

# Enhancing Germination and Growth in Fruit Crops: A Comprehensive Review of Pre-Sowing Treatments

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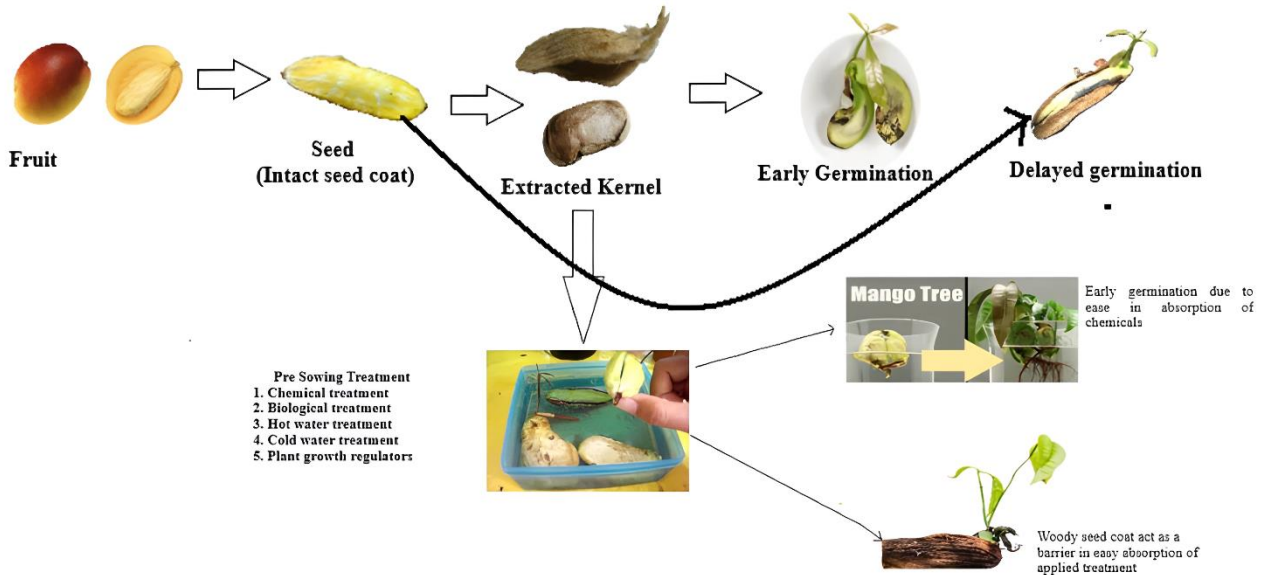
**Abstract**— *Pre-sowing treatments are pivotal interventions in optimizing nursery practices for fruit crop production, addressing the demand for increased planting material, especially grafts. This review paper comprehensively analyzes the efficacy and mechanisms of pre-sowing treatments, encompassing hormonal priming, osmopriming, and halo-priming techniques. Molecular and physiological mechanisms underlying seed germination and seedling growth are elucidated, emphasizing their influence on gene expression patterns, hormonal signaling pathways, and physiological processes within seeds. Interactions with plant hormone signaling pathways, particularly the modulation of gibberellin (GA) and abscisic acid (ABA) levels, are explored in detail, highlighting their role in regulating seed dormancy and germination. Moreover, the review discusses the impact of pre-sowing treatments on gene expression related to germination and growth, shedding light on the molecular basis of their effects. Challenges in fruit crop production, such as the need for accelerated seed germination and seedling growth, are addressed, with pre-sowing treatments identified as key solutions. The paper concludes by outlining future prospects and emphasizing the indispensable role of pre-sowing treatments in modern fruit crop production systems. In summary, this review provides a comprehensive understanding of pre-sowing treatments, their mechanisms of action, and their implications for nursery management and sustainable fruit crop production.*

**Keywords**— *Pre-sowing treatment, seedling emergence, mango.*

## I. INTRODUCTION

Seed germination in horticultural crops, such as mango Kagzi lime, Karonda, Jamun, Papaya, and Phalsa, relies heavily on environmental factors like water potential, temperature, humidity, and light. Successful propagation of these crops from seeds necessitates a comprehensive understanding of seed viability, storage conditions, optimal sowing times, and the factors influencing germination and seedling care. However, poor seed germination is still a significant challenge in fruit crops, often which can be due to the presence of germination inhibitors in the seed coat, including benzoic acid, cinnamic acid, coumarin, naringenin, jasmonic acid, and abscisic acid (ABA). The low germination rates and extended germination periods, along with slow seedling growth rates, hinder the use of these crops as rootstocks, essential for budding and grafting processes. Dormancy or hard seed coats are common reasons for seed germination failure, prompting the exploration of pre-sowing treatments to enhance germination and subsequent seedling growth. Methods such as scarification or soaking in solutions like KNO<sub>3</sub>, Urea, hot or cold water, thiourea, cow urine, cow dung slurry, or GA<sub>3</sub> aim to increase seed coat permeability and improve germination rates as displayed in Fig 1. These pre-sowing treatments enhance embryo growth potential, reduce germination time, weaken seed coats, and promote maximum germination percentages. Additionally, the application of plant growth regulators like GA<sub>3</sub>, IBA, and IAA, in appropriate concentrations alongside scarification, can regulate growth behavior and enhance seed germination and seedling growth. Extensive experimentation has been conducted to identify optimal treatments tailored to

different fruit crops, emphasizing the importance of uniform germination for effective planting or rootstock use. This paper addresses gaps in understanding the molecular and physiological mechanisms of pre-sowing treatments, particularly focusing on hormonal priming. It aims to explore specific genes and signaling pathways influenced by these treatments across different fruit crop species. Additionally, the review highlights the need for long-term studies on the effects of pre-sowing treatments on plant growth and yield. Furthermore, it emphasizes the lack of comparative studies under varying environmental conditions and suggests avenues for future research, including novel treatment exploration and integration into sustainable nursery management practices. Through these efforts, the paper aims to enhance our understanding of pre-sowing treatments and their potential applications in fruit crop production.



**FIGURE 1: Schematic representation of difference on using pre-sowing treatments**



**FIGURE 2: Pre-sowing treatment impacting fruit industry**

**Seed priming:** Seed priming is a widely adopted physiological technique involving seed hydration and drying to enhance metabolic processes prior to germination, thereby accelerating germination, seedling growth, and overall crop yield under normal as well as diverse biotic and abiotic stress conditions. It serves as a cost-effective and efficient method to stimulate seed germination (Dawood, 2018). Seed priming promotes synchronized seed germination and increased emergence (Ghassemi-Golezani *et al.*, 2012; Dalil, 2014), offering multiple benefits such as reduced fertilizer usage, enhanced crop yield through synchronized germination, and induction of systemic resistance in plants, all in a cost-effective and environmentally friendly manner.

**TABLE 1**  
**SEED PRIMING**

Priming Method	Description	Advantages
<b>Hydro-priming</b>	Soaking of seeds with water.	Established and cost-effective method.
<b>Halo-priming</b>	Treatment of seeds with inorganic solutions (e.g., NaCl, KNO <sub>3</sub> , CaCl <sub>2</sub> , CaSO <sub>4</sub> ).	Enhances germination.
<b>Osmo-priming</b>	Soaking seeds in osmotic solutions with varying concentrations of solutes.	Creates an osmotic gradient, facilitates water movement into or out of seeds.
<b>Hormonal-priming</b>	Seed priming with hormone solutions.	Enhances seed germination and vigor.
<b>Solid-based Matrix</b>	Immersing seeds in a solid matrix for gradual water absorption.	Enhances efficacy of fungicides and insecticides, controls soil-borne insects and diseases.
<b>Bio-priming</b>	Integrates biological elements (e.g., seed inoculation with beneficial organisms) and physiological aspects (e.g., seed hydration).	Safeguards seeds, manages diseases, promotes seed vigor.

## II. COMPARATIVE ANALYSIS OF DIFFERENT PRE-SOWING TREATMENT

The comparative analysis of various pre-sowing treatments, as observed by different researchers across different plant species, highlights the diverse effects of chemical treatments, growth regulators, and biological inoculants on seed germination and seedling growth. Among all the chemical treatments (50% HCl, 5% H<sub>2</sub>SO<sub>4</sub>, 1% thiourea, 1% KNO<sub>3</sub>, 2% sucrose, 2% urea, 2% bleaching powder) and growth regulator (100 ppm GA<sub>3</sub>), seeds treated with 2 percent bleaching powder in 24 hrs treatment emerged as the best regarding germination, growth of the seedlings of Passion fruit followed by seeds treated with 100 ppm GA<sub>3</sub> for 30 min (Mehta *et al.*, 2016). Similarly, Patel *et al.*, (2016) found that seed priming with GA<sub>3</sub> 150 mg litre<sup>-1</sup> resulted in germination percentage (84.33 %). Al-Absi, K.M. (2010) recorded the highest germination percentage (65.0%) in mahaleb cherries (*Prunus mahaleb* L.) seeds stratified for 90 days treated with gibberellic acid at 1000 ppm. Whereas, Heidari *et al.*, (2008) found immersion of *P. scoparia* seeds in sulfuric acid for 30 minutes + 30 days of stratification increased the percentage of germination by 74.5%. Sayan *et al.*, (2019) in wood apple (*Feronia limonia*) found that amongst the different concentrations of used chemicals, the maximum germination percentage (81.67 %) was found in treatment with GA<sub>3</sub> 100 ppm. Patil *et al.*, (2012) recorded higher germination of rangpur lime (98.66%) under GA<sub>3</sub> 150 ppm under Akola conditions. In Aonla, Bhadauria *et al.*, (2000) reported that seed treatment with Azospirillum biofertilizer slurry for 24 hrs increased germination percentage (79%). While, Kumar *et al.*, (2008) observed that the mango stones pre-treated with 3% Panchagavya took a lesser number of days for the initiation of germination and recorded maximum germination (75.22%). Additionally, in Khirni seeds, Shirol *et al.*, (2005) found that pre-soaking of seeds in cow dung slurry for 24 hours resulted in higher (66.83%) seed germination whereas, khirni seeds treated with GA<sub>3</sub> 50 ppm resulted in the highest germination percentage (92.31%) followed by GA<sub>3</sub> 75 ppm (92.31%) and GA<sub>3</sub> 75 ppm (89.76%) (Wankhede *et al.*, 2008). Furthermore, Venudevan and Srimathi (2013) in bael observed higher germination (84%, 80%, and 76%) when seeds were soaked in water for (6 hrs, 9 hrs and 12 hours) respectively under Coimbatore conditions. Overall, the findings suggest that the efficacy of pre-sowing treatments varies depending on the plant species and the specific treatment method used. However, treatments involving Gibberellic acid and biological inoculants consistently showed positive effects on seed germination across different plant species.

### 2.1 Effect of pre-sowing treatments on different parameters:

#### 2.1.1 Impact of pre-sowing treatments on number of days for germination:

Germination in certain fruit crops encounters barriers known as dormancy, stemming from internal or external factors. External dormancy can arise from tough seed coats, exemplified by mangoes, walnuts, and almonds, or from a slimy covering like sarcotesta found on papaya seeds. Internally, inhibitors within seeds can hinder germination until removed. Several methods exist to overcome dormancy, including seed coat removal, which promotes early germination by mitigating mechanical constraints on embryo growth. Banyal *et al.*, (2021) reported earlier germination of the extracted kernel in comparison to those that were sown along with seedcoat as the kernel can directly absorb the water while the kernels with seed coat delayed germination as the seed coat was woody which hindered the absorption of water by the seed. Once the seed coat was softened, the entry of water into the seed coat resulting in the initiation of germination. Also, soaking the seed in GA<sub>3</sub> @ 100 ppm resulted in earlier

germination. Similarly, Muralidhara *et al.*, (2016) found that seed coat removal reduced germination time compared to intact seed coats, with initiation and completion of 50% germination occurring in 16.5 and 25.9 days, respectively, compared to 20.2 and 30.5 days by the control. Late germination with intact seed coats may be attributed to the stony endocarp acting as a barrier against inhibitor escape, as observed by Padma and Reddy (1997). Abbas *et al.*, (2015) also observed delayed germination with unhusked seeds compared to husked seeds. Sinnadurai (1975) reported earlier germination in mango seeds with removed seed coats, with initiation on the 6th day for some cultivars, compared to the 10th day for controls. Chemical treatments like GA<sub>3</sub> have also been effective in promoting early germination by increasing amylase activity, as shown by Muralidhara *et al.*, (2015) and Patel *et al.*, (2016). GA<sub>3</sub> @200 ppm induced early germination in 12 days and completion of 50% germination in 28 days, compared to 18 and 32 days for the control, respectively. Patel *et al.*, (2016) found GA<sub>3</sub> @100 ppm reduced germination time in mango seeds compared to beejaaumrit 2%. These findings emphasize the importance of tailored treatments to overcome dormancy and optimize germination in fruit crops.

Reddy and Reddy (2017) found that KNO<sub>3</sub> @2% required 21 days for germination initiation and 29 days for 50% germination completion, while control seeds took 27 days for initiation and 37 days for 50% germination. Reshma and Simi (2019) observed that sowing mango stones with the stalk end up (22.95 days) reduced germination time compared to flat sowing (21.95 days), with 50% germination completing in 31.75 days for stalk end up and 40.91 days for flat sowing. Similarly, GA<sub>3</sub> @ 200ppm exhibited minimum initiation time (22.62 days) and 50% germination completion (31.78 days), while control seeds took longer (31.01 days for initiation, 42.94 days for 50% germination). Vidya *et al.*, (2018) reported that GA<sub>3</sub> @ 250 ppm-initiated germination in 12.07 days, with earliest completion in GA<sub>3</sub> @ 500 ppm and cow urine @ 50% (50.91 days). Dawale *et al.*, (2012) found earliest germination initiation after 10.67 days with panchgavya @ 3%, 50% germination completion in 20.33 days with neem seed kernel extract @ 5%, and quickest complete germination in 36.67 days with neem seed kernel extract @ 5%. Kumar *et al.*, (2008) observed earliest germination initiation (12.25 days) and complete germination (46.18 days) with Panchgavya 3%, while control seeds took longer (17.31 days for initiation, 50.49 days for complete germination). Kolekar *et al.*, (2017) reported minimum initiation time (12.57 days) and completion time (44.34 days) with GA<sub>3</sub> @ 100ppm, similar to water soaking. Chaudhary (2016) found that seeds treated with Cow dung slurry for 24 hours-initiated germination in 10.87 days, while control seeds-initiated germination after 21.30 days. Parmar *et al.*, (2018) provided similar findings in jackfruit, where chemicals were found to initiate quick germination. The first germination was observed in cow dung slurry within 13.73 days. Singh *et al.*, (2015) reported rapid germination in 8.50 days in seeds treated with GA<sub>3</sub> @200ppm, while seeds under control took the maximum number of days (13.50 days). Tandon *et al.*, (2019) studied the effect of organic substances and plant growth regulators on seed germination and survival of tamarind seedlings. They observed germination initiation within 5.27 days in seeds treated with GA<sub>3</sub> @ 200 ppm. 50% germination was observed after 16.00 days, with the maximum time required for germination observed in the control treatment (12.71 days), and 50% germination occurring after 26.67 days. Pavithra *et al.*, (2018) provided reports on the time taken by Surinam Cherry (*Eugenia uniflora* L.) for germination. Water-soaked seeds, initiated germination in 18.33 days, with 50% germination recorded in 25.00 days. Seeds treated with HCl 25% required the maximum number of days (24.33 days) for germination, while 50% germination was completed in 27.67 days with thiourea 1% and KNO<sub>3</sub> 1%. Palepad *et al.*, (2017) recorded the minimum number of days (10.27) required for germination of custard apple seedlings by treating seeds with GA<sub>3</sub> @ 1000 ppm for 24 hours. Babu *et al.*, (2008) found the minimum number of days (29.73 days) required for germination of papaya seeds treated with GA<sub>3</sub> @ 100 ppm. Kalyani *et al.*, (2014) noted that the minimum number of days required for germination was 19.20 days in guava seeds treated with GA<sub>3</sub> @ 1000 ppm. Seed coat removal and chemical treatments, such as GA<sub>3</sub> application, significantly reduce germination time in various fruit crops. External barriers like tough seed coats delay germination by hindering water absorption, while internal inhibitors also contribute to dormancy. Tailored treatments, including seed coat removal and GA<sub>3</sub> application, optimize germination by promoting early water uptake and enhancing enzymatic activity.

### 2.1.2 Impact of pre sowing treatment on Germination percentage:

Sumaila *et al.*, (2019) found removing seed coat before germination resulted in early germination then sowing along with seed coat in mango under Ghana conditions. Ghosh *et al.*, (2003) found that most seed treatments, except for a six-hour soak and treatment with 200 ppm sodium thiosulfate, did not enhance germination in fresh seeds. However, germination rates improved with GA<sub>3</sub> treatment, particularly with 50 ppm GA<sub>3</sub> (75%) and 100 ppm GA<sub>3</sub> (44.00%) (Stenzel *et al.*, 2003). Further, Ratan and Reddy (2004) observed that soaking seeds in 400 ppm GA<sub>3</sub> resulted in the highest germination percentage (69.00%), with seeds soaked in 600 ppm GA<sub>3</sub> initiating germination the earliest (16.00 days). Similarly, Banful *et al.*, (2011) noted a total germination of 29.80% after 42 days when *Annona squamosa* seeds were sown in Ghana. However, maximum germination was achieved by soaking seeds in 400 ppm GA<sub>3</sub> for 12 hours, yielding both the highest germination percentage and seedling

height (Gharge *et al.*, 2011). Jadhav *et al.*, (2015) found that treating custard apple seeds with GA<sub>3</sub> at 50 ppm for 48 hours resulted in higher germination rates. Additionally, Parmar *et al.*, (2016) reported that soaking seeds in GA<sub>3</sub> at a concentration of 200 mgL<sup>-1</sup> for 12 hours led to the shortest germination time (24.00 days) and the highest germination percentage (63.99%). While in citrus Khan *et al.*, (2002) investigated pre-sowing seed treatment effects on grapefruit, Kinnow mandarin, and rough lemon seeds. While GA<sub>3</sub> treatment did not significantly affect final germination percentages, Kalalbandi *et al.*, (2003) found high germination rates in Kagzi lime seeds soaked in GA<sub>3</sub> and NAA, particularly with GA<sub>3</sub> at 80 ppm. Similarly, Shinde *et al.*, (2008) observed higher seed germination rates in Rangpur lime with GA<sub>3</sub> at 80 ppm, while Dhaka and Pal (2009) demonstrated better germination, growth, and survival in lime seeds with GA<sub>3</sub> at 500 ppm. Additionally, Patil *et al.*, (2012) reported higher germination rates in Rangpur lime under GA<sub>3</sub> treatment at 150 ppm compared to the control group.

In anola, various treatments have been studied to enhance anola seed germination. Soaking seeds in 250 ppm GA<sub>3</sub> or distilled water with alternating soaking and drying for 72 hours resulted in the highest germination percentages (Dhankhar and Kumar, 1996). Similarly, soaking seeds in 500 ppm GA<sub>3</sub> led to quicker germination (Sharma, 1996). Treatment with 250 ppm GA<sub>3</sub> resulted in the earliest and highest germination percentages (Dhankhar and Singh, 1996). Treating seeds with 400 ppm GA<sub>3</sub> resulted in a higher percentage of germination (Wagh *et al.*, 1998). Seed treatment with Azospirillum biofertilizer slurry increased germination percentage compared to the control (Bhadauria *et al.*, 2000). Early germination and a high germination percentage were observed with treatment using 200 ppm GA<sub>3</sub> (Gholap *et al.*, 2000). Treatment with Azospirillum + Phosphobacteria + 0.5% KNO<sub>3</sub> resulted in high germination percentages (Rajamanickam and Anbu, 2001). Additionally, treatments using 1% KNO<sub>3</sub> or 200 ppm GA<sub>3</sub> resulted in the highest germination percentages (Rajamanickam and Balakrishnan, 2004). Maximum germination percentages were achieved with treatment using 1% KNO<sub>3</sub> or GA<sub>3</sub> 500 ppm (Purbey and Meghwal, 2005; Kumari *et al.*, 2007). The highest germination percentage was observed with treatment using GA<sub>3</sub> 750 ppm + Azospirillum (Supe *et al.*, 2012). Scarification and treatment with 1% gibberellin overturned seed dormancy, resulting in a 43% germination percentage (Perera *et al.*, 2014).

In sapota Several studies have investigated methods to enhance the germination of sapota and khirni seeds. Pampanna *et al.* (1995) found that soaking sapota seeds with cracked seed coats in GA<sub>3</sub> 300ppm for 24 hours resulted in 53% germination. In contrast, Pampanna and Sulikeri (2001) discovered that treating sapota seeds with GA<sub>3</sub> 400 ppm + ethrel led to significantly higher germination rates of 90% within 11.50 days. Similarly, Shirol *et al.* (2005) observed that pre-soaking khirni seeds in cowdung slurry for 24 hours resulted in 66.83% germination. Additionally, Wankhede *et al.* (2008) reported that in khirni seeds, GA<sub>3</sub> treatments of 50 ppm recorded the highest germination percentage of 92.31%, followed by GA<sub>3</sub> treatments of 75 ppm, both at 92.31%, and GA<sub>3</sub> treatment of 75 ppm at 89.76%. In other fruit crops several studies have explored diverse methods to enhance seed germination in various plant species. Ghyare (2005) observed that tamarind seeds treated with 400 ppm GA<sub>3</sub> exhibited a remarkable 100% germination rate. Abuduca *et al.* (2006) found that wild pistachio seeds treated with GA<sub>3</sub> showed increased germination rates, with the highest rate recorded at a concentration of 200 mg/L. Cetinbas and Koyuncu (2006) reported increased germination in prunus avium seeds soaked in 7500 ppm KNO<sub>3</sub>. Ahmad (2010) discovered that 2000 ppm GA<sub>3</sub> resulted in the maximum germination of kiwi fruit seeds. Singh *et al.* (2011) achieved maximum germination in Manila tamarind seeds treated with 50 ppm IBA and GA<sub>3</sub>. Yattoo *et al.* (2012) observed that kinetin pre-treatment enhanced apple seed germination. Shabaq (2013) demonstrated that GA<sub>3</sub> treatment at 250 ppm improved germination in loquat seeds. Shah *et al.* (2013) reported significant improvement in peach, plum, and apricot germination with GA<sub>3</sub> treatment combined with water soaking. Venudevan and Srimathi (2013) found increased bael seed germination with prolonged water soaking. Gurung *et al.* (2014) achieved maximum passion fruit seed germination with thiourea treatment. Vasantha *et al.* (2014) noted higher tamarind seed germination with GA<sub>3</sub> treatment. Lastly, Parvin *et al.* (2015) observed improved black walnut seed germination with chilling and GA<sub>3</sub> treatment, while Thakur (2015) found that mechanical rupturing of the seed coat enhanced peach rootstock flordaguard seed germination. These studies collectively highlight diverse strategies for optimizing seed germination across different plant species.

## 2.2 Effect of pre-sowing treatment on growth parameters:

### 2.2.1 Seedling height:

Muralidhara *et al.* (2016) found that the mean height of husked seeds was 19.5 cm, while it was only 17.6 cm for un-husked seeds. The highest seedling length was observed for husked seeds, which was 69.02 cm, compared to non-husked seeds without any treatment, where the height was only 28.67 cm in the given time. Among the chemical treatments, the maximum height of 48.76 cm was achieved by using GA<sub>3</sub> @ 1000ppm for 48 hours, as observed by Abbas *et al.* (2015). Shaban (2010) conducted an experiment that resulted in higher seedling length (58.7 cm) for husked seeds and 49.1 cm for unhusked seeds. In the case

of non-husked seeds, GA<sub>3</sub> @200ppm resulted in the highest seedling length (52.50 cm), while in the case of husked seeds, GA<sub>3</sub> @ 200 ppm resulted in the highest seedling length (58.7 cm) according to the study by Muralidhara *et al.* (2015). Thakriya *et al.* (2017) reported the highest seedling height (22.26 cm) for vermiwash 1% treatment, while the lowest height (17.20 cm) was found in custard apple leaf extract 10%. The highest shoot length was found in treatment with thiourea @ 1%, which was 42.77 cm, while the lowest was found to be in the case of beejaumrit @ 2% which turned out to be 34.42 cm according to Patel *et al.* (2016). Reshma and Simi (2019) reported the highest seedling height in the case of stalk end up position (21.84 cm), while in flat sowing position, it was recorded only 18.34 cm. GA<sub>3</sub> @ 200 ppm resulted in the highest seedling height (22.69 cm), and the least height was observed in the case of control (16.45 cm). Aalta and Srihari (2013) reported that GA<sub>3</sub> @ 500 was best for producing the highest seedling in treated stone and extracted kernel, which was recorded as 23.43 cm and 24.13 cm, respectively. Meanwhile, the least height was recorded in control in Whole nut (18.70 cm) and Extracted kernel (20.12 cm). Dawale *et al.* (2012) recorded maximum height after 90 days after sowing in Panachgavya @ 3%, which was found to be 27.30 cm, while the minimum recorded height was recorded in control, which was found to be 19.87 cm. As per reports provided by Reddy and Reddy (2017), the maximum height recorded by using KNO<sub>3</sub> @2% was 26.3 cm, while the height recorded in control was found to be 15.4 cm, which was considerably less. Kumar *et al.* (2008) reported results after 30 days of sowing, in which GA<sub>3</sub> @100 ppm was found to be effective in producing the tallest seedlings with a height of 24.74 cm, whereas treating seeds with cow urine for 12 hours produced only a height of 18.4 cm. Thakriya *et al.* (2017) reported the maximum seedling height of 22.26 cm in seedlings from vermiwash @ 1% treated seedlings, whereas vermiwash @ 2% and basil leaf extract were found at par with this treatment, and the least height (17.20 cm) was recorded in seeds treated with custard apple leaf extract @10%. Vidya *et al.* (2018) recorded the maximum height after 90 days of sowing in the seeds treated with GA<sub>3</sub> @ 500 ppm, which was 44.26 cm, while the least height was recorded in the case of seeds treated with vermiwash @ 50% (25.43 cm). Kolekar *et al.* (2017) recorded the maximum height in seedlings treated with GA<sub>3</sub>@100 ppm for 4 hours, and the minimum height was recorded in seeds treated with cow dung slurry for 4 hours. Chaudhary (2016) observed the height after 8 months of sowing and recorded the maximum height of 65.99 cm in seeds treated with cow dung slurry for 24 hours, while the recorded minimum height in seeds under control was 51.94 cm only. Parmar *et al.* (2018) recorded the maximum plant height of 51.67 cm after 120 days of sowing, whereas seedlings from seeds treated with 3% panchgavya recorded the maximum height of 48.12 cm. Singh *et al.* (2015) reported the highest seedling height in the seeds treated with GA<sub>3</sub> @ 200ppm, where the height was found to be 27.25 cm, whereas the minimum recorded height was found in control, which was found to be 22.62 cm. Harshavardhan and Rajasekhar (2012) reported that the maximum height attained by jackfruit seedling was found to be 70.6 cm with KNO<sub>3</sub> @ 0.50% for 24 hours, and the minimum recorded height was found in control, which was 57.4 cm. Gurung *et al.* (2013) after 90 days of sowing recorded the maximum seedling height of 20.91cm in the seeds treated with GA<sub>3</sub> @ 500 ppm, while the lowest recorded height 13.48 cm was found in the seedlings under control. Dilip *et al.* (2017) reported the effect of different concentrations and time intervals of soaking of GA<sub>3</sub> on the germination and growth of Rangpur lime, where the maximum height of 11.97 cm was recorded with GA<sub>3</sub> @ 80ppm for 12 hours, and seeds without any treatment resulted in plants with the least height of 7.92 cm after 120 days of sowing. Pavithra *et al.* (2018) after 120 days of transplanting recorded the maximum height of 13.67 cm with GA<sub>3</sub> @ 500 ppm, and the lowest recorded height was found to be 8.87 cm in the seeds under control. Archana *et al.* (2015) recorded the maximum height of 12.70 cm on treating seeds with GA<sub>3</sub> 50 ppm, and the minimum height of 8.52 cm was found in the control treatment after 70 days of sowing. Sharaf (2016) conducted an experiment for 2 years and observed the maximum seedling height.

### 2.2.2 Seedling diameter:

Muralidhara *et al.*, (2016) recorded mean diameter of unhusked seeds to be 0.56 cm whereas in case of the seed lacking in the seed coat were found to be 0.62cm. Similar results were also reported by Abbas *et al.*, (2015) where maximum seedling diameter was found 0.91 cm in case of husked seeds when compared to non-husked seeds the diameter of non-husked seeds was only found to be 0.47 cm. In case of chemical treatment, the maximum diameter (0.56 cm) in non-husked seeds was found in GA<sub>3</sub> @500ppm for 48 hours. Same results were reported by Shaban (2010) where seedlings from husked seeds were found to have the diameter of 0.55cm in comparison to the non-husked seeds which were found to have the only 0.51c m of diameter. The results of chemical soaking were also reported were GA<sub>3</sub> @ 200ppm was found superior having diameter of 0.56 cm and 0.59cm in non-husked and husked seeds respectively. Muralidhara *et al.*, (2015) reported the diameter 0.59 cm which was recorded highest among all other treatments as result of KNO<sub>3</sub> @ 1% and lowest stem diameter was found to be in control of 0.40cm. Almost similar result were obtained by Thakriya *et al.*, (2017) in which reports regarding diameter 0.59 cm as the highest obtained by vermiwash 1% and lowest of 0.53 cm with custard apple leaf extract @10%. Maximum collar girth was found to be 9.02 cm in case of GA<sub>3</sub> @ 100 ppm and the lowest collar girth was recorded in beejaumrit @ 2% (8.13 cm) Patel *et al* (2016). Aalta and Srihari (2013) reported KNO<sub>3</sub> @0.5% to best for production of maximum seedling diameter in treated

stone and extracted kernel which was recorded 6.90 mm and 7.10 mm respectively and least diameter was recorded in control in whole nut (5.00 mm) and extracted kernel (6.00 mm). Dawale *et al.*, (2012) concluded panchgavya @ 3% was having highest seeding diameter of 6.40 mm and minimum recorded diameter was recorded in control (5.38 mm). Similar results were reported by Reddy and Reddy (2017) where maximum diameter was achieved by the use of  $\text{KNO}_3$  @2% (0.70 cm) and in control it was only obtained as 0.46cm. Kumar *et al.*, (2008) after 30 days of sowing and  $\text{GA}_3$  @ 100 ppm was found having 5.55mm diameter and water soaking (5.34 mm), panchgavya 3% (5.44 mm) was found at par with  $\text{GA}_3$  @ 100 ppm. Thakriya *et al.*, (2017) provided reports about increase in diameter which was found highest (0.59 cm) in vermiwash @1% and vermiwash @ 2% and Basil leaf extract @10% were found at par with vermiwash@1% and minimum diameter was recorded in custard apple leaf extract @10%. Vidya *et al.*, (2018) after 90 days after sowing recorded maximum seedling diameter in the seeds treated with  $\text{GA}_3$  @ 500 ppm which was 7.93 mm, least diameter was recorded in case of seeds treated with Salicylic acid@2ml/l (5.94 mm). Kolekar *et al.*, (2017) recorded maximum stem diameter (0.67 cm) in the seedling treated with  $\text{GA}_3$  @ 100 ppm for 4 hours and minimum diameter was recorded in seeds soaked in cow urine 12 hours which was 0.61cm. Chaudhary (2016) recorded maximum collar girth (13.08 mm) in seeds treated with cow dung slurry for 24 hours after 8 months of sowing and minimum girth was recorded in control (9.24 mm). Parmar *et al.*, (2018) recorded girth in jackfruit seeds where 9.06 mm was found maximum with seeds treated with cow dung slurry after 120 days after sowing and minimum girth was recorded in seeds under control. Reports about seedling diameter in cashew as provided by Singh *et al.*, (2015) where maximum diameter of 1.15 cm which was found in seeds treated with  $\text{GA}_3$  @200 ppm and minimum seedling diameter was recorded in control where diameter was recorded as 0.82 cm Harshavardhan and Rajasekhar (2012) in jackfruit recorded maximum diameter (0.78 cm) was found in  $\text{GA}_3$  200 ppm for 24 hours and minimum diameter was recorded in control (0.63cm). Pavithra *et al.*, (2018) recorded maximum diameter of 2.17mm with  $\text{GA}_3$  @ 500 ppm and least diameter was recorded in seeds under control which was 1.27mm after 120 days. Archana *et al.*, (2015) provided reports about maximum seedling diameter after 70 days of sowing which was found maximum (0.94cm) in seeds treated with  $\text{GA}_3$  @50 ppm and least diameter (0.64 cm) was found in seeds under control. The maximum diameter of papaya seedling recorded by Mali *et al.*, (2015) was found to be 0.253 cm and 0.323 cm at 20 and 30 days after sowing respectively in variety Taiwan on treating seeds with  $\text{GA}_3$  @ 500. Maximum diameter was recorded in the seedling under treatment of  $\text{GA}_3$  @ 1000 ppm which was found to be 0.926 cm as per reported Palepad *et al.*, (2017). Rahangdale *et al.*, (2019) represented the effect of  $\text{GA}_3$  and maximum diameter was recorded 4.68 mm with concentration of  $\text{GA}_3$  @ 500 ppm after 120 days after sowing. Ramteke *et al.*, (2015) recorded maximum collar diameter of 5.78 mm in seedling arising from the seeds under treatment of  $\text{GA}_3$  @ 200 ppm in papaya seedlings. Manthri and Bharad (2017) recorded stem diameter at 30 days after sowing and was found maximum (0.133 cm) when seeds were treated with  $\text{GA}_3$  @1000 ppm

### 2.3 Number of leaves

In various studies, the number of leaves per plant has been observed in both husked and unhusked seeds. Muralidhara *et al.* (2016) found a higher number of leaves in husked seeds (8.70) compared to unhusked seeds (7.60). Abbas *et al.* (2015) reported that husked seeds had more leaves per plant (28.08) compared to unhusked seeds (11.67). Similarly,  $\text{GA}_3$  @ 500 ppm led to 21.00 leaves. Shaban (2010) found that husked seeds had fewer leaves (25.2) compared to unhusked seeds (31.2). In the case of  $\text{GA}_3$  200ppm, husked seeds (34.2) had more leaves than unhusked seeds (27.6). The highest number of leaves (9.73) was observed with  $\text{GA}_3$  @200 ppm, whereas the control had the lowest number of leaves (5.77) (Muralidhara *et al.*, 2015). Patel *et al.* (2016) found that  $\text{GA}_3$  100ppm had the highest number of leaves per plant (17.90), while beejaumrit @2% had the least (13.17). Aalta and Srihari (2013) reported that  $\text{KNO}_3$  @ 0.5% had the highest number of leaves (10.10) in whole nut and extracted kernel, and the least was found in whole nut (8.50) and extracted kernel (9.00). Dawale *et al.* (2012) observed that the number of leaves per seedling was highest (14.37) after 90 days of sowing, and the control had the least number of leaves per plant (9.47) after 90 days of sowing. Reddy and Reddy (2017) reported that  $\text{KNO}_3$  @2% had the maximum number of leaves (10.9), while the control had 7.6. Kumar *et al.* (2008) found that leaf area after 30 days of sowing was highest in Amritpani 3% for 3 hours, and other treatments were at par with seeds treated with  $\text{GA}_3$  @100 ppm (6.59) and water soaking (5.66). Vidya *et al.* (2018) observed that the number of leaves recorded after 90 days of sowing was maximum in  $\text{GA}_3$  @ 250 ppm (11.28), and  $\text{GA}_3$  @ 500ppm and Salicylic acid@4ml/l were found to be at par with this treatment. The lowest number of leaves was found in seeds under control (9.07). Kolekar *et al.* (2017) reported that  $\text{GA}_3$  @ 100 ppm for 4 hours had the highest number of leaves (15.63), while seedlings under control had the lowest number of leaves (12.0). After 8 months of sowing, the maximum number of leaves per plant (29.97) was observed in cow dung slurry for 24 hours, and the least number of leaves were found in the control treatment (20.08) (Chaudhary, 2016). Parmar *et al.* (2018) found that cow dung slurry resulted in the maximum number of leaves per plant (16.95) after 120 days of sowing. In cashew, Singh *et al.* (2015) found that  $\text{GA}_3$  @ 200 ppm had the highest number of leaves per plant (13.91), while the control had the lowest number of leaves per plant (22.62).

Gurung *et al.* (2013) observed that the maximum number of leaves per plant (14.25) was recorded in GA<sub>3</sub> @ 500 ppm, and the least number of leaves per plant was found in the control treatment (9.45) after 90 days of sowing. Dilip *et al.* (2017) noted that after 120 days of sowing, the maximum number of leaves (18.89) was found in seedlings treated with GA<sub>3</sub> @ 80ppm for 12 hours, while the control had the lowest number of leaves (11.27). Pavithra *et al.* (2018) recorded that GA<sub>3</sub> @ 500 ppm resulted in the maximum number of leaves per plant (24.00), and the lowest number of leaves was recorded in seedlings treated with HCl @ 25% (13.60) after 120 days. Archana *et al.* (2015) found that the maximum number of leaves per seedling (8.66) was observed in the seeds treated with GA<sub>3</sub>@ 50 ppm, while the lowest number of leaves (6.00) was found in the control treatment after 70 days of sowing. Palepad *et al.* (2017) reported that the number of leaves was highest in seeds treated with GA<sub>3</sub> @ 1000 ppm (32.64). Rahangdale *et al.* (2019) found that the maximum number of leaves per plant (13.86) was observed after 120 days of sowing in the seedlings emerged from seeds treated with GA<sub>3</sub> 500 ppm. Ramteke *et al.* (2015) reported that the maximum number of leaves per plant (9.22) was found in seedlings treated with GA<sub>3</sub>@ 200 ppm. Manthri and Bharad (2017) found that the significantly maximum number of leaves per seedling (3.77) was observed GA<sub>3</sub> @ 1000 ppm (24 hours).

## 2.4 Leaf area:

Muralidhara *et al.* (2016) found that the mean leaf area in different mango cultivars was higher (219.2 cm<sup>2</sup>) for husked seeds, whereas the maximum mean leaf area was found to be 158.5 cm<sup>2</sup> for unhusked seeds. The maximum leaf area (101.56 cm<sup>2</sup>) was recorded in the case of husked seeds, while the area recorded in the case of non-husked seeds (53.56 cm<sup>2</sup>) treated with 0.3% KNO<sub>3</sub> was found to be lower, as reported by Abbas *et al.* (2015). Shaban (2010) reported higher leaf area in plants that originated from husked seeds (61.9 cm<sup>2</sup>) than in those that originated from non-husked seeds (55.1 cm<sup>2</sup>). Seeds treated with GA<sub>3</sub> without seed coat (68.6 cm<sup>2</sup>) were found to have more leaf area than those treated with GA<sub>3</sub> @ 200 + seed coat (60.4 cm<sup>2</sup>), as reported by Abbas *et al.* (2015). Muralidhara *et al.* (2015) recorded the maximum leaf area (226.8 cm<sup>2</sup>) in the case of GA<sub>3</sub> @ 200 ppm, which was considerably higher than the control treatment, which had an area of only 61.3 cm<sup>2</sup>. Similar results were obtained by Patel *et al.* (2016), where the highest leaf area (69.85 cm<sup>2</sup>) was found in the seedlings that were treated with thiourea @ 1%, and the least leaf area was recorded in the seedlings that were treated with beejaumrit @ 2% (60.50 cm<sup>2</sup>). Kolekar *et al.* (2017) recorded the maximum leaf area (37.89 cm<sup>2</sup>) in GA<sub>3</sub> @ 100 ppm, and the minimum leaf area was found in cow dung slurry 12 hours, which was 32.35 cm<sup>2</sup>. Chaudhary (2016) reported the maximum leaf area (176.2 cm<sup>2</sup>) in cow dung slurry for 24 hours, and the minimum leaf area was observed in the control (154.9 cm<sup>2</sup>). According to Parmar *et al.* (2018), the significantly maximum leaf area in the plant (69.58 cm<sup>2</sup>) was recorded after 120 days of sowing in the seeds treated with cow dung slurry. Singh *et al.* (2015) reported that the maximum leaf area in cashew (37.75 cm<sup>2</sup>) was obtained with GA<sub>3</sub> @200 ppm, and the smallest leaf area was recorded in the control (28.28 cm<sup>2</sup>). Harshavardhan and Rajasekhar (2012) found that the maximum leaf area per seedling was 2526 cm<sup>2</sup>, whereas the minimum recorded leaf area per seedling was found in the control (1290 cm<sup>2</sup>). The maximum leaf area of papaya seedling, as recorded by Mali *et al.* (2015), was found to be 6.67 cm and 9.78 cm at 20 and 30 days after sowing, respectively, in the Taiwan variety on treating seeds with GA<sub>3</sub> @ 500. The maximum leaf area of 76.42 cm<sup>2</sup> was recorded in the seedling that had germinated from seeds under treatment of GA<sub>3</sub> 1000 ppm. Ramteke *et al.* (2015) recorded leaf area of 44.89 cm<sup>2</sup> in seedlings arising from papaya seeds under treatment with GA<sub>3</sub> @200 ppm. Manthri and Bharad (2017) recorded the maximum leaf area (3.13 cm<sup>2</sup>) at 60 days after sowing when seeds were treated with GA<sub>3</sub> @1000.

## III. CROP VIGOUR (SEEDLING VIGOUR INDEX, FRESH WEIGHT)

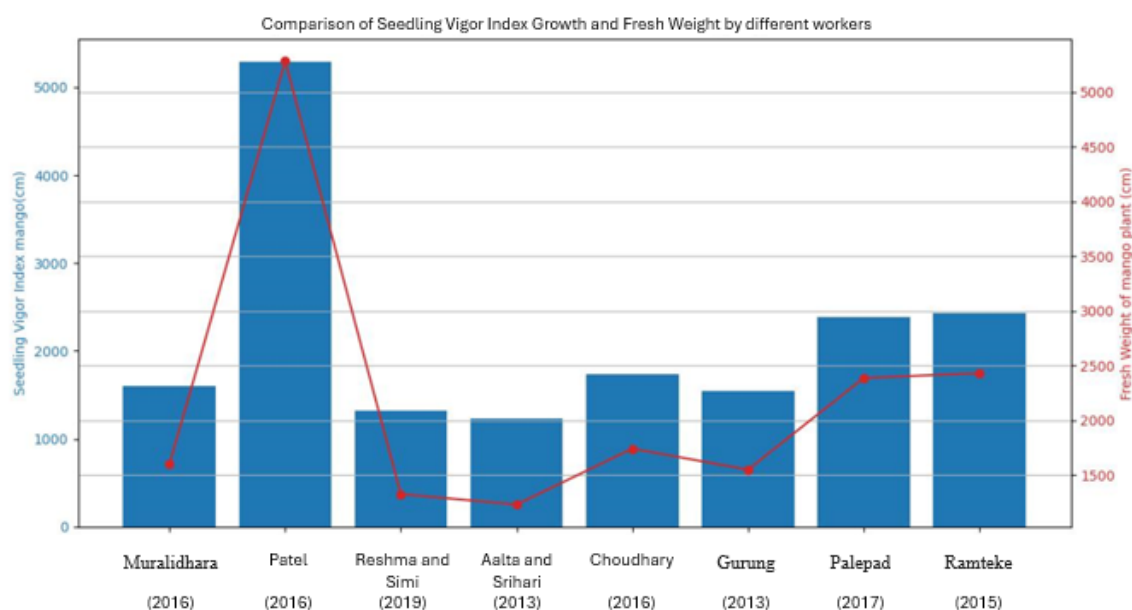
### 3.1 Assessment Seedling vigor index growth basis following pre-sowing treatments

Different pre sowing treatments have resulted in improved seedling vigor index which is an indication of improved plants growth and development. Various workers have provided favorable results of applying pre-sowing treatments. Muralidhara *et al.* (2016) found that the husked seed had a seedling vigor of 1599 cm, while the unhusked seed had a vigor of 1123.4 cm. GA<sub>3</sub> 100ppm produced the highest seedling vigor index of 1248.8 cm, and the lowest was recorded in the control treatment at 612.2 cm (Muralidhara *et al.*, 2015). Patel *et al.* (2016) reported that Thiourea 1% resulted in the highest seedling vigor at 5286.17 cm, while the lowest was found in the beejaumrit @2% treatment at 3337.16 cm. Reshma and Simi (2019) discovered that the stalk end up position had the highest seedling index at 1324.23 cm, while the flat position only had 746.93 cm. GA<sub>3</sub> @100 ppm produced the highest seedling vigor index at 1322.78 cm, and the lowest was recorded in the control treatment at 613.06 cm. Aalta and Srihari (2013) found that KNO<sub>3</sub> @0.5% resulted in the highest vigor index in the whole nut at 1227.80 cm and in the extracted kernel at 1517.30 cm. The lowest vigor index was found in the whole nut at 928.73 cm and in the extracted kernel at 1026.1 cm. Chaudhary (2016) discovered that the highest vigor was found in seedlings treated with cow dung slurry at 1739.60 cm, while the lowest vigor was recorded in the control treatment at 982.16 cm. Gurung *et al.* (2013) reported that the highest

seedling vigor index was 1547.34 cm in seeds treated with GA<sub>3</sub> @ 500 ppm, while the lowest was found in the control treatment at 404.4 cm. Palepad *et al.* (2017) found that the highest seedling vigor index was 2385.7 in seedlings treated with GA<sub>3</sub> @ 100 ppm for 24 hours. Ramteke *et al.* (2015) recorded a seed vigor index of 2430.50 in papaya seedlings using GA<sub>3</sub> @ 100 ppm, which was the highest among all other treatments.

### 3.2 Fresh weight:

Muralidhara *et al.* (2016) found that the husked seed had a seedling vigor of 1599 cm, while the unhusked seed had a vigor of 1123.4 cm. The application of GA<sub>3</sub> at a concentration of 100 ppm produced the highest seedling vigor index of 1248.8 cm. The lowest vigor was recorded in the control treatment at 612.2 cm (Muralidhara *et al.*, 2015). Patel *et al.* (2016) reported that Thiourea at a concentration of 1% resulted in the highest seedling vigor of 5286.17 cm. Meanwhile, the lowest vigor was found in the beejaumrit treatment at 2%, which recorded only 3337.16 cm. Reshma and Simi (2019) discovered that the best position for seedling growth was with the stalk end up, which had a seedling index of 1324.23 cm. In contrast, the flat position only had 746.93 cm. GA<sub>3</sub> at a concentration of 100 ppm produced the highest seedling vigor index at 1322.78 cm, whereas the control treatment had the lowest vigor at 613.06 cm. Aalta and Srihari (2013) found that KNO<sub>3</sub> @0.5 % resulted in the highest vigor index in the whole nut at 1227.80 cm and in the extracted kernel at 1517.30 cm. The lowest vigor index was found in the whole nut at 928.73 cm and in the extracted kernel at 1026.1 cm. Chaudhary (2016) discovered that the highest vigor was found in seedlings treated with cow dung slurry, which had a seedling vigor index of 1739.60 cm. In contrast, the control treatment only recorded 982.16 cm of vigor. Gurung *et al.* (2013) reported that the best vigor index was 1547.34 cm in seeds treated with GA<sub>3</sub> at a concentration of 500 ppm. Meanwhile, the control treatment had the lowest vigor index of 404.4 cm. Palepad *et al.* (2017) found that the highest seedling vigor was recorded at 2385.7 in seedlings treated with GA<sub>3</sub> at a concentration of 100 ppm for 24 hours. Ramteke *et al.* (2015) recorded the highest seed vigor index of 2430.50 in papaya seedlings, which was the highest among all other treatments.



**FIGURE 3: Year wise finding of seed vigor**

### 3.3 Mode of action:

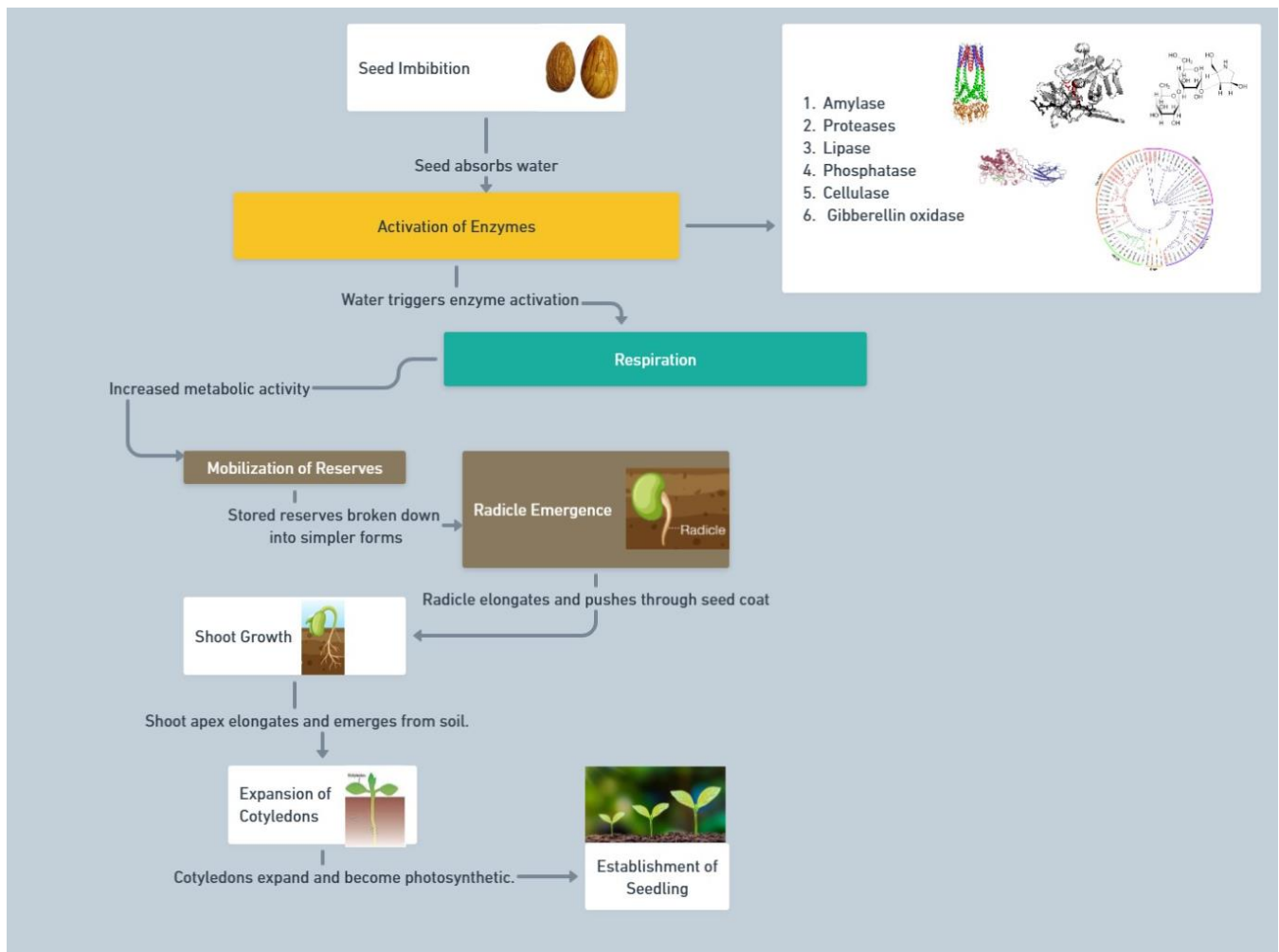
#### 3.3.1 Molecular and physiological mechanism under lying pre sowing treatment:

Pre-sowing treatments exert their effects on seeds through intricate molecular and physiological mechanisms that underlie seed germination and subsequent seedling growth. These mechanisms vary depending on the type of treatment applied and its specific mode of action. At the molecular level, pre-sowing treatments can influence gene expression patterns within seeds. For example, hormonal priming treatments, such as gibberellic acid (GA<sub>3</sub>) application, can activate specific genes involved in breaking seed dormancy and promoting germination. This activation triggers a cascade of molecular events that lead to the production of hydrolytic enzymes responsible for breaking down stored reserves in the seed, making them available for germination and early seedling growth. Physiologically, pre-sowing treatments can affect processes such as water uptake, metabolic activity, and nutrient mobilization within the seed. Osmopriming treatments, which involve soaking seeds in osmotic

solutions, facilitate water uptake by seeds, leading to increased hydration levels and activation of metabolic pathways necessary for germination. Similarly, halo-priming treatments, which utilize inorganic solutions like potassium nitrate ( $KNO_3$ ) or calcium chloride ( $CaCl_2$ ), can enhance nutrient uptake and ion balance within seeds, optimizing conditions for germination and early growth. Furthermore, pre-sowing treatments can modulate hormonal signaling pathways within seeds. Hormonal priming treatments alter the balance between different plant hormones, such as gibberellins (GA) and abscisic acid (ABA), which play crucial roles in regulating seed dormancy and germination. By influencing hormone levels, pre-sowing treatments can orchestrate physiological responses that promote germination and seedling vigor.

### 3.3.2 Interaction with plant hormone and signaling pathway:

Pre-sowing treatments can significantly impact the interaction with plant hormone signaling pathways, thereby influencing seed germination and subsequent plant growth. For instance, hormonal-priming treatments involve the application of hormone solutions to seeds, which can modulate hormone levels within the seed and interact with various signaling pathways.



**FIGURE 4: Mechanism of seed germination**

Seed priming with IAAs enhances cell division, photosynthetic activities, and translocation of carbohydrates, which results in lateral root initiation, flowering, and good stand establishment. Seed priming with IAAs enhances cell division, photosynthetic activities, and translocation of carbohydrates, which results in lateral root initiation, flowering, and good stand establishment. (MacDonal 1997; Naeem *et al.*, 2004) Gibberellic acid ( $GA_3$ ), a commonly used hormone in seed priming, can stimulate the expression of genes involved in germination by promoting cell elongation and breaking seed dormancy (Ge *et al.*, 2023; Rao *et al.*, 2019; Zahang *et al.*, 2024). Additionally, hormone treatments may interact with abscisic acid (ABA), another crucial hormone involved in seed dormancy regulation. By modulating the balance between  $GA_3$  and ABA levels, pre-sowing treatments can regulate downstream signaling pathways, such as those involved in reactive oxygen species (ROS) production,  $Ca^{2+}$  signaling, and gene expression. These interactions ultimately influence processes like seed imbibition, embryo growth, and radicle emergence, contributing to improved seed germination and seedling vigor.

### 3.3.3 Influence on gene expression related to germination and growth:

Pre-sowing treatments exert a significant influence on gene expression related to germination and growth processes in seeds. These treatments can modulate the expression of specific genes involved in various physiological pathways essential for seed germination and subsequent seedling growth. For instance, hormonal priming treatments, such as gibberellic acid (GA<sub>3</sub>) application, can trigger the upregulation of genes associated with cell elongation, cell division, and nutrient mobilization within the seed. GA<sub>3</sub> activates specific transcription factors that regulate the expression of genes involved in breaking seed dormancy and promoting germination. This includes genes encoding hydrolytic enzymes responsible for breaking down stored reserves such as starch and proteins into forms that can be readily utilized by the growing embryo. Similarly, other pre-sowing treatments like osmopriming and halo-priming can also influence gene expression patterns. Osmopriming treatments involve soaking seeds in osmotic solutions, which can induce the expression of genes involved in stress tolerance and osmotic regulation. These genes help seeds cope with environmental stresses such as drought or salinity during germination and early seedling establishment.

## IV. CHALLENGE AND FUTURE PROSPECTS

Pre-sowing treatments play a vital role in optimizing nursery practices for fruit crop production, especially in addressing the pressing need for increased planting material, such as grafts. With the demand for fruit crops steadily rising, nursery managers face the challenge of producing sufficient rootstocks with graftable sizes within shorter timeframes. To expedite this process, accelerating seed germination and seedling growth becomes imperative, making pre-sowing treatments a cornerstone of efficient nursery management. These treatments are not only crucial for meeting the immediate demands of nursery production but also contribute significantly to broader agricultural objectives. They play essential roles in various aspects of fruit crop cultivation, including propagation techniques, breeding programs, and germplasm evaluation. By enhancing germination rates and promoting robust seedling growth, pre-sowing treatments facilitate the timely development of healthy and vigorous planting material, which is essential for achieving optimal yields and maintaining orchard productivity. The effectiveness of pre-sowing treatments transcends individual fruit species, encompassing a wide array of crops in the fruit production sector. Whether it's accelerating the germination of mango, papaya, citrus, or aonla seeds, these treatments have consistently demonstrated their efficacy in fostering rapid and uniform seedling establishment. Consequently, their integration into nursery management practices has become increasingly prevalent, reflecting their indispensable role in modern fruit crop production systems. In a nut shell, pre-sowing treatments represent a cornerstone of nursery management in fruit crop production, offering a pragmatic solution to the challenges posed by increasing demand and time constraints. By expediting seed germination and enhancing seedling growth, these treatments not only optimize nursery operations but also contribute to broader agricultural goals, ensuring the sustainable supply of high-quality planting material for fruit growers worldwide.

## V. CONCLUSION

Pre-sowing treatments have proven to be valuable tools for enhancing seed germination and seedling growth in fruit crop production. By overcoming challenges like dormancy and germination inhibitors, these treatments significantly improve nursery practices and ultimately lead to increased yields. Various techniques, including chemical treatments, growth regulators, and biological inoculants, have demonstrated effectiveness in promoting seed germination and seedling vigor. Hormonal priming, particularly with gibberellic acid, has been particularly effective in reducing germination time and increasing germination percentages. Additionally, pre-sowing treatments have been shown to positively impact seedling height, diameter, and the number of leaves, resulting in healthier and more robust seedlings. However, the effectiveness of these treatments can vary depending on the specific fruit crop species, emphasizing the need for tailored approaches. Future research should focus on understanding the underlying mechanisms, long-term effects, and the development of innovative treatment methods. Overall, pre-sowing treatments offer promising avenues for improving fruit crop production and ensuring sustainable agricultural practices.

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