Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

Special Issue 2022, Volume 35, Page 44-52

Effect of Gibberellic Acid on Germination and Growth Responses of Pummelo Seedlings under Eastern Himalayan Foothills

Bidyarani Devi Senjam[1] • Nilesh Bhowmick[1*] • Prodyut Kr. Paul[1] • Sarad Gurung[2] • Amarendra Nath Dey[3]

[1]Department of Pomology and Post Harvest Technology, [2] Regional Research Station, Hill Zone, Kalimpong,
[3]Dept. of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar- 736165, West Bengal

ARTICLE INFO

Article history:
Received: 07 June, 2022
Revision: 13 June, 2022
Accepted: 26 July, 2022

Key words: Pummelo, gibberellic acid, germination, growth

DOI: 10.56678/iahf-spl2022.7

ABSTRACT

The research was conducted at Uttar Banga Krishi Viswavidyalaya, Cooch Behar district of West Bengal, under eastern Himalayan foothills during the year 2019–2020. This trial was aimed to evaluate the effect of seed treatment of pummelo with varying concentrations of gibberellic acid (GA_3) on germination and successive growth behaviour of seedlings. Seven treatments were employed *viz.*, Control, 50 ppm GA_3, 100 ppmGA_3, 150 ppm GA_3, 200 ppm GA_3, 250 ppm GA_3 and 300 ppm GA_3 and each treatment was replicated three times. All treatments significantly performed better as compared to control. According to the results obtained, treatment with 300 ppm GA_3 was found to be superior among all the treatments with highest germination percentage (98.33 %), germination value (5.30), shortest minimum days to germination (18.83), mean germination time (27.95), maximum number of leaves (13.67), number of roots (29.00), shoot length (26.33 cm), root length (21.40 cm), seedling length (47.73 cm), seedling vigour index (4693.90), fresh root weight (1.80 g), fresh shoot weight (1.33 g), fresh leaf weight (3.67 g), dry root weight (0.77 g), dry shoot weight (0.52 g), dry leaf weight (0.96 g), root:shoot ratio (0.52) and total biomass (2.25 g plant^{-1}). Therefore, pre-sowing treatment of pummelo seeds with 300 ppm GA_3 may be recommended to the growers to enhance germination and growth of seedlings leading to the production of vigorous plants which can be utilized in crop improvement programme as well as rootstock studies.

1. Introduction

Pummelo [*Citrus grandis* (L.) Osbeck] belonging to the family Rutaceae is regarded as the citrus species bearing largest fruit. It is indigenous to Malayan and East Indian Archipelago and is now cultivated in many tropical and semi- tropical countries. This fruit is also commonly known as *Batabi, Rabab, Papanas, Chakotra* or *Shaddock* (Uzun and Yesiloglu 2012; Chattopadhyay 2007). Typically, the fruit is around 15–25 cm in diameter, usually weighing 1–2 kg, pale green to yellow when ripe with sweet white or pink flesh, thick albedo and distinctly winged leaf petioles.

Pummelo has numerous health benefits owing to the presence of different bio-active substances such as ascorbic acid, vitamin B complex, phenol, pectin, carotenoids, coumarins, tannin, lycopene, dietary fibre, naringin and other flavonoids in various parts of the fruit (Gupta *et al.*, 2021; Tocmo *et al.*, 2020; Nishad *et al.*, 2018). Naringin, hesperidin, neohesperidin and naringenin extract of pummelo possess antiglycation properties for preventing diabetic complications (Caengprasath *et al.*, 2013). The peel of white variety of pummelo is a potential source of natural antioxidants (Toh*et al.*, 2013). Ethanolic extract of pummelo seeds and pulp is reported to have antimicrobial effect, which makes it a natural preservative ingredient for food and cosmetic (Sahlan *et al.*, 2018).

Since pummelo is monoembryonic in nature, the resulting seedling is not true to type to the mother plant. So, it is commonly propagated vegetatively by air layering or budding (Sharaf *et al.*, 2016). However, sexual propagation through seed is highly essential in performing a successful crop improvement work and study of rootstocks. Pummelo seeds are usually large, plump, pale yellowish white, flattened and angular. Since citrus seeds are recalcitrant in nature, they are best to be sown immediately after extraction

*Corresponding author: nilesh@ubkv.ac.in

from fully ripe fruits to avoid from moisture loss. The germination and growth rate of citrus seeds are very slow which hinders the process of hybridization (Khopkar *et al.*, 2017).

Gibberellic acid is a phytohormone which is essential for various plant development processes, including seed germination (Cornea-Cipcigan*et al.*, 2020; Ma *et al.*, 2018; Urbanova andLeubner-Metzger 2018), leaf expansion, stem elongation (Oh *et al.*, 2015; Oh and Kim 2014), root proliferation, pollination, flower induction and fruit development (Alshakhaly and Qrunfleh 2018; Vishal and Kumar 2018; Amin *et al.*, 2017; Dong *et al.*, 2017). It is well known for its role in promoting enzymes gene expression that helps in the movement of reserved food materials stored in the endosperm (starch, protein and lipids) thereby enhancing the biological yield of the plant (Mayur *et al.*, 2022). It is also widely applied to break dormancy of seed and facilitate germination by activating embryo growth, mobilization of photosynthates and weakening of the endosperm layer (Pallaoro *et al.*, 2016; Baskin and Baskin 2014).

The effect of GA_3 has been studied in different fruit crops including guava (Hosseini *et al.*, 2020; Brijwal and Kumar 2013), papaya (Anjanawe *et al.*, 2013), apple (Grzesik*et al.*, 2017), loquat (Al-Hawezy 2013), jackfruit (Maiti *et al.*, 2003) etc. Several researchers have reported that pre sowing treatment of citrus seeds with gibberellic acid (GA_3) promotes better germination and uniform growth of seedlings (Dilip*et al.,* 2017; Khopkar*et al.*,2017; Sharaf *et al.*,2016;) but very few papers were found where effect of GA_3 on pummelo seed germination was studied. Therefore, the present trial was conducted with an attempt to shorten the duration taken for seed germination as well as enhance the growth of pummelo seedlings in response to different concentrations of GA_3 treatments.

2. Materials and Methods

The experiment was performed during the year 2019-2020 under net house condition of Department of Pomology and Post-Harvest Technology at Uttar Banga Krishi Viswavidyalaya, Cooch Behar district, West Bengal, India. Geographically the district lies in the foothills of the eastern Himalayas and is located at 28°58'86" N latitude, 81°66'73" E longitude at an elevation of 42 m above mean sea level. The experiment was laid out in Complete Randomized Design (CRD) with seven treatments each replicated thrice. The seven treatments employed were: T_1 (Control), T_2 (50 ppm GA_3), T_3 (100 ppmGA_3), T_4 (150 ppmGA_3), T_5 (200 ppm GA_3), T_6 (250 ppm GA_3) and T_7 (300 ppmGA_3).

The seeds were extracted from fully matured and ripe fruits collected from the college campus and washed properly with tap water followed by soaking them in different concentrations of $GA_3$for overnight. On the next day, the treated seeds were sown in polybags filled with homogeneous mixture of soil:FYM (1:1) and irrigated lightly thereafter. In total, 100 seeds were sown in each replication. The seeds were irrigated whenever necessary and observed periodically for any sign of seed germination and data was recorded. Four months after germination, ten representative seedlings were selected from each replication of a treatment to measure seedling growth parameters. A total of 18 parameters were evaluated under this experiment. Germination percentage and seedling growth parameters like seedling length (cm), fresh weight (g), dry weight (g) and total biomass (g plant^{-1}) were recorded according to ISTA, 1999. The parameters recorded are listed below:

1. Germination Percentage (%)

$$= \frac{\text{Total number ofseeds germinated}}{\text{Total number ofseeds sown}} \text{ X } 100$$

2. Germination value (GV) = It is a composite value that includes both total germination and germination speed. It was calculated using the formula given by Djavanshir and Pourbeik (1976).

$GV = (\sum DGS/N)\ GP/10$

where, GP= germination percentage at the end of the test,

DGS= daily mean germination speed obtained by dividing the cumulative germination percentage by the number of days since sowing,

$\sum$DGS= the total germination obtained by adding every DGS value obtained from the daily counts,

N= the total number of daily counts starting from the date of first germination.

3. Minimum days to germination: Number of days taken for the first seed to germinate was noted.

4. Mean germination time (MGT): The total time period taken to accomplish germination was recorded as MGT following Bonner (1983) and Phartyal *et al.* (2001) as given below:

$MGT = \sum(\text{Daily germination} \times \text{Days})/\text{Number of seeds sown}$

Un-germinated seeds at the end of the test were given values of n+1, where n= number of days in the test.

5. Number of leaves: Total number of leaves per plant was noted.

6. Number of secondary roots: Total number of secondary roots per plant was recorded.

7. Length of primary root (cm): Length of root was measured from the tip to the base of the tap root by using a scale.

8. Shoot length (cm): Length of the shoot was measured from the tip to the base of the seedling by using a scale.

9. Seedling length (cm) = Shoot length (cm) + Length of primary root (cm)

10. Seedling Vigour Index (SVI) = Germination (%) x Seedling length (cm) (Abdul-Baki and Anderson 1973)
11. Fresh root weight (g): Fresh root weight per plant was determined using a precision weighing balance after washing and drying the roots properly with filter paper.
12. Fresh shoot weight (g): Fresh weight of the shoot portion was measured using a precision weighing balance.
13. Fresh leaf weight (g): The total fresh leaf weight per plant was measured using a precision weighing balance.
14. Dry root weight (g): Roots were detached from the stem, washed and kept in hot air oven at 60 ^{0}C to 65 ^{0}C until a constant value was obtained and then weighed using a precision weighing balance.
15. Dry shoot weight (g): Shoot portion was detached and dry weight was noted as mentioned above.
16. Dry leaf weight (g): Leaves were detached and dry weight was noted as mentioned above.
17. Root:Shoot ratio= $\frac{\text{Dry weight of root}}{\text{Dry weight of top portion of plant}}$ (Racey *et al.*, 1983)
18. Total biomass (g plant^{-1}) = Dry root weight (g) + Dry shoot weight (g) + Dry leaf weight (g)

Observations recorded during the experiment were subjected to the statistical analysis of variance for Complete Randomized Design (CRD). Significance and non-significance of the variance due to different treatments were governed by determining the respective 'F' values based on the method given by Gomez and Gomez (2010).

3. Results and Discussion

3.1. Seed germination

The results shown in Table 1 revealed that GA_3 treatments significantly improved all the germination parameters. Highest germination percentage of 98.33 % was found in treatment 300 ppm GA_3 and lowest was found in control (93.50 %). Initiation of seed germination was earliest (18.83 days) in 300 ppm GA_3 treated seeds while it started at 28.00 days in control. Mean germination time (MGT) was minimum in 300 ppm GA_3 (27.95) as compared to control (37.99). Germination value (GV) was also found to be highest in 300 ppm GA_3 (5.30) whereas it was lowest in control (3.78). The accelerated and improved germination in this treatment may be due to the role of exogenous GA_3 in enhancing various aspects of germination.

During germination, GA_3 can promote embryo growth and facilitate radicle protrusion through the seed coat (Sun 2008) by overcoming the inhibitory effects of the seed coat and abscisic acid-related embryo dormancy on seed germination (Groot and Karssen 1987; Debeaujon and Koornneef 2000). The advance germination of seeds may also be due to the role of GA_3 in facilitating enzyme activities thereby enhancing the production of food reserves for growth and emergence of the embryo (Mayur *et al.*, 2022). GA_3 also provides better water absorption and cell growth by stimulating transmission of calcium from cell wall to the cytoplasm (Al-Hawezy 2013). Improvement in germination of seeds with the application of GA_3 has also been reported by Hosseini *et al.* (2020) in guava, Dilip *et al.* (2017) in Rangpur lime, Joshi *et al.* (2015) and Kalalbandi *et al.* (2003) in acid lime, Khopkar *et al.* (2014) in pummelo, Al-Hawezy (2013) in loquat, Anburani and Shakila (2010) in papaya and Maiti *et al.* (2003) in jackfruit.

3.2. Seedling growth

Data in Table 1 and Table 2 shows that numbers of leaves, number of roots, shoot length, root length and seedling length were significantly increased by different treatments. Highest number of leaves was observed in 300 ppm GA_3 treatment (13.67) while the lowest was recorded in control (8.00). Highest number of leaves in this treatment may be because of the effect of GA_3 in promoting cell division and cell elongation which leads to the increase development of young leaves (Salisbury and Ross, 1988). Pararell results were also reported by Dilip *et al.* (2017) in Rangpur lime and Joshi *et al.* (2015) in acid lime.

Maximum number of roots (29.00) germination speed and length of primary root (21.40 cm) was also found in seedlings treated with 300 ppm GA_3 and lowest was recorded in control (16.33 and 15.07 cm). It might be due to increased photosynthetic activity and enhanced movement of food materials through phloem to the root zone thereby increasing the number and length of roots (Shukla *et al.*, 1997). These data are in concordance with the reports of Khopkar *et al.* (2017) in pummelo and Ramteke *et al.* (2015) in papaya.

Seedlings treated with 300 ppm GA_3 recorded maximum shoot length (26.33 cm) and minimum value was found in control (17.50 cm). Seedling length was also observed to be maximum in those treated with 300 ppm GA_3 (47.73 cm) and minimum was found in control (32.57 cm). This may be due to enhanced cell elongation (Shanmugavelu 1970) and cell division (Stowe and Yamaki 1957) which will consequently extend the intermodal length. This observation is in harmony with the results of Anjanawe *et al.* (2013) in papaya, Dilip *et al.* (2017) in Rangpur lime and Sharaf *et al.* (2016) in Cleopatra mandarin and Rangpur lime

Seedling Vigour Index (SVI), which determines the quality of seed during germination and seedling development was found to be significantly varied among different treatments (Table 2). Highest value of SVI was recorded in 300 ppm GA_3 (4693.90) while lowest value was recorded in control (3063.00). The vigorous growth of seedlings may be the result of increased photosynthetic rate and translocation of the photosynthetic products to different parts of the plant due to GA_3 treatments. This finding is

supported by Al-Hawezy (2013) in loquat and Anburani and Shakila (2010) in papaya.

It is apparent from Table 2 and Table 3 that fresh weight and dry weight of seedlings were significantly influenced by different treatments. Maximum fresh root weight (1.80 g), fresh shoot weight (1.33 g) and fresh leaf weight (3.67 g) was recorded in 300 ppm GA_3 treatment and lowest was recorded in control. Dry weight of seedling is an essential factor in study of seeds as it is directly correlated with seedling vigour. The seeds with higher seedling dry weight along with better germination are regarded as favourable for longer storage (Sharma *et al.*, 2016). Maximum dry root weight (0.77 g), dry shoot weight (0.52 g) and dry leaf weight (0.96 g) was recorded in 300 ppm GA_3 treatment while lowest value was obtained in control. Apparently, total biomass content was recorded highest in 300 ppm GA_3 treatment (2.25 g/plant) and lowest content was recorded in control (0.80 g/plant).

The increase in fresh weight, dry weight and total biomass of the seedlings may be attributed to the influence of GA_3 in promoting transportation of water and nutrients to various parts of the plant leading to enhanced rate of photosynthesis and resulted in greater accumulation of food reserves in the plant cell and increased vegetative growth (Mayur *et al.*, 2022). These results are in conformity with the studies of Khatana *et al.* (2015) in Kagzi lime and Dilip *et al.* (2017) in Rangpur lime. Effect of different treatments on root:shoot ratio was resulted to be highly significant (Table 3) and maximum value was obtained in 300 ppm GA_3 treatment (0.52) while lowest was recorded in control (0.28). This finding is in close conformity with Meshram *et al.* (2015) in acid lime and Patel *et al.* (2018) in tamarind.

4. Conclusion

Pre-sowing treatment of pummelo seeds with 300 ppm GA_3 for overnight can be recommended to achieve higher seed germination as well as enhanced successive development of seedlings.

5. Acknowledgements

The authors gratefully acknowledge the Department of Science and Technology (DST), New Delhi for providing financial assistance during the research in the form of INSPIRE Fellowship.

6. References

Abdul-Baki A and Anderson JD (1973) Physiological and biological deterioration of seeds. Seed biology, Vol. 2. Academic Press, New York

Al-Hawezy SMN (2013) The role of the different concentrations of GA_3 on seed germination and seedling growth of Loquat (*Eriobotrya japonica* L.). IOSR Journal of Agriculture and Veterinary Science4:3–6

Alshakhaly ZM and Qrunfleh MM (2018) Effect of plant growth regulators on flower development and quality of five Cyclamen persicum hybrids. In: Proceedings of the XXX International Horticultural Congress IHC2018: International Symposium on Ornamental Horticulture and XI International, Istanbul, Turkey, pp 215–222

Amin MR, Sultana S, Hossain MI and Sarkar MD (2017) Floral and yield attributes of tuberose as influenced by gibberellic acid. International Journal of Bio-resource and Stress Management 8(4): 553-555

Anburani A and Shakila A (2010) Influence of seed treatment on the enhancement of germination and seedling vigour of papaya. Acta Horticulturae 851:295–298

Anjanawe SR, Kanpure RN, Kachouli BK and Mandloi DS (2013) Effect of plant growth regulators and growth media on seed germination and growth vigour of papaya. Annals of Plant and Soil Research 15(1): 31–34

Baskin CC and Baskin JM (2014) Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination (2nd Edn.). Academic Press, San Diego, pp 86

Bonner FT (1983) Germination responses of loblolly pine to temperature differentials on a two-way thermogradient plate. Journal of Seed Technology 8(1): 6-14

Brijwal M and Kumar R (2013) Studies on the seed germination and subsequent seedling growth of guava (*Psidium guajava* L.). Indian Journal of Agricultural Research 47(4): 347–352

Caengprasath N, Ngamukote S, Makynen K and Adisakwattana S (2013) The protective effects of pomelo extract (*Citrus grandis* L. Osbeck) against fructose-mediated protein oxidation and glycation. EXCLI Journal12:491–502

Chattopadhyay TK (2007) A Textbook on Pomology: Subtropical Fruit. Kalyani Publishers, pp 21

Cornea-Cipcigan M, Pamfil D, Sisea CR and Margaoan R (2020) Gibberellic acid can improve seed germination and ornamental quality of selected cyclamen species grown under short and long days. Agronomy 10: 516

Debeaujon I and Koornneef M (2000) Gibberellin requirement for Arabidopsis seed germination is determined both by testa characteristics and embryonic abscisic acid. Plant Physiology 122: 415–424

Dilip WS, Singh D, Moharana D, Rout S and Patra SS (2017) Effect of gibberellic acid (GA) different concentrations at different time intervals on seed germination and seedling growth of Rangpur lime. Journal of Agroecology and Natural Resource Management 4:157–165

Djavanshir K and Pourbeik H (1976) Germination value: A new formula. Silvae Genetica 25: 79-83

Dong B, Deng Y, Wang H, Gao R, Stephen GU, Chen S and Chen F (2017) Gibberellic acid signaling is required to induce flowering of chrysanthemums grown under both short and long days. International Journal of Molecular Sciences 18: 1259

Gomez AK and Gomez AA (2010) Statistical procedures for agricultural research. 2nd edn. Wiley India Private Limited, New Delhi, pp 134-138

Groot SPC and Karssen CM (1987) Gibberellins regulate seed germination in tomato by endosperm weakening: a study with gibberellin-deficient mutants. Planta 171: 525–531

Grzesik M, Górnik K, Janas R, Lewandowki M, Romanowska-Duda Z and Duijn BV (2017) High efficiency stratification of apple cultivar Ligol seed dormancy by phytohormones, heat shock and pulsed radio frequency. Journal of Plant Physiology 219: 81–90

Gupta AK, Dhua S, Sahu PP, Abate G, Mishra P and Mastinu A (2021) Variation in phytochemical, antioxidant and volatile composition of pomelo fruit (*Citrus grandis* (L.) Osbeck) during seasonal growth and development. Plants 10: 1941–1964

Hosseini MS, Zahedi SM, Hoveizeh NF, Li L, Rafiee M and Farooq M (2020) Improving seed germination and seedling growth of guava under heat and osmotic stresses by chemical and hormonal seed treatments. Bragantia 79(4): 512–524

ISTA (1999) International rules for seed testing. Seed Science and Technology 27, 1-33.

Joshi AS, Sahoo AK, Bhoyar RK and Meshram PC (2015) Effect of various plant growth promoting substances on seedling growth of acid lime. Trends in Biosciences 5(19): 5222-5225

Kalalbandi BM, Dabhade RS, Ghadge PM and Bhagat V (2003) Effect of gibberelic acid, napthalene acetic acid and potassium nitrate on germination and growth of Kagzi lime. Annals of Plant Physiology 17(1):84-87

Khatana KJ, Jadav RJ and Nehete DS (2015) Influence of GA_3 on germination and growth of acid lime cv. Kagzi lime seed (*Citrus aurantifolia* Swingle) under field as well as net house conditions. Asian Journal of Horticulture10: 11–16

Khopkar RR, Haldavanekar PC, Parulekar YR, Mali PC and Thorat SB (2014) Seed germination of pummelo (*Citrus Grandis* L. Osbeck) as affected by storage period and presowing treatments. Asian Resonance 3(3): 55-59

Khopkar RR, Nagaharshitha D, Haldavanekar PC and Parulekar YR (2017) Studies on seed germination of pummelo (*Citrus Grandis* L. Osbeck). International Journal of Agricultural Science and Research 7: 257–264

Ma H, Zhao D, Ning Q, Wei J, Li Y, Wang M, Liu X, Jiang C and Liang Z (2018) A Multi-year beneficial effect of seed priming with gibberellic acid-3 (GA_3) on plant growth and production in a perennial grass, *Leymus chinensis.* Scientific Reports 8: 13214

Maiti CS, Wangchu L, Sen SK (2003) Effect of pre-sowing seed treatments with different chemicals on seed germination and seedling growth of jackfruit (*Artocarpus heterophyllus* Lam.). Environment and Ecology 21(2): 290–292

Mayur RL, Desai BS, Sumankumar SJ, Patel DP and Hegde HT (2022) Effect of different seed treatments and media on growth and biomass of Indian Cheese Maker - *Withaniacoagulans* (Stocks) Dunal. International Journal of Economic Plants 9(1): 006–010

Meshram PC, Joshi PS, Bhoyar RK and Sahoo AK (2015) Effect of different plant growth regulators on seedling growth of acid lime. Research in Environment and Life Sciences 8(4): 725-728

Nishad J, Singh SP, Singh S, Saha S, Dubey AK, Varghese E and Kaur C (2018) Bioactive compounds and antioxidant activity of selected Indian pummelo (*Citrus grandis* L. Osbeck) germplasm. Scientia Horticulturae 233: 446–454

Oh W and Kim KS (2014) Light intensity and temperature regulate petiole elongation by controlling the content of and sensitivity to gibberellin in Cyclamen persicum. Horticulture Environment and Biotechnology 55: 175–182

Oh W, Kim J, Kim YH, Lee IJ and Kim KS (2015) Shoot elongation and gibberellin contents in Cyclamen persicum are influenced by temperature and light intensity. Horticulture Environment and Biotechnology 56: 762–768.

Pallaoro DS, Avelino ACD, Camili EC, Guimaraes SC and de Figueiredo e Albuquerque MC (2016) Priming corn seeds with plant growth regulator. Journal of Seed Science 38: 227–232

Patel M, Tank RV, Bhanderi DR, Patil HM, Patel V and Desai M (2018) Response of soaking time and chemicals on germination and growth of tamarind (*Tamarindus indica* L.). Plant Archives 18(1): 51-56

Phartyal SS, Thapliyal RC, Nyal JS and Joshi G (2001) Optimum seed germination requirements o *Ulmus wallichiana*- An endangered tropical highland tree species. In: Proceedings of IUFRO joint symposium on Tree seed technology, physiology and tropical silviculture, pp 128-137

Racey GD, Glerum C and Hutchinson RE (1983) The practicability of top root ratio in nursery stock characterization. Forestry Chronicle 59: 240-243

Ramteke V, Paithankar DH, Ningot EP and Kurrey VK (2015) Effect of GA_3 and propagation media on germination, growth and vigour of papaya cv. Coorg honey dew. International Journal of Life Sciences 10:111–116

Sahlan M, Damayanti V, Tristantini D, Hermansyah H, Wijanarko, A and Olivia Y (2018) Antimicrobial activities of pomelo (*Citrus maxima*) seed and pulp ethanolic extract. In: AIP Conference Proceedings, Bali, pp 1-6

Salisbury FB and Ross CW (1988) Plant Physiology. CBS Publishers and Distributors, Delhi, pp 319-329

Shanmugavelu KG (1970) Effect of gibberellic acid on seed germination and development of seedlings of some tree species. Madras Agricultural Journal 57: 311–314

Sharaf MM, Atawia AR, Bakry KA and EL-Rouby MZ (2016) Effect of pre-sowing seeds soak in different GA_3 and $ZnSO_4$ solutions on germination and growth of Cleopatra mandarin and Rangpur lime rootstocks. Middle East Journal of Agriculture Research5:233–238

Sharma N, Shukla YR and Mehta DK (2016) Seed priming and its consequences on seedling vigour of bell pepper (*Capsicum annuum* L.) under low temperature condition. International Journal of Bio-resource and Stress Management 6(6): 759-764Stowe BB and Yamaki T (1957) The history and physiological action of the gibberellins. Annual Review of Plant Physiology 8: 181–216

Shukla KC, Singh OP and Samaiya PK (1997) Effect of foliar spray of growth regulator and nutrient complex on productivity of soyabean. Crop Research 19: 213–215

Sun T (2008) Gibberellin metabolism, perception and signaling pathways in arabidopsis. The Arabidopsis Book 6: 1–28

Tocmo R, Pena-Fronteras J, Calumba KF, Mendoza M and Johnson JJ (2020) Valorization of pomelo (*Citrus grandis*Osbeck) peel: A review of current utilization, phytochemistry, bioactivities, and mechanisms of action. Comprehensive Reviews in Food Science and Food Safety 19: 1969–2012

Toh JJ, Khoo HE and Azrina A (2013) Comparison of antioxidant properties of pomelo [*Citrus grandis* (L) Osbeck] varieties. International Food Research Journal20: 1661–1668

Urbanova T and Leubner-Metzger G (2018) Gibberellins and seed germination. Annual Plant Reviews 49: 253–284

Uzun A and Yesiloglu T (2012) Genetic diversity in citrus. In: Caliskan M (ed) Genetic Diversity in Plants. IntechOpen, pp 213–231

Vishal B and Kumar PP (2018) Regulation of seed germination and abiotic stresses by gibberellins and abscisic acid. Frontiers in Plant Science 9: 838.

Table 1. Effect of GA_3 on seed germination and seedling growth of pummelo at 120 DAS

Treatments	Germination percentage (%)			Germination value (GV)			Minimum days to germination			Mean Germination time (MGT)			Number of leaves			Number of secondary roots		
	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool
T_1	94.33 (9.76)	92.67 (9.68)	93.50 (9.72)	3.87	3.69	3.78	28.67	27.33	28.00	37.79	38.19	37.99	9.00	7.00	8.00	18.67	14.00	16.33
T_2	94.67 (9.78)	93.00 (9.70)	93.83 (9.74)	3.97	3.79	3.88	25.67	24.67	25.17	36.07	36.65	36.36	9.67	9.67	9.67	22.33	17.00	19.67
T_3	95.33 (9.82)	94.00 (9.75)	94.67 (9.78)	4.20	3.91	4.06	23.67	23.33	23.50	33.96	35.72	34.84	12.67	10.67	11.67	19.33	17.33	18.33
T_4	95.67 (9.83)	96.00 (9.85)	95.83 (9.84)	4.35	4.25	4.30	23.00	22.67	22.83	33.44	34.17	33.80	13.00	11.00	12.00	24.33	19.00	21.67
T_5	97.00 (9.90)	97.00 (9.90)	97.00 (9.90)	4.52	4.49	4.51	22.67	21.33	22.00	32.75	33.06	32.91	13.67	11.00	12.33	25.33	23.33	24.33
T_6	97.67 (9.93)	97.67 (9.33)	97.67 (9.93)	4.88	4.98	4.93	20.67	19.33	20.00	29.99	29.76	29.88	14.00	12.67	13.33	27.00	25.67	26.33
T_7	98.00 (9.95)	98.67 (9.98)	98.33 (9.97)	5.21	5.39	5.30	19.33	18.33	18.83	28.57	27.33	27.95	14.33	13.00	13.67	30.67	27.33	29.00
SEm ±	0.08	0.05	0.05	0.18	0.09	0.12	0.49	0.40	0.33	0.49	0.38	0.33	0.55	1.73	0.92	2.51	2.94	2.48
CD (5%)	NS	0.14	0.15	0.54	0.29	0.36	1.48	1.21	0.99	1.48	1.16	1.00	1.66	NS	2.75	7.60	8.91	7.52

*** T_1 (Control), T_2 (50 ppm GA_3), T_3 (100 ppmGA_3), T_4 (150 ppmGA_3), T_5 (200 ppm GA_3), T_6 (250 ppm GA_3) and T_7 (300 ppm GA_3)**

***Figures in the parenthesis are the square root transformed values**

Table 2. Effect of GA_3 on seedling growth and fresh weight of pummelo seedlings at 120 DAS

Treatments	Length of primary root (cm)			Shoot length (cm)			Seedling length (cm)			Seedling Vigour Index (SVI)			Fresh root weight (g)			Fresh shoot weight (g)		
	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool
T_1	14.47	15.67	15.07	19.47	15.53	17.50	33.93	31.20	32.57	3233.57	2892.43	3063.00	0.80	0.56	0.68	0.67	0.43	0.55
T_2	14.57	15.90	15.23	20.77	18.77	19.77	35.33	34.67	35.00	3369.23	3258.23	3313.73	0.98	0.61	0.79	1.29	0.85	1.07
T_3	15.13	17.13	16.13	24.23	20.23	22.23	39.37	37.37	38.37	3744.23	3477.37	3610.80	1.05	0.76	0.90	1.27	0.79	1.03

T_4	15.17	17.10	16.13	25.70	21.70	23.70	40.87	38.80	39.83	3896.47	3765.47	3830.97	1.53	1.04	1.28	1.28	0.98	1.13
T_5	16.20	18.73	17.47	27.37	22.70	25.03	43.57	41.43	42.50	4253.00	4050.00	4151.50	1.58	1.13	1.36	1.36	1.23	1.29
T_6	16.27	20.27	18.27	28.57	23.57	26.07	44.83	43.83	44.33	4349.37	4224.57	4286.97	1.81	1.18	1.50	1.34	1.22	1.28
T_7	19.87	22.93	21.40	29.00	23.67	26.33	48.87	46.60	47.73	4789.33	4598.47	4693.90	2.34	1.26	1.80	1.42	1.25	1.33
SEm ±	1.07	1.09	0.95	1.41	1.74	1.50	1.63	1.54	1.42	200.29	170.96	164.95	0.30	0.15	0.20	0.15	0.18	0.12
CD (5%)	3.25	3.29	2.90	4.28	5.27	4.56	4.95	4.69	4.32	607.51	518.55	500.33	0.91	0.46	0.62	0.45	0.54	0.36

***T_1 (Control), T_2 (50 ppm GA_3), T_3 (100 ppmGA_3), T_4 (150 ppmGA_3), T_5 (200 ppm GA_3), T_6 (250 ppm GA_3) and T_7 (300 ppmGA_3)**

Table 3. Effect of GA_3 on fresh weight and dry weight of pummelo seedlings at 120 DAS

Treat-ments	Fresh leaf weight (g)			Dry root weight (g)			Dry shoot weight (g)			Dry leaf weight (g)			Root:Shoot ratio			Total biomass (g/plant)		
	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool	2019	2020	Pool
T_1	2.26	1.12	1.69	0.19	0.15	0.17	0.20	0.15	0.18	0.50	0.34	0.42	0.27	0.31	0.28	0.90	0.64	0.77
T_2	2.96	1.83	2.39	0.35	0.22	0.28	0.41	0.23	0.32	0.74	0.57	0.66	0.30	0.28	0.29	1.50	1.02	1.26
T_3	3.18	2.05	2.62	0.45	0.27	0.36	0.39	0.24	0.32	0.78	0.61	0.70	0.39	0.32	0.36	1.62	1.13	1.37
T_4	3.22	1.86	2.54	0.57	0.31	0.44	0.53	0.39	0.46	0.82	0.65	0.74	0.43	0.31	0.37	1.93	1.35	1.64
T_5	3.28	2.14	2.71	0.64	0.35	0.49	0.52	0.33	0.42	0.98	0.81	0.89	0.43	0.31	0.38	2.13	1.49	1.81
T_6	3.77	2.64	3.20	0.81	0.41	0.61	0.49	0.32	0.40	0.98	0.72	0.85	0.56	0.41	0.50	2.27	1.45	1.86
T_7	4.23	3.10	3.67	1.03	0.51	0.77	0.59	0.44	0.52	1.05	0.88	0.96	0.63	0.39	0.52	2.67	1.84	2.25
SEm ±	0.35	0.28	0.25	0.09	0.06	0.07	0.05	0.06	0.05	0.08	0.08	0.08	0.07	0.07	0.05	0.16	0.14	0.14
CD (5%)	1.06	0.84	0.77	0.27	0.20	0.20	0.16	0.17	0.15	0.25	0.25	0.23	0.21	NS	0.14	0.48	0.42	0.44

***T_1 (Control), T_2 (50 ppm GA_3), T_3 (100 ppmGA_3), T_4 (150 ppmGA_3), T_5 (200 ppm GA_3), T_6 (250 ppm GA_3) and T_7 (300 ppmGA_3)**

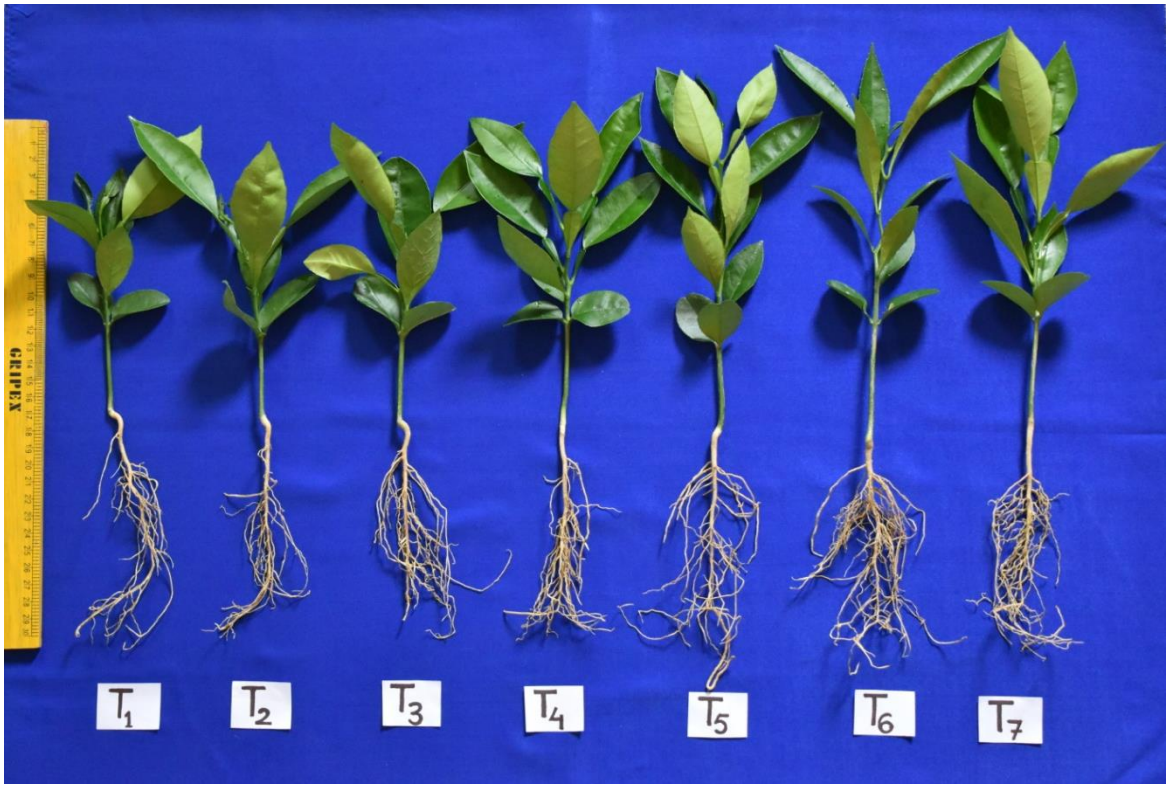

Figure 1. Comparision of seedling growth under different treatments