other advantageous characteristics. Because of their high nutritional content and well-known antioxidant qualities, its sprouts are frequently consumed (Tang *et al.,* 2014). Traditional medicine also makes use of mung beans to treat a variety of ailments, including heat stroke, kidney problems and improved digestion (Kahraman, 2014). Despite its richness in nutrition and being a potent medicinal source, it faces a key issue that occurs if it is exposed to wet conditions just before the harvest of crop which is often referred to as pre-harvesting sprouting.

Pre-harvesting sprouting, also referred to as vivipary or premature germination, is a major issue that mung bean growers around the world deal with. In the final phases of seed development, it relates to the premature germination of seeds while still attached to the mother plant, which is frequently caused by climatic factors such as excessive humidity or intermittent rainfall. According to Bewley *et al.* (2013), pre-harvest sprout ing can result in significant yield losses, lowered seed quality and a drop in the crop's marketability. During threshing and processing, sprouted seeds are vulnerable to microbial contamination, nutritional losses and physical damage (Gubler *et al.,* 2005). Pre-harvest sprouting is a complex trait and is controlled by many genes showing significant interaction with the environment (Ahmad *et al*., 2014). Furthermore, variable maturity brought on by sprouting might complicate harvesting and raise the possibility of additional losses.

According to Finch-Savage and Leubner-Metzger (2006), seed dormancy is a natural process that maintains plant species' survival and propagation by preventing germination in difficult environmental conditions. Mung bean seeds can be made to undergo dormancy in order to

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stop pre-harvest sprouting and keep the seeds viable until the time of targeted germination. Many strategies, such as chemical treatments, physical techniques and genetic engineering, have been investigated to induce seed dormancy. Based on its efficiency and practical applicability, chemical induction of seed dormancy using plant growth regulators or synthetic substances has garnered a lot of attention among all the other techniques. Resistance to pre-harvest sprouting is mainly due to shorter pod beak length, thicker pod wall, higher pod epicuticular wax, phenol, lignin content and more number of hard seeds which have led to development of hydrophobic thick coat of pod and seed, which, possess impermeable nature for water absorption and prevent pre-harvest sprouting of pods on mother plant under heavy and continuous rainfall coupled with high humidity coupled with intermittent sunshine conditions (Mogali *et al.,* 2023). By understanding the mechanisms and factors influencing chemically induced seed dormancy, researchers and agronomists can develop strategies to mitigate the problem of pre-harvesting sprouting in mung bean, thereby improving crop yields, seed quality and overall productivity (Finch-Savage and Leubner-Metzger, 2006).

Types of dormancy

Physiological dormancy

A kind of dormancy in seeds which is mostly brought on by physiological processes inside the seed is known as physiological dormancy (endodormancy). The balance of plant growth regulators, including gibberellins (GAs) and abscisic acid (ABA), as well as how they interact with other hormones like auxins and ethylene, are the main factors governing it. When an embryo is in physiological dormancy, it is fully grown, but unless environmental stimuli or chemical treatments break the dormancy. specific metabolic processes or hormone signalling pathways prevent germination (Baskin, 2004).

Morphological dormancy

The embryo inside the seed is undeveloped or immature, which results in morphological dormancy. Usually, stratification or chemical treatments are needed to break this kind of dormancy and encourage the growth and development of the embryo. A stiff, impermeable seed coat that limits gas exchange and water intake during physical dormancy makes seed unfit from germination (Baskin, 2004).

Chemical dormancy

Certain chemical substances present in seeds that prevent germination are the cause of chemical dormancy. These substances can be created artificially by applying chemical treatments, or they can arise spontaneously. To induce chemical dormancy and stop pre-harvesting sprouting in mung beans and other crops, researchers have investigated the use of chemical inducers such as abscisic acid (ABA), ethylene, auxins and synthetic chemicals like maleic hydrazide or sodium azide. To effectively induce or break dormancy as desired, it is essential to comprehend the distinct types of seed dormancy seen in mung beans and other crops (Finkelstein, 2008). The different types of inducers and their action have been summarised in Table 1.

Mechanisms of chemical inducers

Chemical inducers are the compounds or the substances that stimulates/activates certain genes or metabolic pathways within the cell that triggers the process of dormancy. These inducers work in a certain way, which have been briefly highlighted below:

Inhibition of the germination process

Chemical inducers of seed dormancy could directly disrupt the several physiological mechanisms that are involved in the germination of seeds, hence hindering, or delaying the radical's appearance and the seedling's subsequent growth. For example, some synthetic chemicals, such as Abscissic acid (Sano, 2021), can inhibit cytochrome oxidase activity, which is essential for cellular respiration. These substances cause the respiratory system to malfunction, which makes the environment unpleasant for the embryo and prevents it from breaking dormancy and starting germination.

Table 1: Different chemical inducers of seed dormancy, their sources and mode of action.

Chemical inducer	Source	Mode of action	References
Abscisic acid (ABA)	Plant hormones	Regulates gene expression and metabolic pathways to prevent germination and preserve seed dormancy.	Ali *et al.,* 2022
Ethylene	Plant hormones	Regulates ABA production and signalling pathways to encourage seed dormancy.	Simontacchi, 2015
Auxins	Plant hormones	Restrict seed germination and encourage dormancy through ABA and ethylene pathway interaction.	Kucera, 2005
Cytokinin	Plant hormones	Counteract ABA's effects by stimulating germination, but at certain doses, they can also cause dormancy.	Kucera, 2005
Maleic Hydrazide	Synthetic compound	Suppresses the growth and division of cells, favouring seed dormancy.	Kamdi, 2022
Sodium Azide	Synthetic compound	Suppresses cytochrome oxidase activity, which prevents respiration and induces dormancy.	Siddiqui, 2007

Similarly, it has been reported that the synthetic plant growth regulator maleic hydrazide impairs cell division and growth (Kamdi, 2022). Maleic hydrazide can successfully stop the embryo from going through the rapid cell division and elongation necessary for radicle emergence and subsequent seedling establishment when administered to mung bean seeds or plants.

Alteration of hormone balance

Several chemical inducers of seed dormancy work by adjusting the complex ratio of plant hormones that controls the processes of dormancy and germination. A crucial hormone for plants, abscisic acid (ABA), is essential for causing and sustaining seed dormancy (Finch-Savage and Leubner-Metzger, 2006). By tipping the hormonal balance in favour of dormancy through exogenous injection of ABA or chemicals that increase their production, germination in mung beans and other crops can be effectively prevented. However, hormones that reverse the effects of ABA, like as ethylene and gibberellins (GAs), are known to stimulate germination. These hormones' production or signalling pathways can be disrupted by chemical inducers, which can change the delicate hormonal balance and cause dormancy.

Modification of gene alteration

Chemical inducers of seed dormancy may also be effective by modifying the expression of several genes related to the processes of germination and dormancy. For instance, it is well known that ABA controls the expression of many genes associated with dormancy, such as those pertaining to hormone signalling, metabolic pathways and transcriptional regulation. By changing the cellular environment or interfering with molecular pathways, synthetic chemicals such as sodium azide and maleic hydrazide can affect the expression of genes. The ultrastructural architecture of pod, morpho-physiological features endowed with differential biomolecular alignment together determine the trait of tolerance or susceptibility to pre-harvest sprouting in mungbean genotypes (Rao *et al.,* 2023). In the end, these modifications in gene expression may result in the inhibition of germination-promoting mechanisms and the formation of dormancy in the seed. The mode of action may differ based on the chemical inducer, its concentration, the species or genotype of the plant and the mechanisms of action frequently combine these activities. The complex physiological and molecular pathways involved are still being studied, which will open the door to more focused and efficient methods of inducing seed dormancy in mung beans and other crops (Nonogaki, 2017).

Seed dormancy mechanisms

Mung bean (*Vigna radiata*) is a widely cultivated pulse crop whose seeds have a complicated dormant mechanism that is influenced by several physiological processes and seed properties. Following are some of the mechanisms that cause mung bean seeds to go under dormant stage. These factors aid in resistance to pre harvesting sprouting in mung beans.

Seed coat characteristics

The mung bean′s seed coat functions as a physical barrier, obstructing the gaseous exchange and absorption of water that are essential for germination (Debeaujon and Koornneef 2000). Seeds might fail to germinate because of the impermeability of the seed coat to water (Singh *et al.,* 2020). High concentrations of phenolic substances, such as tannins, provide the seed coat its impermeability and dormancy.

Regulation of abscisic acid (ABA)

ABA is a plant hormone that is essential for causing and preserving seed dormancy. Elevations in ABA levels occur during seed growth and maturity, which prevents germination by blocking the synthesis and activity of enzymes involved in the mobilisation of seed reserves (Bailly, 2019).

Deficiency in gibberellins

Gibberellins are plant hormones that mitigate the effects of ABA on seed germination. Gibberellin levels in dormant mung bean seeds are comparatively low, which helps to maintain dormancy.

Environmental factors

Although internal factors play a major role in regulating physiological dormancy, mung bean seeds' state of dormancy can also be influenced by external elements such as temperature, light and moisture (Bewley and Black, 2013). To disrupt or promote secondary dormancy, for instance, specific temperature regimes or light exposure can be helpful.

Sensitivity of the embryo

The embryo of mung bean seeds exhibits varying proportions of sensitivity to the hormonal balance between Gibberellins and ABA and the length of dormancy and its depth can be affected by this sensitivity (Miransari and Smith, 2014). To effectively regulate the dormancy and germination processes in mung bean seeds and ensure seedling establishment under ideal environmental circumstances, a combination of these physiological mechanisms and external treatment is applied.

Genetic aspects of dormancy

The physiological stages of dormancy in seeds are primarily influenced by their genetic makeup and differ significantly between species and even among the same species. For the purpose of improving variety, the strain may exhibit the variance. Groundnut dormancy is a hereditary trait (Shelar *et al.,* 2014), extending the dormant period for as long as two years for some varieties. According to Ndoye (2001), dormancy is a natural characteristic of Virginia groundnuts. It was discovered that the trait

dormancy was rather dominant over the trait nondormancy. Numerous researchers have shown that strains belonging to various botanical families differ genetically in terms of seed dormancy (Yaw *et al.,* 2008) demonstrated that monogenic inheritance controls seed dormancy with dominant over non-dominant.

Challenges of natural dormancy

Environmental factors including temperature, light and moisture can affect dormancy and can differ between growing circumstances and geographic locations. Plant dormancy induction and maintenance are made more challenging by the complexity of the surrounding environment. Furthermore, the duration and timing of dormant periods are critical for plant growth and production and any deviation from these patterns may result in lower yields and lower quality plants. These factors are mentioned in the points below:

Temperature

When it comes to causing and breaking dormancy, temperature is a major factor. In certain species, dormancy can be induced by high temperatures, whereas low temperatures, or chilling, are frequently necessary to break dormancy. Dongjie *et al.* (2022) investigates how non-thermal plasma affects mung bean sprouts, implying subtly that regulating temperature during seed treatment can affect germination and growth. The quality results demonstrated that long-term plasma treatment (6 min) had inhibitory effects whereas short-term plasma treatment (1 and 3 min) enhanced seed germination and seedling growth.

Light

The induction and release of dormancy can be influenced by exposure to light, particularly photoperiod (day length) and light quality. Certain species can only emerge from dormancy under certain light conditions. Differential sensitivity to light quality is demonstrated by the study on soybean genotypes, with flowering responses depending on the red to far-red light ratio (Yang *et al.,* 2020). Certain species exhibit a response to light quality, but others, such as the white spruce (*Picea glauca*), predominantly react to photoperiod throughout the dormant season (Hamilton *et al.,* 2016).

Moisture

Besides the aforementioned factors moisture level also determines the dormancy of seeds. The release of dormancy and subsequent growth depend on adequate soil moisture levels. Both premature and prolonged dormancy can be brought on by drought. A study by Hawryzki *et al.* (2011) on Amaryllidaceae revealed that dormancy could be a survival tactic in water deficit conditions. This species and possibly other species' capacity to endure in arid environments with erratic supplies is facilitated by extended periods of dormancy. Pictorial representation of the interaction between genetic, environmental and hormonal factors for regulation of seed dormancy and germination illustrated in Fig 1.

The production of abscissic acid (ABA) in seeds is influenced by both genotype and environment throughout seed development, leading to varying levels of primary dormancy. For these seeds, conditions such as temperature and light help to relieve dormancy. It may not be necessary to break the primary dormancy in some cases, as varying genotypes or environmental factors during seed filling can result in less ABA buildup in the seed, making it non fertile or non-dormant. When their water and temperature needs are met, non-dormant seeds will encourage germination. After undergoing a period of high temperature changes, anoxia, light, or aging stress, seeds

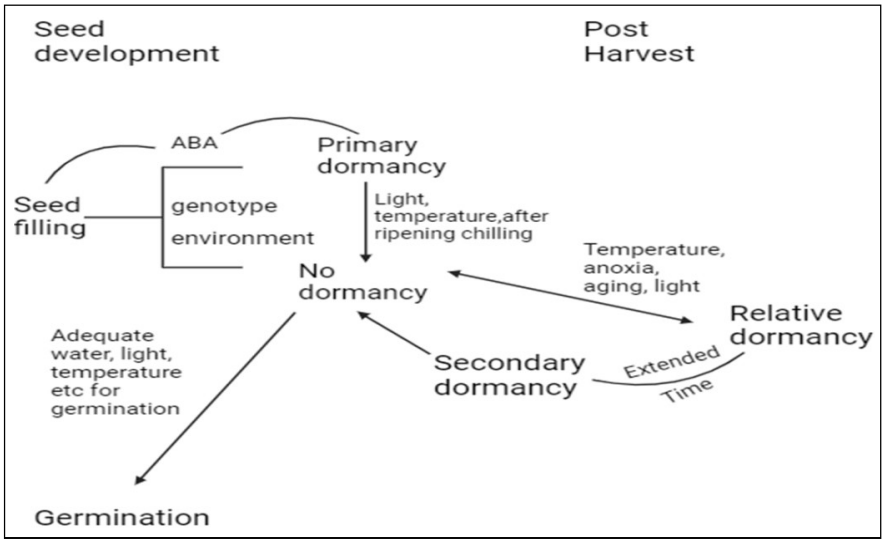


Fig 1: Pictorial representation of the interaction between genetic, environmental and hormonal factors for regulation of seed dormancy and germination.

that have undergone primary dormancy removal or non-dormant seeds may undergo relative dormancy, which can eventually lead to secondary dormancy with extended time. Under proper circumstances like temperature, light, chilling conditions *etc*. along with proper time, secondary dormancy and relative dormancy can be avoided.

Application methods and timing

Appropriate timing is essential because mistimed treatments can result in insufficient dormancy induction or unfavorable effects on the growth and development of plants. Further, the concentration and formulation of chemicals play a key role in assuring the optimal penetration and distribution of chemicals within the tissues therefore proper timing in the application plays a vital role in inducing dormancy.

Seed treatment

Applying chemical inducers through seed treatment is one of the most popular techniques. This method requires immersing or coating the seeds in a solution that contains the intended chemical inducer prior to seeding. In order to facilitate the inducer's absorption and maybe increase its effectiveness in inducing dormancy, seed treatment makes sure that the inducer is in direct touch with the seed (Buijs, 2020). It has been shown that applying solutions containing maleic hydrazide and sodium azide to mung bean seeds enhanced their storage capacity and seed quality by causing dormancy. Similarly, it was discovered that soaking mung bean seeds in the ABA biosynthesis inhibitor fluridone led to an increase in ABA accumulation and the induction of seed dormancy, which stopped premature germination (Ali, 2022).

Foliar application

Foliar sprays and foliar treatments are another way of using chemical inducers. This method allows the chemical to be absorbed and translocated to the growing seeds by applying the inducer directly to the plant's foliage during the final stages of seed development. The foliar spraying of chemicals at 50 and 60 DAS are found to be useful in inducing seed dormancy in mungbean. The foliar sprays of maleic hydrazide @ 250 ppm found to be beneficial in inducing seed dormancy up to 35 days without adversely affecting the yield (Kamdi, 2022). Maleic hydrazide used locally has been shown to successfully induce seed dormancy and decrease pre-harvest sprouting in mung beans as shown in Fig 2. Similarly, (Bewley *et al.,* 2013) talked about how to induce seed dormancy in a variety of crop species, including legumes, using foliar sprays of abscisic acid (ABA) or its synthetic analogs. spraying of malathion at 20+10 days before harvest proved to be better compare to other treatments and these treatments can be used to increase the seed yield of greengram (Raghu *et al*., 2016).

Optimal application stage

For chemical inducers to effectively induce seed dormancy, application timing is critical. In general, the best time to apply seeds is in their later stages of development, just when they are getting close to physiological maturity but before they lose their natural dormancy or sprout before harvest. According to (Rodríguez-Gacio, 2009), ABA treatment works best to induce dormancy when it is given during the late maturity phase of seed development because this is when endogenous ABA levels naturally peak. In a similar manner, it is found that applying maleic hydrazide to milk thistle plants during the late blooming stage roughly two weeks prior to seed maturity was the most successful way to induce seed dormancy. It's crucial to remember that the ideal application stage can change according to the particular crop species, cultivar, surrounding circumstances and chemical inducer that is used.

The mung bean (*Vigna radiata* L.) is an invaluable crop due to its high nutritional value and versatility, playing

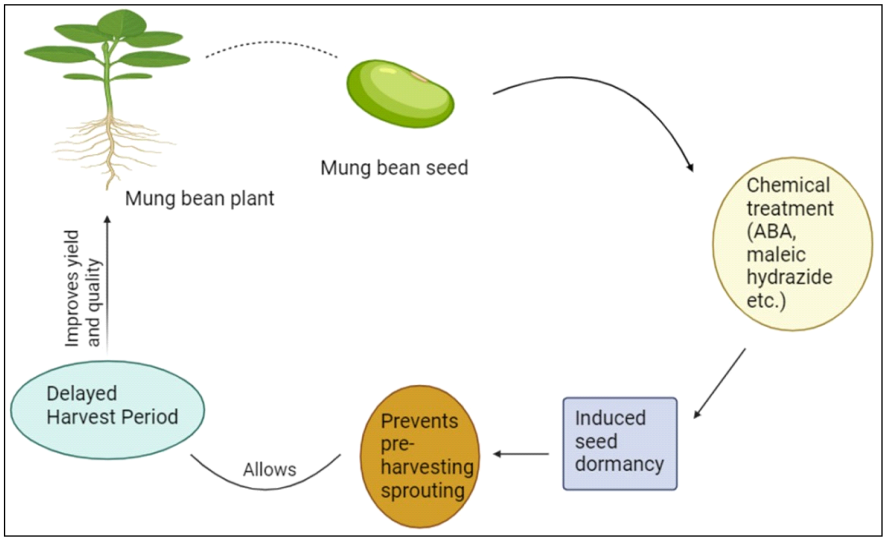


Fig 2: Overview of induction of chemical dormancy to prevent pre-harvesting sprouting in mung bean.

a critical role in food security across Asia, Africa and the Middle East. However, pre-harvest sprouting-a phenomenon where seeds begin to germinate while still attached to the plant-remains a significant challenge, often leading to reduced yield, compromised seed quality and increased risk of microbial contamination.

Chemical induction of dormancy

Our review highlights the potential of chemical inducers to manage pre-harvest sprouting by inducing dormancy in mung bean seeds. Chemical treatments have shown promise in mitigating the risks associated with pre-harvest sprouting by influencing various physiological and hormonal pathways that control seed dormancy and germination.

Types of chemical inducers

Abscisic acid (ABA)

This hormone plays a crucial role in maintaining seed dormancy by inhibiting germination through modulation of gene expression related to hormone signaling and metabolic pathways. Increased application of ABA or its analogs has been effective in inducing dormancy and delaying germination (Finch-Savage and Leubner-Metzger, 2006).

Maleic hydrazide

This chemical disrupts cell division and elongation processes, which are essential for seedling establishment. Its application has demonstrated effectiveness in controlling premature sprouting by impeding the physiological processes required for germination (Kamdi, 2022).

Sodium azide

Known for altering gene expression related to dormancy, sodium azide has been used to induce dormancy in mung beans by modifying hormonal balances and inhibiting germination-promoting mechanisms (Nonogaki, 2017).

Mechanisms of action

Inhibition of germination

Chemical inducers like ABA can inhibit key enzymes involved in the germination process, such as cytochrome oxidase, thus creating an unfavorable environment for embryo development and delaying germination (Sano, 2021).

Alteration of hormone balance

Chemical inducers can shift the hormonal balance by enhancing ABA levels or inhibiting gibberellins and ethylene, thereby promoting dormancy and preventing premature sprouting (Finch-Savage and Leubner-Metzger, 2006).

Modification of gene expression

By affecting the expression of genes associated with dormancy and germination, chemical inducers can regulate seed physiological responses and dormancy status (Finkelstein, 2008).

Seed dormancy mechanisms in mung beans

The intrinsic seed dormancy mechanisms of mung beans involve several factors:

Seed coat characteristics

The physical barrier provided by the seed coat can prevent germination by limiting water absorption and gas exchange (Debeaujon and Koornneef, 2000).

Abscisic acid (ABA) regulation

High ABA levels during seed maturation contribute to dormancy by inhibiting enzymes responsible for seed reserve mobilization (Bailly, 2019).

Gibberellins deficiency

Lower gibberellin levels in dormant seeds maintain dormancy by counteracting the effects of ABA (Bewley and Black, 2013).

Environmental factors

Conditions such as temperature, light and moisture play crucial roles in modulating seed dormancy and germination (Hawryzki *et al*., 2011).

Application methods and timing

Effective dormancy induction relies on the correct application methods and timing:

Seed treatment

Immersion or coating seeds with chemical solutions like maleic hydrazide or sodium azide before planting has been successful in inducing dormancy and enhancing seed quality (Ali, 2022).

Foliar application

Applying chemical inducers directly to the plant foliage during seed development can be effective. For instance, foliar sprays of maleic hydrazide have been shown to induce dormancy and prevent pre-harvest sprouting (Bewley *et al*., 2013).

Optimal timing

Applying chemical inducers at the later stages of seed development, just before physiological maturity, aligns with the natural peak of endogenous ABA levels, thereby optimizing dormancy induction (Rodríguez-Gacio, 2009).

Chemical induction of seed dormancy presents a viable solution to the challenge of pre-harvest sprouting in mung beans. By targeting the physiological and hormonal mechanisms that regulate seed dormancy, chemical inducers can enhance seed quality and yield. Continued research into the precise application methods and timing of these chemicals, as well as their impact on different mung bean varieties, will further refine strategies to mitigate pre-harvest sprouting and improve overall crop productivity.

LIMITATIONS

A major problem in the production of mung beans is pre-harvest sprouting, which lowers seed quality and reduces yield. Chemical treatments that induce seed dormancy have emerged as a viable solution to this issue. Numerous chemicals, including sodium azide and maleic hydrazide, as well as plant growth regulators like ethylene, auxins, cytokinins and abscisic acid, have been investigated as possible chemical inducers of seed dormancy. These inducers work by preventing germination, changing the hormone balance and changing the expression of genes involved in germination and dormancy. These inducers' effectiveness is contingent upon various circumstances, including concentration, time, application technique, ambient conditions and genotypic variation. Although encouraging outcomes have been documented, possible hazards like environmental concerns, food safety issues and financial viability must be taken into consideration. In order to reduce potential hazards, future research should concentrate on creating better formulations, innovative techniques and genetic engineering strategies for greater seed dormancy induction. Sustainability and responsible behaviours should also be taken into account.

FUTURE PROSPECTS

Although the present study has yielded significant knowledge regarding the application of chemical inducers for mung bean seed dormancy, there are several encouraging avenues for future research that could move this topic forward. To increase their effectiveness, reduce their negative effects on the environment and improve targeted achievement, one area of focus might be the creation of novel formulations and delivery systems for these chemical inducers, such as seed coatings, nanoparticle formulations, or controlled-release systems. Furthermore, investigating combinations strategies that incorporate several chemical inducers or blend them with other methods like seed priming or physical treatments could result in cumulative impacts and improved induction of seed dormancy (Nonogaki, 2019). Additionally, the use of innovative biotechnological techniques like genome editing and genetic engineering may open the door to the creation of mung bean cultivars with better seed dormancy traits, possibly lowering the need for outside chemical inducers. Pre-harvesting sprouting in mung beans and other crops may be addressed with more effective, focused and long-lasting remedies if these fields of study continue (Humphry, 2005).

CONCLUSION

Pre-harvesting sprouting in mung beans has serious financial implications since it causes large yield losses, lower-quality seeds and diminished crop marketability. Chemical treatments that induce seed dormancy have shown promising effect in addressing this issue and ensuring the generation of quality mung bean seeds. The various kinds and processes of seed dormancy, including physiological, morphological, physical and chemical dormancy, have been emphasised in this review. Chemical inducers have been investigated as possible agents to induce seed dormancy in mung beans and other legumes. These include synthetic substances like maleic hydrazide, sodium azide and plant growth regulators like abscisic acid, ethylene, auxins and cytokinins. These chemical inducers act by inhibiting germination processes, changing the hormone balance and changing the expression of genes associated with germination and dormancy. Numerous factors including concentration, timing, application technique, environment and genotypic variation, affect how efficient these inducers are. Even though chemical treatments, to induce seed dormancy and inhibit pre-harvesting sprouting in mung beans have shown encouraging results, there are still issues and possible hazards that need to be resolved. Prior to widespread use, it is imperative to assess environmental problems, food safety considerations and economic feasibility.

Conflict of interest

All authors declare that they have no conflict of interest.

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