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Impact of pre-sowing seed treatments on germination and seedling growth of different fruit crops: A review

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Abstract
Seed germination is the resumption of active growth of embryo that results in the emergence of the young plant. Seeds of many fruit crops remain ungerminated even under favourable conditions. Such kind of dormancy in seeds may be due to presence of hard and impermeable seed coat, germination inhibitors or due to improper development of embryo. Such seeds may require special treatments like scarification, soaking in water, growth regulators and chemical treatments etc. in order to overcoming dormancy. This review summarizes the effect of pre sowing seed treatment on seed germination and seedling growth of different fruits crops.

Keywords: Fruit crops, germination, growth regulators and pre-sowing treatment methods

1. Introduction

Seed germination is a complex physiological process which is mainly depended on environmental signals such as water potential, temperature, humidity, light, nitrate and other factors. Most of horticultural crops especially in fruit crops such as Kagzi lime, Karonda, Jamun, Papaya, Phalsa are propagated by seeds. For raising a plant by seeds, a thorough knowledge of seed viability, its storage, time of sowing, factors responsible for germination and care of germinated seedlings is essential. While, poor seed germination is the major limiting factor of some of the important fruit crops. It has been postulated that seed coat (testa) of many fruit species contains considerable amount of germination inhibitor *viz.*, benzoic acid, cinnamic acid, coumarin, naringenin, jasmonic and abscisic acid (ABA), which prevent their seed germination. However, the seed germination percentage of many fruit crops is very poor and takes long time, and also showes very slow growth rate of seedlings, which limit its use as rootstock which is very much essential to meet the growing demands for budding and grafting. The failure of seed germination may be due to dormancy or due to hard seed coat. Studies have been indicated that use of pre-sowing treatments which will improve the germination and subsequent growth of seedlings in many fruits species. Therefore, pre-treating seeds of fruit crops is very important and can be done either by physical method such as scarification or by soaking in KNO_3, Urea, hot water treatment, cold water treatment, thiourea, cow urine, cow dung slurry or GA_3 to increase impermeability of the seed coat and also to improve germination.

The above seed treatment increase the embryo growth potential, reduce the germination time, weakens the seed coat and promote maximum percentage of germination. The use of plant growth regulators in proper concentration with scarification may regulate growth behavior in many fruit crops and pre-sowing treatment of growth regulators could lead to increase seed germination and enhancement of seedling growth. Plant growth regulators like GA_3, IBA, and IAA enhance the germination, growth and survival of seedlings. Many experiments has been carried out to identify a suitable treatment for getting better seed germination and seedling growth vigour. As a germination and growth of seedlings is significantly affected by various pre-sowing seed treatments in various fruit crops. In order to have uniform germination and to avoid the problem of uneven and irregular germination and to get sapling either for planting or to be used as rootstocks the seed treatment for seeds of different fruit crops is of quite important.

In this regard there is a need for identifying the best pre-sowing seed treatments for different fruit crops. For this reason, many researchers have been conducted experiment to identify a suitable treatment for getting better seed germination and seedling growth vigour.

Hence, the literature pertaining to their work has been reviewed in different fruit crops which are presented under following headings.

2. Effect of pre-sowing treatments on germination percentage of different fruit crops

2.1 Custard apple (*Annona squamosa*)

The seed treatment with GA_3 at 100 ppm for 24 hours was effective in increasing the germination 82.76 and 69.48 per cent as against 59.36 and 47.21 per cent in control in charoli and custard apple, respectively (Borle, 1991) [8]. Ghosh *et al.* (2003) [22] reported that, all the seed treatments were ineffective in enhancing the germination of fresh seeds except for seed soaking for six hours and treatment with 200 ppm sodium thiosulfate which reduced seed germination to 8 days. Whereas, seed germination increased when the seeds were treated with GA_3 50 ppm (75%) followed by 100 ppm GA_3 treatment (44.00%) (Stenzel *et al.*, 2003). Similarly, seeds soaked with 400 ppm GA_3 gave the highest seed germination percentage (69.00) and also observed that seed soaked with 600 ppm GA_3 for 12 h gave the earliest days for initiation of germination (16.00) (Ratan and Reddy, 2004) [60]. Banful *et al.* (2011) [6] observed the 29.80% total germination at 42 days after sowing when *Annona squamosa* freshly sown seeds in Ghana condition. While, the maximum germination percentage was recorded when seed soaked in 400 ppm concentration of GA3 and also found that soaking of seeds in GA_3 400 ppm for 12 h gave maximum germination percentage and seedling height (Gharge *et al.*, 2011) [19]. The seed treatment with GA_3 at 50 ppm for 48 hours was helpful to get higher germination of custard apple (Jadhav *et al.*, 2015) [27]. Parmar *et al.* (2016) [47] found that Soaking the seed in GA_3 @ 200 mgL-1 for 12 hours recorded the minimum days taken to germinate (24.00 days) and the maximum germination percentage (63.99%).

2.2 Aonla (*Phyllanthus emblica*)

In aonla seeds the highest germination percentage was obtained in 250 ppm GA_3 treatment (75.98%) as compared to control (50.76%) after 35 days of sowing, similarly pre-soaking treatment of aonla seeds with distilled water consisted of alternate soaking and drying for 12 hours repeated thrice for a total period of 72 hours followed by surface sterilization of seeds with 0.2% mercuric chloride gave significantly earlier initial germination than GA_3 250 and 500 ppm, thiourea 750 ppm and control. (Dhankhar and Kumar, 1996) [15]. Similarly, when the seeds of aonla soaked in 500 ppm GA_3 before sowing gave quicker germination of seeds (Sharma, 1996) [64]. Dhankhar and Singh (1996) [17] reported that *P. emblica* (cv. Gujarat Aonla 1) seeds were treated with 250, 500 or 750ppm gibberellic acid (GA_3). Seed germination was earliest and percentage germination was highest (75.98% and 64.14% in the laboratory and in pots in seeds treated with 250ppm GA_3. Whereas, the GA_3 at 50 and 100 ppm increased the percentage seed germination in aonla (Pawshe *et al.*, 1997) [50]. Wagh *et al.* (1998) [76] conducted an experiment on effect of seed treatment on germination of seed and initial growth of aonla seedling in polybag. They reported that 400 ppm GA_3 resulted higher percentage of germination. Bhadauria *et al.* (2000) [7] reported that seed treatment with Azospirillum biofertilizer slurry for 24 hrs increased germination percentage of aonla (79%) than control (50%). Gholap *et al.* (2000) [20] observed the early initial germination (15.33 days) and highest germination percentage (67.58%) as compared to control in aonla when the seeds were treated with 200 ppm GA_3. While, the highest germination percentage (52.08%) was found when the seeds were treated with Azospirillum + Phosphobacteria + 0.5% KNO_3 for 8 hrs (Rajamanickam and Anbu, 2001) [56]. While, the fresh seeds treated with 0.5% KNO_3 and one-year-old seeds treated with 200 ppm GA3 for 8 h recorded the highest germination (69.33 and 46.00%, respectively) (Rajamanickam and Balakrishnan, 2004) [55]. While, the maximum seed germination (93.33%) was observed in seeds treated with 1% KNO3 for 18 hours, while least seed germination (53.33%) was recorded in the control (Purbey and Meghwal, 2005) [53]. Whereas, the maximum germination of aonla seeds (75.50%) was recorded when seeds were treated with GA_3 500 ppm over other treatment under Haryana conditions (Kumari *et al.*, 2007) [33]. Similarly, in aonla the maximum seed germination (75.6%) was found when seed were soaked in GA_3 750 ppm + Azospirillum for 24 hrs over control (48.90%) under Rahuri condition (Supe *et al.* 2012) [71]. Whereas, Perera *et al*. (2014) [51] reported that, the *Phyllanthus emblica* seed dormancy was overturned with a germination percentage of 43 per cent when the seeds were scarified and treated with one per cent gibberellin.

2.3 Ber (*Zizyphus mauritiana*)

Hore and Sen (1994) [26] reported that, the highest germination percentage after 1 and 17 months was obtained from seeds treated with 200 ppm GA_3 (98.76 and 77.82%, respectively). Days to first germination were lowest with 1.0% thiourea treatment, while the shortest span of germination was recorded under concentration of 1000-2000 ppm Cycocel [chlormequat]. While, the extracted seeds of ber soaked for 24 hours in water promoted early germination, good vegetative growth and higher germination percentage compared with sowing whole seeds (control). Similarly, cracked seeds exhibited better germination than control seeds but were not good as water soaked seeds (Mankar *et al.*, 1997) [36]. Whereas, After 30 days from seed extraction, germination was highest (84%) in ber seeds scarified mechanically, however, after 203 days, it was highest (88%) in seed treated with 1% potassium hydroxide (Ghosh and Sen, 1998) [21]. Whereas, breaking of hard shell in Ber helps in early germination (Singh *et al.*, 2002) [67]. Singh *et al.* (2004) [68] reported that, seed treated with 600 ppm GA_3 + 6% sucrose resulted in the greatest germination at 4 weeks after sowing (90.95%). Singh *et al. (*2004) [68] found that, the greatest seed germination was obtained with the use of medium seeds (50.93%) and treatment with H_2SO_4 for 10 minutes (54.22%). Seeds of the ber cv. Local Desi Gola while soaking in acid for 6 minutes and sowing on 20 May gave the highest germination (90%) (Singhrot and Makhija, 1979) [70]. The effect of seed treatments with growth regulators (250 and 500 ppm GA_3, 250 and 500 ppm thiourea), chemicals (sulphuric acid) and distilled water on seed germination of wild ber (*Zizyphus nummularia*) were studied and the highest percentage of seed germination was recorded with 500 ppm GA_3 (Rajwar *et al.*, 2007) [57]. The mechanical cracking of seeds resulted in the lowest number of days to germination (23.66 days). While, seeds soaked with water for 24 hours + keeping in gunny bags for 2 days under Jammu conditions, the numbers of days take for initiation of germination was minimum (10 days) (Mahital *et al.*, 2013) [35]. Whereas, the seed germination and seedling emergence of was highest (90% ± 7.3 SE) when the hard seed coat was cracked and sown and the duration taken by the seeds to germinate was also faster in these treatment (≈ 2 - 5 days) (Dorji *et al*., 2015) [18].

2.4 Mango (*Mangifera indica*)
Seed soaking in 150 ppm concentration of thiourea for 24 h followed by soaking for 12 or 24 hours in 150 ppm GA_3 resulted in the highest germination percentage of mango (cultivars Local, Neelum and Totapuri) seeds (Pillewan *et al.*, 1997) [52]. Whereas, GA_3 at 200 ppm for 12 h was the best treatment which recorded the maximum germination percentage (85.5%) in mango stones as compared to other treatments (Rao and Reddy, 2005) [59]. Kumar *et al.* (2008) [32] found that, the mango stones pre-treated with 3% Panchagavya recorded significantly lesser number of days for the initiation of germination (12.25 days) and completion of germination (46.18 days) as well as maximum germination (75.22%). Whereas, the germination percentage increased with seed husking and soaking in GA_3 at 100 or 200 ppm concentrations for 48 hours (Shaban, 2012) [61]. Aatla *et al.* (2013) [1] found that, extracted kernel pre-treated with KNO_3 @ 0.5 per cent recorded maximum germination percentage (64%) in mango.

2.5 Citrus (*Citrus spp.*)
An experiment on seeds of sour orange, Cleopatra mandarin, Mexican lime and rough lemon for 2 successive seasons on germination was carried out. In the first season, percentage germination in all species except sour oranges was significantly improved compared with control. Average germination percentage was highest in sour oranges and rough lemons and lowest in Mexican limes (Moustafa and Al-Zidgali, 1995) [40]. Wahab and Shah (1995) [77] studied the effect of seed dressings @ 2 g/kg of quintozene, thiophanate-methyl, carbendazim and benomyl on damping off of *Citrus aurantium* and reported the highest germination percentage (82%) with carbendazim followed by quintozene (63%) was observed. Khan *et al.* (2002) [31] reported the effect of pre sowing seed treatment of gibberellic acid (GA_3) solutions on rate of germination and final percentage germination of grapefruit (*Citrus paradisi*), Kinnow mandarin (*C. reticulate*) and rough lemon (*C. limon*) seeds collected from Pakistan was investigated. The seed size, coat thickness, thousand seed weight and polyembryony were higher in grapefruit followed by Kinnow mandarin and rough lemon while moisture content was higher in Kinnow mandarin followed by grapefruit. No significant effect of GA_3 treatment on final percentage germination was observed. The Kagzi lime seed soaked in GA_3 and NAA for 12 hours resulted in high germination and also observed that GA_3 at 80 ppm concentration was the most effective for improving germination (Kalalbandi *et al.*, 2003) [30]. Similarly, The GA_3 concentration at 80 ppm showed higher of seed germination (93.33%), in Rangpur lime (*Citrus limonia*) followed by 90.00 and 86.66% with the application of NAA at 80 ppm and cow dung paste treatments, respectively (Shinde *et al.*, 2008) [65]. The GA_3 at 500 ppm with seed soaking period of 40 hours resulted in better germination, growth and survival as compared to other treatments in lime seeds (Dhaka and Pal, 2009) [14]. Patil *et al.* (2012) [49] found higher germination of rangpur lime (98.66%) under GA_3 150 ppm over control under Akola conditions.

2.6 Papaya *(Carica papaya)*
In papaya, the maximum percentage of germination and percent survival were noted under 100 ppm GA_3 treatment and found that the GA_3 significantly affected the germination percentage, days required for completion of germination and survival percentage in all the cultivars of papaya (Meena *et al.*, 2003) [38]. While, soaking for 24 hours in tap water; and soaking for 24 hours in GA_3 (500 or 1000ppm), enhanced germination percentage, reduced the time required to attain 50% germination, and improved germination rate of pawpaw cv. Fairchild compared with the control (Helail *et al.*, 1999) [25]. Similarly, found that, the seeds should be washed and soaked 24 hours before sowing to enhance germination under Maseno conditions (Okeyo and Ouma, 2008) [43]. Whereas, the papaya seeds soaked with GA_3 at 150ppm was found best in respect to seed germination (72.2%) (Deb *et al.*, 2010) [12]. Anjanwe *et al.* (2013) [4] observed that the maximum seed germination of papaya was obtained under 100 ppm GA_3 (60.4%) followed by 200 ppm GA_3 (50.39%) over control (39.29%) under Mandsaur conditions. While similar results was found when, papaya seed soaked in GA_3 @ 300 ppm for 12 hours and KNO_3 @ 2% for 24 hours (93 and 91% respectively) over control (64%) under Banglore conditions (Lay *et al.*, 2013) [34]. While, Ramteke *et al.* (2015) [58] observed the maximum germination of papaya (73.01%) when seeds were treated with GA_3 200 ppm for 12 hrs as compared to control (62.85%) under Navsari, Gujarat condition.

2.7 Sapota *(Manilkara zapota)*
Pampanna *et al.* (1995) [46] found that, pre soaking of sapota seed with cracked seed coat in GA 300ppm for 24 hours resulted in the highest germination (53%). Whereas, Pampanna and Sulikeri (2001) [45] observed that the sapota seeds treated with GA3 400 ppm + ethrel resulted in significantly highest germination (90%) and the number of days taken for initiation of germination was minimum (11.50 days) compared to all other treatments under Dharwad conditions. Shirol *et al.* (2005) [66] found that pre-soaking of khirni seeds in cowdung slurry for 24 hours which resulted in higher (66.83%) seed germination under Arabhavi conditions. Similarly, in khirni seeds, GA3 50 ppm recorded the highest germination percentage (92.31%) followed by GA3 75 ppm (92.31%) and GA3 75 ppm (89.76%) (Wankhede *et al.* 2008) [78].

2.8 Other fruit crops
Deol *et al.* (1993) [13] reported that seeds extracted immediately from fruits of the peach cv. Sharbati harvested 10-12 days before commercial maturity had a significantly higher germination rate than seeds from fruits harvested at commercial maturity (37.6 and 30.4%, respectively). Ozguven *et al.* (1995) [44] studied the effect of GA_3 (0, 125, 250, 500 and 1000 ppm for 24 or 48 h) on germination of Pistachio (cv. Siirt) seeds. The higher germination (73.33%) was observed when seed soaked in concentration of 125 ppm GA_3 for 48 hours. Studies on the effect of GA_3 on seed germination of kiwifruit cultivars Abbot, Allison, Bruno, Hayward and Monty was carried out and found that, the highest seed germination was recorded with concentration of 30 ppm GA_3 (Verma *et al.*, 1998) [75]. Ynoue *et al.* (1999) [81] noticed that the higher percentage germination and reducing the average time of germination of kiwi fruit seed was when seed where

treated with 150 mg GA_3/litre. While, germination of tamarind seeds increased compared with the control and showed 100% germination at 400 ppm of GA_3 (Ghyare, 2005) [23]. Similarly, the concentrations of GA_3 solution markedly promoted the germination rate in seeds of wild pistachio and also at the concentrations of GA_3 200 mg/L and soaking for 3-4 days, under such conditions the germination rate could reach upto 76% (Abuduca *et al.*, 2006) [2]. Cetinbas and Koyuncu (2006) [10] reported that *prunus avium* seed germination was increase (64.54%) when seed of *prunus avium* were soaked in 7500 ppm KNO_3 over control (29%) under Turkey condition. Ahmad (2010) [3] found the maximum seed germination (67.25%) of kiwi fruit was with the application of 2000 ppm GA_3 over other treatments under Srinagar conditions. Whereas, the seeds of Manila tamarind (*Pithecellobium dulce* Roxb.) treated with 50 ppm IBA and GA_3 exhibited maximum germination percentage (Singh *et al.*, 2011) [69]. Likewise, the kinetin pre-treatment at lower concentrations (5, 10, 15 and 20 mg/l for 6-12 hours) proved to break embryonic dormancy of apple (Yatoo *et al*., 2012) [79]. While, the maximum germination of loquat seeds (98.75%) was recorded when seeds were treated with GA_3 250 ppm over control (92.65%) under Iraq condition (Shabaq, 2013) [62]. The GA_3 treatment combined with water soaking for nine days showed significant improvement in germination in peach, plum and apricot (31.33, 75.33 and 73.33%), respectively (Shah *et al*., 2013) [63]. Venudevan and Srimathi (2013) [74] observed the higher germination (84%, 80% and 76%) when bael seed soaked in water for (6 hrs, 9 hrs and 12 hrs) respectively over control (68%) and minimum period was recorded for seed germination (12 days) under Coimbatore condition. While, in passion fruit the maximum germination percentage and germination index was observed when seeds treated with thiourea (1%) (Gurung *et al.* 2014) [24]. Vasantha *et al.* (2014) [73] seen significantly higher seed germination (97.78%) in tamarind seeds when seeds were treated with GA_3 200 ppm under Bengaluru, Karnataka condition. Parvin *et al.* (2015) [48] found that the maximum germination of black walnut seeds (69.27%) was recorded with the combined treatment of two months chilling and GA_3 400 ppm over other treatment under Iran condition. In peach (*Prunus persica* L. batsch) rootstock flordaguard, seeds sown after mechanical rupturing of the seed coat had exhibited significantly higher percent of seed germination (57.26), the minimum duration of seed germination (16.33 days) and mortality rate (1.9%) (Thakur, 2015) [72].

3. Effect of pre-sowing treatments on seedling growth of different fruit crops.

3.1 Custard apple (*Annona squamosa*)

Borle (1991) [8] observed that, seed treatment with 100 ppm GA_3 for 12 hours after pre soaking in water for 24 hours recorded increased height of seedlings of custard apple than other treatments. The water soaking of seed for 24 hrs + 100 ppm GA_3 soaking for 12 hrs was the best method for enhancing the seedling height in custard apple (Yelure, 1992) [80]. Ghosh *et al.* (2003) [22] conducted an experiment to see the effect of pre sowing seed treatment on seedling growth of custard apple (*Annona squamosa*) seeds. The seedling vigour in 180-day-old seeds increased with 200 ppm potassium metabisulfide treatment. Ratan and Reddy (2004) [60] studied the seeds of custard apple (*Annona squamosa*) cv. Balanagar soaked in 200, 400, 600 ppm GA_3 for 12 and 24 hours to determine their effect on seedling growth. Seed soaked with 400 ppm GA_3 gave the maximum plant height (25.33 cm), root length (12.23 cm) dry weight of stems (0.245 g) and roots (0.175 g). Further they observed that seed soaked with 600 ppm GA_3 for 12 hours gave the maximum leaf dry weight (0.795), whereas, the highest stem diameter (2.86 cm) was obtained with 200 ppm GA_3 for 24 hours. Banful *et al.* (2011) [6] stated that the higher values of leaf number of *Annona squamosa* (10.95) per plant were recorded at freshly sown seed in Ghana condition. While, the seed soaking in 50 ppm GA_3 for 48 hours showed the significant differences on seedling height, stem diameter and number of leaves per seedling of custard apple (Jadhav *et al.*, 2015) [27]. Parmar *et al.* (2016) [47] studied the influence of seed priming treatments on seedling vigour of custard apple and reported that, soaking the seed in GA_3 @ 200 mgL-1 for 12 hours recorded the maximum height of seedling (64.87 cm), shoot length (45.90 cm), root length (20.00 cm), fresh and dry weight of seedling (7.27 g and 4.36 g), stem girth (0.73 cm), relative growth rate (0.026 g/day), vigour index-I and II (0.99 and 14.68) at 120 days of sowing. While, the maximum plant height (14.0 cm), number of leaves (5), stem diameter (2.7 mm), root length (10 mm) of *Annona muricuta* seedling was observed when seeds were treated and soaked with cold water under Abeokuta, Organ state condition (Joseph, 2014) [28].

3.2 Aonla (*Phyllanthus emblica*)

Dhankhar *et al.* (1997) [16] reported that seeds treated with 250ppm GA_3 gave the best results in terms of plumule and radical length, seedling height (28.84 cm 75 days after sowing), seedling girth (0.90cm 75 days after sowing) and seedling fresh and dry weight of aonla. Pawshe *et al.* (1997) [50] conducted an experiment to determine the effect of pre-germination seed treatment on seedling growth of aonla (*E. officinalis*) seeds. While, the tallest plants were observed when seed treated with 100 ppm GA_3 and soaking for 24 hours. Wagh *et al.* (1998) [76] found that, 400 ppm GA3 resulted the maximum seedling development (plant height, number of leaves/plant and root development). Whereas, Bhadauria (2000) [7] reported that aonla seeds treated with Azospirillum biofertilizer slurry for 24 hrs resulted in maximum shoot length (5.5 cm) which was double than control (2.4 cm). The biofertilizer application enhanced the total length of seedlings in all the treatments as compared to control. Gholap *et al.* (2000) [20] studied effects of plant growth regulators on seedling growth of aonla or Indian gooseberry (*P. emblica* cv. banarasi) under climatic conditions of akola, India, during 1998-99. And found the tallest seedling height (27.63 cm), the greatest seedling stem girth (0.86%) and the highest number of roots per seedling was recorded with thiourea at 200 ppm. The fresh seeds of aonla treated with Azospirillum + Phosphobacteria + 200 ppm GA_3 for 8 hrs recorded the higher shoot length than all other treatments (Rajamanickam and Anbu, 2001) [56] and they also observed that seeds treated with Azospirillum + Phosphobacteria + 0.5% KNO_3 for 8 hrs recorded maximum seedling height at 90 and 120 days after sowing as compared to untreated control. While the Soaking aonla seeds in 200 ppm GA_3 resulted in the highest stool length in both fresh and one-year-old seeds (8.92 and 6.58 cm. respectively). Fresh seeds treated with 0.5% KNO_3 and one-year-old seeds treated with 200 ppm GA_3 recorded the highest root lengths (3.26 and 2.94 cm, respectively). The highest dry matter production was recorded in fresh seeds soaked in 0.5% KNO_3 and one-year old seeds soaked in 200 ppm GA3 for 8 hours (0.210 and 0.117 g, respectively). Fresh and one-year-old seeds treated with 0.5% KNO_3 and 200 ppm GA_3 for 8 h recorded the highest vigour indices (246.80 and 236.40 and 217.00 and 229.10, respectively) (Rajamanickam and Balakrishnan, 2004) [55]. Whereas, the maximum root length (31.33 cm) and root diameter (0.39 cm) were observed in seeds treated with 1% KNO_3 for 18 hours and the seedling height, number of leaflets and survival of 100 days old seedlings were significantly highest in the 1% KNO_3 treatment (Purbey and Meghwal, 2005) [53]. Kumari *et al.* (2007) [33] noticed that, maximum seedling height of aonla (72.94 cm), girth of seedling (0.63 cm) was recorded when seeds were treated with GA_3 500 ppm over other treatments under Haryana conditions. The aonla seedlings gave maximum height (12.0 cm), survival percentage (68.90%) when seeds were soaked in GA_3 750 ppm + Azosperillum for 24hrs, maximum number of leaves (20.0) when seeds were soaked in GA_3 750 ppm + carbendazim (0.1%) and longest root of seedling (22.4 cm), maximum fresh weight seedlings (2.6 g) was obtained when seeds were soaked with GA_3 (500 ppm) + Azospirillum under Rahuri condition (Supe *et al.*, 2012) [71].

3.3 Ber (*Zizyphus mauritiana*)

Singh *et al.* (2004) [68] found that, all treatments significantly enhanced root and shoot growth and seedling survival of ber. Seed treatment with 600 ppm GA_3 + 6% sucrose resulted in the greatest seedling survival at 90 days after sowing (90.98%), seedling height (80.63 cm), girth of seedling at ground level (1.72 cm), buddable stage (1.48 cm), root length (26.05 cm), root fresh (4.35 g) and dry (1.55 g) weights. Similarly, the best seedling growth were obtained when the kernels were extracted by breaking endocarp + water soaking. The tallest seedlings were obtained with medium seeds (25.26 cm) and water-soaked seeds (26.33 cm) (Murthy and Reddy, 1989) [42]. Singh *et al.* (2004) [68] found that, water-soaked seeds and large seeds gave the greatest stem diameters (0.54 and 0.51 cm, respectively). The diameter of the seedling stem (15 cm above ground) at 90 days after sowing was greatest (0.74 cm) after soaking in acid for 6 minutes and sowing on 20 April (Singhrot and Makhija, 1979) [70]. In a related study, the combined effect of seed treatments and foliar applications of growth regulators GA_3 and maleic hydrazide (MH) at 50 ppm) on seedling growth of wild ber was assessed. Foliar spray of 50 ppm GA_3 on seedlings obtained from different seed soaking treatments accelerated seedling vigour. GA_3 gave maximum plant height (56.29 cm), plant girth (2.75 cm) and internode length (2.69 cm). Foliar spray of 50 ppm MH reduced plant height and internode length (Rajwar *et al.*, 2007) [57].

3.4 Mango (*Mangifera indica*)

Rao and Reddy (2005) [59] reported that, mango stones soaked in GA_3 at concentration of 200 ppm recorded the maximum seedling growth compared to other treatments. The stones pre-treated with 3% Panchagavya recorded significantly the maximum rootstock diameter (7.35 mm), number of leaves (14.77) and sprout height (5.96 cm). However GA_3 at 100 ppm registered the highest rootstock height (36.43 cm), which was at par with KNO_3 and water soaking (Kumar *et al.* 2008) [32]. While, gibberellic acid (200 ppm) produced the maximum height and more number of leaves. Whereas, IAA (500 ppm) produced the maximum girth and leaf area (Munde and Gajbhiye, 2010) [41]. Shaban (2012) [61] found that, the number of seedlings per seed increased with seed husking and soaking in GA_3 at 100 or 200ppm concentrations for 48 hours. The highest number of seedlings were recorded by Sabre rootstock meanwhile, the Seedling length, seedling diameter, number of leaves per seedling, leaf area and root length of the studied rootstocks were increased with seed husking and GA_3 treatments. While, Zebda, Sukkary and Sabre rootstocks recorded higher values of growth parameters than "13-1" rootstock. The treatment extracted kernel pre-treated with KNO_3 @ 0.5 per cent showed maximam seedling diameter (7.10 mm), number of leaves (10.90), leaf length (15.83 cm), leaf width (8.00 cm), root length (23.40 cm), root spread (8.66 cm), root to shoot ratio (0.807), vigour of seedling (1094.33) and vigour index (1517.30) over all the other treatments. Whereas maximum seedling height (24.13 cm) and inter-nodal length (3.66 cm) was recorded in extracted kernel pre-treated with GA_3 @ 500 ppm (Aatla *et al.*, 2013) [1]. Sangeeta and Mani (2014) reported that the maximum seedling height (30.5 cm), maximum leaves (16.4), diameter of stem (3.9 cm), root length (20.7 cm) of mango was found when seeds were soaked in KNO_3 (1%) under Tamilnadu condition.

3.5 Citrus (*Citrus spp.*)

Moustafa and Al-Zidgali (1995) [40] reported that, the seedling length was greatest in rough lemons, it was greater for seedlings grown from seeds treated with GA_3 than for those in other treatments. Dalal *et al.* (2002) [11] conducted an experiment to improve seedling growth of Rangpur lime (*Citrus limonia*) to enable it to become buddable rootstocks earlier. The four foliar applications of 25 ppm GA_3 were found most effective for enhancing stem height and girth, number of leaves and increasing the percentage of buddable seedlings (31.59% more than control) followed by foliar applications of 1% urea which gave 28.77% more buddable seedlings than control. The seed soaked in GA_3 and NAA for 12 hours increased the shoot length and further observed that GA_3 at 80 ppm concentration was the most effective for improving seedling height and number of leaves of kagzi lime (Kalalbandi *et al.*, 2003) [30]. The maximum seedling height (8.94 cm), number of leaves per plant (16), stem diameter (0.44 cm), length of root (15.03 cm), survival percentage (96.60%) was found when the seeds were soaked in GA_3 500 ppm for 40 hours under Dhampur conditions (Dhaka and Pal, 2009) [14]. The maximum length of the tap root, number of secondary and fibrous roots were recorded with concentration of 150 ppm NAA, significantly less length of tap root, minimum number of secondary and fibrous roots were produced under the treatment control (Kadam *et al.*, 2010) [29].

3.6 Papaya (*Carica papaya*)

Deb *et al.* (2010) [12] reported that, the maximum height of papaya seedling was observed when seeds are treated with GA_3 at 200ppm. The maximum seedling height (17.83 cm), number of leaves (10.08), stem diameter (0.41 cm), leaf area (10.08 cm^2), fresh weight of stem and leaves (11.54 g), number of secondary roots/seedling (3.97) and seedling dry weight of stem and leaves (1.30 g) of papaya seedlings obtained in fifth week when seeds were soaked in GA_3 100 ppm over control under Jhalawar conditions (Meena and Jain, 2012) [37]. Anjanwe *et al.* (2013) [4] noticed that, the maximum seedling height (17.41 cm), number of leaves (10.46), stem diameter (0.44 cm), leaf area (41.28 cm2), longest root (25.36 cm), primary roots (8.83), secondary roots (76.32), maximum fresh weight of stem, leaves and root (15.88 g), dry weight seedlings (1.36 g), fresh weight of roots (2.43 g) and dry weight of roots (0.324 g) of papaya was obtained under 200 ppm GA_3 under Mandsaur conditions. Lay *et al.* (2013) [34] found that maximum seedling height (13.67 cm), dry matter (4.00 mg) of papaya was observed when seed were soaked in GA_3 400 ppm under Bangalore condition. The seeds soaked in 200 ppm gibberellic acid solution for 12 hours showed maximum plant (14.92 cm) height, (4.28 mm) stem diameter, (38.58 cm2) leaf area, (7.90 cm) root length, (11.55) number of secondary roots, (4.54 g) fresh weight of plant, (0.66 g) dry weight of plant, (75.06%) maximum survival percentage and (8.20) leaf number at 50 DAS under Navsari, Gujarat condition (Ramteke *et al.*, 2015) [58].

3.7 Sapota (*Manilkara zapota*)

Pampanna *et al.* (1995) [46] observed that, the maximum seedling height of sapota was obtained under 400 ppm GA_3 (5.30 cm) at 60 DAS, (8.35 cm) at 90 DAS over control (2.17 cm) at 60 DAS, (2.97 cm) at 90 DAS and maximum number of leaves per plant of sapota was obtained under 400 ppm GA_3 (3.69) for 60 DAS, (4.44) for 90 DAS over control (1.94) for 60 DAS, (2.19) at 90 DAS under Dharwad condition. Seeds soaked with GA_3 400 ppm + ethrel resulted in maximum number of leaves (6.75) and longest length of root (6.73 cm) under Dharwad conditions (Pampanna and Sulikeri, 2001) [45]. While, Pre-soaking of Khirnee seeds in cow dung slurry for 24 hours resulted in the highest (66.83%) seed germination and also found that *Khirnee* seedlings sprayed with GA_3 at 200 ppm on the 3rd and 6th months enhanced the seedling growth (Shirol *et al.*, 2005) [66].

3.8 Other fruit crops

Bal *et al.* (1990) [5] noticed that, the wild pear seedlings had more leaves and maximum stem diameter when seeds were treated with GA_3 50 ppm after longer stratification (28 days) under Punjab conditions. Ozguven *et al.* (1995) [44] studied the effect of GA3 (0, 125, 250, 500 and 1000 ppm for 24 or 48 h) on seedling growth of Pistachio (cv. Siirt) seeds and found the maximum seedling height and internode length under 1000 ppm concentration of GA3. Rahemi and Baninasab (2000) [54] studied the effect of gibberellic acid (GA_3) at different concentrations of 100, 250, 500, 750 and 1000 mg/litre, applied during and after stratification, to enhance seedling growth of Beneh and Kolkhog wild species of pistachio. The results showed that GA_3, applied during and after stratification, significantly increased the length, trunk diameter, internodal length, leaf area and fresh and dry weight of seedlings of both species. They observed that the application of GA_3 after stratification was more effective on seedling growth of Beneh. Further they reported that the GA_3 applied at higher concentrations (500 and 750 mg/litre) increased the growth rate. While, the six-week-old seedlings were treated with gibberellic acid (GA_3) (100 mg/lit) alone or with GA_3 followed by ethephon [(100 and 200) mg/lit], or chlormequat chloride (CCC) [(500 and 1000) mg/lit], or paclobutrazol (PBZ) [(500 and 1000) mg/lit] in *Prunus amygdalus* and *P. webbii*. Most levels of plant growth regulators significantly enhanced seedling growth. However, GA3 alone was most effective on stem height, leaf area, shoot fresh and dry weights of both almond species (Mobli and Baninasab, 2008) [39]. An attempt was made to pre-treat Manila tamarind (*Pithecellobium dulce* Roxb.) seeds with IBA, KNO_3, GA_3 PEG and water to increased seedling growth under hot arid conditions and observed that the various seeds were treated with 50 ppm IBA and GA_3 exhibited maximum seedling growth and biomass production (Singh *et al.*, 2011) [69]. When the jackfruit seed treated with GA_3 200 ppm for 24 hours gave the maximum seedling height (72.1cm) over control 57.4 cm, seedling girth (0.78 cm) over control (0.63 cm) and maximum leaf area (2526) with KN03 (0.5%) for 24 hours over control (1290) under Venkataramannagudem condition (Harshavardhan and Rajasekhar, 2012). Whereas, the maximum seedling height (8.21 cm), root length (10.15 cm) was recorded when loquat seeds were treated with GA3 300 ppm and number of leaves (8.34), seedling diameter (1.69 mm), dry weight of seedling (0.23 g), dry weight of roots (0.04 g) was recorded when treated with GA3 250 ppm under Iraq condition (Shabaq, 2013) [62]. Venudevan and Srimathi (2013) [74] observed that the higher shoot length (9.7, 8.0, 8.0 and 7.6 cm), root length (8.6, 6.8, 6.0 and 5.8 cm) and dry matter production of seedling (30.3, 24.1, 22.8 and 20.4 mg), was recorded in bael. When the seeds soaked in water for (6, 3, 9 and 12 hours) respectively in Coimbatore condition. Brijwal and Kumar (2014) [9] reported that, the maximum seedling height (4.90 cm), stem girth (0.32 cm) and number of leaves per seedlings (9.46) in 30 days after transplanting and 17.94 cm, 1.31 cm and 18.69, respectively in 120 days after transplanting were observed in scraping of seed coat of guava with sand paper + seeds soaked in GA_3 50ppm for 24 hours as compared to control. Likewise, the maximum fresh and dry weight of stems (335.66 mg and 50.36 mg, respectively), leaves (830.53 g and 258.90 mg, respectively) and roots (344.80 mg and 74.10 mg, respectively) were observed in scraping of seed coat with sand paper + seeds soaked in GA_3 50 ppm for 24 hours. Whereas, sowing of seeds without pre-sowing treatment showed poor results for all parameters. In passion fruit, The maximum seedling height 16.23 cm, 19.62 cm and 20.91 cm and number of leaves 10.25, 11.35 and 14.25 were observed in seeds treated with GA3 500 ppm at 30, 60 and 90 days respectively. Vigour index-I (1547.34 cm), Vigour index-II (128.76 g) as well as maximum fresh weight (3.76 g) and dry weight (0.98 g) of shoot were recorded under GA_3 500 ppm (Gurung *et al.*, 2014) [24]. Similarly, in tamarind the maximum seedling height (27.70 cm), number of leaves per plant (28.53), highest root length (41.67 cm), fresh weight of shoot (23.99 g), dry weight of shoot (8.07 g), fresh weight of root (7.90 g) and dry weight of roots (4.80 g) for 90 DAS was recorded when seeds were soaked in GA_3 200 ppm over control 12.80 cm for 60 DAS and 16.80 cm for 90 DAS under Bengaluru, Karnataka condition(Vasantha *et al.*, 2014) [73].

To meet the growing demand of planting material (grafts), nursery man has to produce more number of rootstocks with graftable size in a shorter time. It is, therefore, highly essential to accelerate the seed germination and growth of seedlings with pre-sowing treatments to attain graftable size earlier. Therefore, enhancement of seed germination is important in propagation, breeding programmes, as well as for testing and using germplasm. In this aspect pre-sowing treatments seems to be the most promising in many fruit species. Therefore, it can be concluded that pre-sowing treatments are effective to get higher germination rate and better seedling growth of fruit crops.

4. References

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