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# Influence of PGRs and Chemicals on Seed Germination and Seedling Growth of Apple (*Malus* × *domestica* Borkh) var. Golden Delicious

**Ishu Nautiyal[1] • Manju[1] • Subham Kandwal[1*] • Anita Panwar[1]**

[1]*Department of Fruit Science, Veer Chandra Singh Garhwali, Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand*

*Corresponding Author Email Id: *subhamkandwal@gmail.com*

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**Abstract:** Apple (*Malus* × *domestica* Borkh.) is an important temperate fruit crop widely cultivated in the Himalayan regions of India, where uniform and vigorous seedling rootstocks are essential for successful orchard establishment. Among the various cultivars grown in India, Golden Delicious is a widely cultivated, diploid apple cultivar known for its attractive yellow skin, sweet–mild flavour and fine-textured, juicy flesh. The fruits are medium to large in size with good keeping quality, while the cultivar is highly valued in nurseries for producing vigorous seedling rootstocks. The present study was conducted to enhance the seed germination and seedling growth of apple using various concentrations of plant growth regulators. The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising ten treatments with three replications. The results revealed that pre-sowing seed treatment with $GA_3$ at 500 ppm exhibited superior performance over all other treatments by recording the minimum days to initial germination (91.00 days), maximum germination percentage (65.56%), survival percentage (74.41%), seedling length (20.74 cm), shoot diameter (4.04 mm), number of leaves (16.33), root length (12.70 cm), shoot fresh and dry weight (5.59 g and 3.29 g), root fresh and dry weight (1.75 g and 0.92 g) and total fresh and dry biomass (7.34 g and 4.03 g). The maximum seedling moisture content (84.93%) was observed with thiourea at 10,000 ppm. Thus, $GA_3$ at 500 ppm can be recommended for improving seed germination and raising vigorous apple seedlings under nursery conditions.

**Keywords:** Apple • Golden Delicious • Gibberellic acid ($GA_3$) • Nursery management • Seed germination

## Introduction

Apple (*Malus* × *domestica* Borkh.) is one of the leading temperate fruit crops of global importance, originating from Central Asia, where *Malus sieversii* is considered its wild progenitor. It belongs to the Rosaceae family, genus *Malus*, with a chromosome number 2n = 34. Apple is a deciduous tree with simple oval leaves and brown scaly bark at maturity. The fruits are highly nutritious and rich in carbohydrates, dietary fiber, vitamin C, potassium and organic acids, particularly malic acid, which contributes to fruit flavour and digestive health (Ali *et al* 2004; Campeanu *et al* 2009). In India, apple cultivation was introduced during the British period and is mainly grown in the temperate and high-altitude regions of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. The Delicious group of cultivars was introduced from the USA and first planted in the Kullu valley of Himachal Pradesh in 1887. Later, these cultivars were introduced to the Shimla hills in 1916 (Kumar and Kamra 2018).

Apple is commercially propagated through budding and grafting, whereas seed propagation is mainly used for raising rootstocks. Apple rootstocks are broadly classified into seedling and clonal types. For successful germination, apple seeds require stratification at 3-5 ˚C for 60-120 days to overcome dormancy, which is common practice for raising seedling rootstocks and hybrid populations. Seedling rootstocks are generally produced from seeds of diploid cultivars such as Golden Delicious, developed by Anderson Mullins, West Virginia, USA in 1890, with yellow- green skin, tender texture and mild sweet flavor. These rootstocks are widely used but exhibit considerable variability in growth and productivity, which influences scion performance (Chadha 2010). In contrast, clonal rootstocks propagated vegetatively show uniform growth and performance. Despite their variability, seedling rootstocks develop a deep and extensive root system that provides strong anchorage, efficient absorption of water and nutrients and better acclimatization under diverse environmental conditions. Moreover, rootstocks significantly influence tree vigour, production efficiency, yield quality, adaptability, greater tolerance to drought, waterlogging and resistance to biotic and abiotic stresses than clonal rootstocks.

Seeds of apple are incompetent of germinating at the time of harvest, post-harvesting period and after removing from fruit flesh because they remain in different dormant states, including deep physiological endogenous dormancy, embryonic dormancy, testa-imposed dormancy and thermo-dormancy (Geneve 2003; Militaru *et al* 2010; Lewak 2011). Seed dormancy is defined as a condition in which seeds fail to germinate despite the presence of favourable environmental conditions such as adequate moisture, temperature and aeration (Nikolaeva 1977; Bewley and Black 1994; Hartmann *et al* 1997). Consequently, various physical, chemical and physiological approaches have been developed and employed to overcome seed dormancy.

To overcome seed dormancy and enhance germination percentage as well as the production of vigorous and healthy seedlings, various plant growth regulators are widely used, including gibberellic acid, potassium nitrate and thiourea. Gibberellic acid plays an important role in breaking seed dormancy and promoting seed germination by stimulating the synthesis of α-amylase in the aleurone layer, which converts stored starch into simple sugars required for embryo growth. It also enhances cell division, internodal elongation, leaf expansion and overall seedling vigour (Ghosh and Haldar 2018). Potassium nitrate ($KNO_3$) enhances germination by improving membrane permeability and activating enzymes associated with protein synthesis and carbohydrate metabolism, thereby stimulating metabolic activity essential for germination (Nasri *et al* 2014; Vidal *et al* 2018). Thiourea has also been reported to improve germination, seedling growth and stress tolerance when used as a seed treatment (Boakar and Gaikwad 2020).

The present study emphasizes the research significance of chemical interventions in overcoming seed dormancy and improving seedling vigour in Golden Delicious, a widely used seedling rootstock cultivar. Standardization of such treatments can contribute to efficient nursery management, production of healthy rootstocks and sustainable apple cultivation under temperate conditions.

## Materials and Methods

The present investigation was conducted during 2021–2022 at the naturally ventilated polyhouse of Fruit Nursery, Department of Fruit Science, College of Horticulture, VCSG Uttarakhand University of Horticulture and Forestry, Bharsar, Pauri Garhwal, Uttarakhand. Mature fruits of apple (*Malus* × *domestica* Borkh.) cv. Golden Delicious were collected and seeds were manually extracted and washed under running water. The seeds were separated by using a flotation test, in which light-weight, non-viable seeds floated and were discarded, while seeds that settled at the bottom of the bucket, were considered viable and used for direct sowing.

The experiment consisted of ten treatments with three replications arranged in a Randomized Complete Block Design (RCBD). Treatments included $GA_3$ (250, 500 and 750 ppm), $KNO_3$ and thiourea (5000, 7500 and 10000 ppm) and distilled water as a control. $GA_3$ solutions were prepared using a few drops of 95% ethyl alcohol followed by dilution with distilled water, while $KNO_3$ and thiourea were dissolved directly in distilled water. Apple seeds were soaked for 24 hours in the respective treatment solutions and control seeds were soaked in distilled water. Treated seeds were sown in pro-trays under polyhouse conditions. The growing medium consisted of soil, FYM, sand and cocopeat mixed in a 1:1:1:1 ratio. Five plants are randomly selected from each treatment in every replication for recording observations. Parameters such as days taken for initial germination, germination percent, survival percent, shoot length, shoot diameter, number of leaves per plant, root length, shoot and root fresh and dry weights and total fresh and dry seedling weights were recorded 180 days after seed sowing. The experimental data were analyzed using MS-Excel and OPSTAT software.

## Result and Discussion

### Germination Parameters

Pre-sowing treatments and plant growth regulators significantly influenced the number of days to initial germination, germination per cent and survival per cent. Among all treatments, $GA_3$ 500 ppm performed best across all germination parameters, with days taken for initial germination (91.00 days), the highest germination per cent (65.55%) and the maximum survival per cent (74.40%). The delayed germination observed during December to February may be attributed to the prevailing low temperature conditions (1 to –4 °C), which likely restricted metabolic and enzymatic activities necessary for embryo growth and radicle emergence. Germination commenced only after the onset of favourable environmental conditions in March, indicating that temperature played a crucial role in overcoming physiological dormancy and activating seed metabolism (Fig 1).

**Fig 1.** Growth stages at different intervals: (a) 90 DAS, (b) 92 DAS, (c) 94 DAS, (d) 120 DAS, (e) 150 DAS, and (f) 180 DAS. *(DAS = Days After Sowing)*

The superior performance of $GA_3$-treated seeds may be associated with the well-established physiological role of gibberellic acid in dormancy breaking and germination enhancement. $GA_3$ promotes the synthesis and activation of hydrolytic enzymes, particularly α-amylase, which catalyses the conversion of stored starch reserves into soluble sugars required for embryo respiration and growth. Enhanced mobilization of food reserves increases metabolic activity, accelerates cell elongation and stimulates radicle emergence, thereby reducing the time required for germination. $GA_3$ also reduces the inhibitory effect of abscisic acid (ABA), which is generally responsible for maintaining seed dormancy under unfavourable conditions. The improved germination and survival observed under $GA_3$ application may also be linked to enhanced membrane permeability, greater water uptake and increased protein synthesis, all of which collectively support vigorous seedling establishment and acclimatization (Table 1).

**Table 1. Effect of $GA_3$, $KNO_3$ and Thiourea on germination parameters of Apple var. Golden Delicious**

| Treatment details | Days taken for initial germination | Germination per cent (%) | Survival per cent (%) |
|---|---|---|---|
| Control | 129.00 | 26.67 | 44.01 |
| $GA_3$@ 250 ppm | 98.33 | 61.11 | 65.45 |
| $GA_3$@ 500 ppm | 91.00 | 65.55 | 74.40 |
| $GA_3$@ 750 ppm | 102.00 | 63.33 | 68.26 |
| $KNO_3$ @ 5,000 ppm | 101.00 | 55.56 | 65.72 |
| $KNO_3$ @ 7,500 ppm | 115.33 | 58.89 | 69.69 |
| $KNO_3$ @ 10,000 ppm | 113.66 | 54.44 | 67.49 |
| Thiourea @ 5000 ppm | 125.00 | 31.11 | 50.86 |
| Thiourea @ 7,500 ppm | 128.00 | 28.89 | 53.29 |
| Thiourea @ 10,000 ppm | 127.66 | 34.44 | 51.48 |
| $SE_{(d)}$ | 7.87 | 5.31 | 5.10 |
| C.D.(0.05) | 16.67 | 11.24 | 10.81 |

The higher survival percentage recorded in $GA_3$-treated seedlings further suggests that early and uniform germination produced more vigorous seedlings capable of better adaptation under ventilated polyhouse conditions. Enhanced seedling vigour may have contributed to improved root and shoot development, thereby reducing mortality during the early establishment phase (Lalitha *et al*., 2020; Rawat *et al*., 2023; Anagha *et al*., 2024).

**Growth Parameters**

Among the various treatments, maximum shoot length (20.744 cm) and shoot diameter (4.036 mm) were recorded under treatment $T_3$ ($GA_3$ 500 ppm), indicating its strong promotive effect on overall seedling vigour. The enhanced vegetative growth observed under $GA_3$ treatment may be attributed to its role in stimulating cell division, cell elongation and rapid differentiation of meristematic tissues. Gibberellic acid enhances stem elongation by increasing cell wall extensibility and promoting internode elongation, thereby facilitating greater shoot development. Simultaneously, improved cambial activity and vascular differentiation under $GA_3$ application may have contributed to increased shoot thickness and efficient translocation of water and nutrients within the seedlings (Wani *et al* 2014; Rahangdale *et al* 2019; Lalitha *et al* 2020).

The maximum number of leaves per seedling (16.333) was recorded under treatment $T_3$. This enhancement may result from increased metabolic activity and physiological regulation induced by $GA_3$. Gibberellic acid is known to promote chlorophyll synthesis, protein metabolism and nucleic acid activity, which collectively improve photosynthetic efficiency and support rapid vegetative development. Enhanced mobilization of stored food reserves and efficient assimilate partitioning towards actively growing regions may have further accelerated leaf initiation and expansion (Wani *et al*., 2014; Rahangdale *et al*., 2019; Rawat *et al*., 2023).

Moreover, the maximum root length (12.7 cm) was recorded under ($GA_3$ 500 ppm), which indicates better root establishment and nutrient absorption capacity. The stimulatory effect of $GA_3$ on root growth may be associated with enhanced enzymatic activity and increased osmotic uptake of water and nutrients, resulting in greater cell elongation in root tissues (Table 2). A well-developed root system likely supported vigorous shoot growth and improved overall seedling establishment (Wani *et al* 2014; Singh *et al* 2017; Anagha *et al* 2024).

**Table 2. Effect of $GA_3$, $KNO_3$ and Thiourea on growth parameters of Apple var. Golden Delicious**

| Treatment details | Shoot length (cm) | Shoot diameter (mm) | Number of leaves | Root length (cm) |
|---|---|---|---|---|
| Control | 8.54 | 1.64 | 8.33 | 7.92 |
| $GA_3$@250 ppm | 12.96 | 2.89 | 15.44 | 9.21 |
| $GA_3$@ 500ppm | 20.74 | 4.03 | 16.33 | 12.70 |
| $GA_3$@ 750ppm | 16.42 | 3.32 | 13.33 | 10.55 |
| $KNO_3$ @5000 ppm | 14.93 | 3.09 | 12.11 | 10.87 |
| $KNO_3$ @ 7,500 ppm | 12.86 | 2.88 | 14.22 | 10.20 |
| $KNO_3$ @10,000 ppm | 11.24 | 2.77 | 11.00 | 11.67 |
| Thiourea @5000 ppm | 11.53 | 2.11 | 11.66 | 10.96 |
| Thiourea @ 7,500 ppm | 12.60 | 2.00 | 13.66 | 9.20 |
| Thiourea @10,000 ppm | 9.32 | 2.71 | 15.88 | 9.14 |
| $SE_{(d)}$ | 2.40 | 0.41 | 1.32 | 1.24 |
| $C.D._{(0.05)}$ | 5.09 | 0.87 | 2.79 | 2.64 |

Moreover, the maximum root length (12.7 cm) was recorded under ($GA_3$ 500 ppm), which indicates better root establishment and nutrient absorption capacity. The stimulatory effect of $GA_3$ on root growth may be associated with enhanced enzymatic activity and increased osmotic uptake of water and nutrients, resulting in greater cell elongation in root tissues (Table 2). A well-developed root system likely supported vigorous shoot growth and improved overall seedling establishment (Wani *et al* 2014; Singh *et al* 2017; Anagha *et al* 2024).

**Biomass and Total Biomass**

Gibberellic acid significantly influenced biomass accumulation in apple seedlings. Among the different concentrations of gibberellic acid, the maximum shoot fresh weight (5.588 g), root fresh weight (1.748 g), shoot dry weight (3.289 g), root dry weight (0.923 g), total fresh weight (7.336 g) and total dry weight (4.038 g) were recorded under the treatment $T_3$ ($GA_3$ 500 ppm). The increased accumulation of fresh and dry weight under $GA_3$ treatment may be attributed to enhanced metabolic activity, efficient mobilization of reserve food materials and improved translocation of assimilates towards actively growing tissues. Gibberellic acid promotes cell division and elongation, which increases vegetative growth and consequently enhances biomass production in both shoots and roots. In addition, $GA_3$-mediated activation of hydrolytic enzymes may have accelerated the conversion of stored reserves into soluble metabolites required for continuous growth and biomass production.

The higher root fresh and dry weight under $GA_3$ application may further be linked to enhanced root initiation, root elongation and development of secondary and fibrous roots. Gibberellic acid possibly increased endogenous auxin activity in root tissues, thereby improving nutrient absorption capacity and translocation efficiency within the seedlings. A more developed root system likely supported greater uptake of water and minerals, which in turn enhanced shoot growth and overall seedling vigour. The coordinated enhancement of physiological and biochemical processes under $GA_3$ treatment ultimately resulted in significantly higher biomass accumulation (Rawat *et al* 2023).

The comparatively poor performance observed at higher $GA_3$ concentration (750 ppm) indicates that excessive application of gibberellic acid may negatively affect normal seed metabolism and seedling growth (Table 3). Higher concentrations of $GA_3$ possibly caused hormonal imbalance and excessive utilization of stored food reserves during germination, resulting in reduced seedling vigour and growth. Higher concentrations may also have disturbed endogenous auxin–gibberellin interactions and adversely affected coordinated root and shoot development. These findings suggest that the response of apple seeds to $GA_3$ is concentration-dependent and that application beyond the optimum threshold may become inhibitory rather than stimulatory (Ma *et al* 2018).

**Table 3. Effect of $GA_3$, $KNO_3$ and Thiourea on shoot and root fresh and dry weight and total fresh and dry weight of seedlings**

| Treatment details | Shoot fresh weight (g) | Shoot dry weight (g) | Root fresh weight (g) | Root dry weight (g) | Total fresh weight (g) | Total dry weight (g) |
|---|---|---|---|---|---|---|
| Control | 0.33 | 0.11 | 0.26 | 0.05 | 0.72 | 0.26 |
| $GA_3$@250 ppm | 1.84 | 1.14 | 0.95 | 0.62 | 2.79 | 1.77 |
| $GA_3$@ 500 ppm | 5.58 | 3.28 | 1.74 | 0.92 | 7.33 | 4.03 |
| $GA_3$@ 750 ppm | 1.94 | 0.40 | 0.55 | 0.53 | 2.49 | 0.94 |
| $KNO_3$ @5000 ppm | 2.90 | 1.73 | 1.54 | 0.84 | 4.44 | 2.58 |
| $KNO_3$ @ 7,500 ppm | 1.24 | 0.64 | 1.35 | 0.74 | 2.59 | 1.08 |
| $KNO_3$ @10,000 ppm | 3.65 | 1.76 | 1.64 | 0.44 | 5.29 | 2.68 |
| Thiourea @5000 ppm | 0.77 | 0.31 | 0.84 | 0.34 | 1.61 | 0.66 |
| Thiourea @ 7,500 ppm | 1.41 | 1.15 | 0.74 | 0.15 | 1.47 | 1.07 |
| Thiourea @10,000 ppm | 0.46 | 0.26 | 0.75 | 0.32 | 2.16 | 0.32 |
| SE (d) | 0.07 | 0.15 | 0.01 | 0.01 | 0.05 | 0.15 |
| C.D. (0.05) | 0.16 | 0.32 | 0.02 | 0.02 | 0.16 | 0.32 |

## Conclusion

The findings of the present investigation indicate that pre-sowing treatment with $GA_3$ at 500 ppm can be effectively utilized for the production of vigorous, uniform and healthy apple rootstock seedlings under nursery conditions, particularly in temperate regions where low temperatures and physiological seed dormancy often delay germination. The treatment significantly improved germination, seedling establishment, vegetative growth and biomass accumulation, thereby enhancing overall nursery efficiency and the quality of planting material for large-scale propagation. However, further investigations are required to standardize the optimum concentration of $GA_3$ across different apple cultivars, growing environments and storage conditions. In addition, future studies focusing on the physiological mechanisms associated with dormancy release and seedling vigour may provide deeper insights into $GA_3$-mediated responses and strengthen the practical applicability of these findings for commercial nursery production.

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