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Dwarfism in Fruit Plants: A Review

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ABSTRACT

In this modern era, farmers are adopting high density planting (HDP) for most of the fruit crops. Dwarfing is based on the principle of making the optimal use of vertical and horizontal space per unit time and harnessing the highest potential returns per unit of inputs and natural resources. Dwarfing in fruit crops can be accomplished through a variety of methods, including the use of dwarfing rootstock, the selection of spur type scion cultivars, use of interstock, pruning, root pruning, various training systems, girdling, scoring, bark invasion and the application of growth retardants. One strategy for promoting early fruiting, less vigour and increasing production is to utilize dwarf root stocks. The mechanism underlying dwarfing involves anatomical, physiological and biochemical changes. It has been proposed that dwarfing rootstock or interstock control tree size by regulating the auxin that passes through the rootstock or interstock's bark. Paclobutrazol retards growth, shoot elongation and reduced internodal length by inhibiting gibberellins synthesis. Dwarfness can be imparted by the using incompatible rootstock. Dwarfing can be induced by inducing viral infection, although, it is not commercially adopted. Recombinant DNA technology has recently expanded the gene pool that can be managed to cause dwarfism and maximize benefits in horticulture crops.

Key words: Dwarf rootstocks, Dwarfism, Fruit crops, Interstock, Pruning, Training, Vigour.

Dwarfing is a modification of the usual pattern of development. Dwarfing fruit trees are important for fruit growth, production and quality. Big, vigorous fruit trees are a challenge for fruit farmers because cultural operations such as fruit thinning, bagging, picking, pruning, *etc*. are difficult to perform. In dwarf, small and compact trees operations like pruning, thinning, spraying and harvesting, *etc.* are easy which lead to high grade fruit production at lower cost of cultivation. Dwarf plants exhibit precocity, canopy architecture, early blooming and altered fruit size in addition to being smaller than average at full maturity (Dhillon and Bhat, 2012). Anatomically and histologically Dwarf plants are like normal plants, but horticultural methods change the tree's physiology, resulting in dwarfing. In modern orchards, dwarfing is called attractive traits, where dwarf genetics can be picked and propagated. Dwarfing is based on the principle of making the optimal use of vertical and horizontal space per unit time and harnessing the highest potential returns per unit of inputs and natural resources (Goswami *et al*., 2014). Genetic modifications and horticultural manipulation can be used to grow dwarf trees, *e.g*. rootstock, pruning, training, deficient irrigation and plant bioregulators.

Most modern fruit farmers who pick fruits by hands for the fresh market prefer dwarf trees for easy harvesting, pruning and fruit thinning operations with no or minimal use of ladders. Dwarf trees are also easier to spray, eliminating unwanted spray drift and enhancing spray effectiveness.

Dwarf rootstock is one of the main means of obtaining a tree of dwarf stature (Atkinson and Else, 2001). The physiological processes through which dwarfing rootstocks influence vigour of scion, tree growth and fruiting are obscure, despite the fact that various hypothesis have been proposed in an attempt to understand these consequences.

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This review article briefly describe physiology of dwarfism, anatomical, physiological and biochemical mechanisms of dwarfing rootstocks and different methods to achieve dwarfism in fruit trees.

Physiology of dwarfism

Various horticultural techniques are used in fruit crops like selection of spur type scion cultivar, use of different interstocks, plant and root pruning, use of growth retardants, management of nutrients, girdling, scoring, bark inversion, use of dwarfing rootstocks.

Dwarfing function includes anatomical, physiological and biochemical changes. Since auxins are synthesized in young leaves and shoots, it flows basipetally to the roots through phloem and cambial cells. Some auxins are degraded in bark by IAA oxidase, peroxidase and phenols and other compounds that are genetically regulated. The amount of auxins that enters the roots affects roots development and metabolism, such as production of other hormones like cytokinins, gibberellins and abscisic acid

(ABA), which in turn retains balance in shoot and root growth. It has been observed that the thicker bark and higher starch content of the dwarf rootstock suggest a low level of auxins in these tissues. It has been proposed that dwarfing rootstock or interstock control tree size by regulating the auxin that passes through the rootstock or interstock's bark (Soumelidou *et al*., 1994). The dwarfing Fuji/M9 exhibited lower indole-3-acetic acid (IAA) than the vigorous Fuji/MM106. When apple cv. Fuji grafted in M9 rootstock, the indole acetic acid (IAA) concentration in the phloem of M9 rootstock was greater than Fuji scion phloem. Generally the lower auxin concentration was caused by the reduced expression of the auxin synthesis gene MdYUCCA10a in Fuji on M9 rootstock (Song *et al*., 2016). Foster *et al*. (2017) found overabundance of flavanoids and the down regulation of auxin influx transporters *MdAUX1* and *MdLAX2* in dwarfing rootstocks. Both variables believed to decrease polar auxin transport in dwarfing rootstocks.

Toft *et al*. (2019) studies anatomical structure of Macadamia cvs. B 63 (low vigour), B 25 (intermediate vigour) and D 4 (High vigour). They found that variations in tree height were related to xylem vessel parameters such as average vessel area of the 10 largest vessels per section, pith size and total additive vessel area.

Nutrient absorption research reveals that conducting phloem has more calcium than non-conducting phloem, cambium and xylem. The non-conducting phloems are much more in dwarfing rootstocks and Calcium concentrates in necrotic tissues. A higher number of non-conducting phloems have been observed in rootstocks with thick bark (M9) than those with thin bark *i.e*. MM106 or M7 (Simons and Chu, 1984).

Significant progress is being made in the identification of genes that influence morphological characteristics and their incorporation in the breeding programme for fruit crops. New genotypes and endogenous hormones are likely to be adopted in cultural practices that affect tree shape as important links for the management of crowns through genetic and cultural techniques.

Methods to achieve dwarfism

1. Use of dwarfing rootstock/interstock.
2. Use of bioregulators.
3. Use of incompatible root stock.
4. Induction of viral infection.
5. Pruning and training.
6. Use of phenols.
7. *In vitro* techniques.
8. Genetic engineering.
9. Ringing or girdling.

Use of dwarf rootstock/interstock

Utilization of dwarfing rootstocks is one of the way of encouraging early fruit bearing, reduced vigour and increased yield. Several research indicated a link between precocity and compact tree size (Lauri *et al*., 2006; Costes and Garcia, 2007). Dwarfing rootstocks promoted precociousness in scion, which is associated with increased starch content (Zhou *et al*., 2020). When apple cultivars are grafted on dwarfing rootstocks M 9 and M 27 flowered more frequently than those on M 793 (Foster *et al*., 2016). Mango cv. Pusa Surya grafted on Olour and Kurakkan rootstocks produce dwarf trees. Rootstock K-5 and K-2 induced dwarfness in scion of mango cvs. Pusa Surya and Pusa Arunima (Dubey *et al*., 2021). Due to its high yield efficiency and fruit quality, the hybrid HTR-051 rootstock promotes dwarfism in citrus species and appears to offer good prospects for high density orchards (de Carvalho *et al*., 2019). Cashew cv. VRI-3 grafted on Taliparamba-1 consistently reduce mean tree height, trunk cross-sectional area, canopy spread and plant volume, indicating decreased growth and vigour (Janani *et al*., 2020). The self-compatible dwarf seedlings of Morabbaei and Zinati apples improved the uniformity of the trees, resulting in a good yield and a long blooming phase (Saghafian Larijani *et al*., 2021).

Dwarfing rootstocks in different fruit crops

Apple: M 27, M 9, M 26, P 2, MAC 9, M 4, M 7, MM 106.
Pear: OH × F 51, Oregon 211, Oregon 249, BP-1, Quince C.
Almond: Adafuel bitter almond.
Apricot: *P. besseyi*, P 2038.
Cherry: Colt, Charger, Gisela 5, CAB 6P, CAB 11 EW.
Peach: Siberian C.
Plum: Pixy, St. Julien K, GF 43, *P. maritima*, *P. tomentosa*.
Citrus: Flying Dragon.
Guava: *P. fredrichsthalianum*, *P. pumilum*, Pusa Srijan.

It has also been suggested that dwarfing is induced by reduction in water flowing to the anatomical features of the dwarf rootstock. Dwarfing has also been linked to partial incompatibility between the scion and rootstock, which may interfere with mineral and hormone transport.

Physiological processes of root stock inducing dwarfness

Anatomy of dwarfing rootstock

Dwarfing rootstocks have less xylem fibers and smaller xylem vessels than vigorous rootstock, besides having higher percentage of bark and wood ray tissues per unit cross sectional area of root system. Dwarfism and graft incompatibility are associated to vessels frequency and size, as well as the location and size of the cambial zone (de Carvalho *et al*., 2018). Periderm thickness, cortex thickness, pith radius and sieve tube area of dwarfing rootstock were considerably lower than that of the vigrous rootstock, whereas average vessel density, xylem thickness/branch radius, vessel area near phloem/sieve tube area, central vessel area/sieve tube area, vessel area near pith/sieve tube area and average vessel area/sieve tube area of dwarfing rootstock were considerably higher (Li *et al*., 2019). The hybrids derived from crosses between *Prunus cerasus* and *Prunus fruticosa*, the weaker parental species with smaller vessels, might produce rootstock choices with improved size-controlling ability. The size of xylem vessels is mostly determined by genetics and demonstrates various degrees of dominance-partial (very near to better parent), full and over dominance (Ljubojevic *et al*., 2021).

Carbohydrate partitioning

Rootstock influences carbohydrate partitioning between, above and below the graft union parts of the tree (Olmstead *et al*., 2010). With both dwarfing rootstocks P 67 and B 396, apple cv. Ligol had a much greater leaf area and lower leaf carbohydrate content and photosynthetic pigment (Samuolienë *et al*., 2016). Under intense crop load (150 inflorescences per tree), super-dwarfing P 22 rootstock resulted in N deficit in the leaves of apple cv. Ligol, resulting in an accumulation of leaf sugars (Samuolienë *et al*., 2016). Apple plants grafted on dwarfing and super dwarfing rootstocks had increased starch content in leaves, which could be a contributing factor to the observed enhanced precocity (Zhou *et al*., 2020). Starch concentrations were twice as high in M 9 roots, stems and grafted Royal Gala (RG) apple scions as in equivalent tissues from Royal Gala homo-grafted trees (RG/RG). Glucose and Fructose levels were significantly decreased in all three tissues of Royal Gala apple trees grafted on M 9 rootstock. These findings suggest that dwarfing rootstocks, despite possessing enormous starch reserves, are suffering from sugar depletion and diminished cellular activity (Foster *et al*., 2017). Although Troyer citrange performed badly in terms of fruiting density and nutrient accumulation, Troyer citrange rootstock decreased scion cultivar vigour and leaf sodium content of lemon cv Kagzi Kalan (Dubey and Sharma, 2016). All scions of apple cultivars grown on dwarf rootstock M 27 had the lowest dry weight of stem and leaf (Tworkoski and Fazio, 2016).

Hydraulic conductivity

Dwarfing rootstocks are distinguished by a significant decrease of xylem hydraulic conductivity near the grafting point, where callus and meristematic tissues frequently develop in consequences to varying degrees of variation among the two live tissues (Olmstead *et al*., 2006). When compared to vigorously growing trees, dwarf trees frequently have lower hydraulic conductance and are less resistant to diseases, pests and abiotic stress (Albacete *et al*., 2015). Zhou *et al*. (2020) found that Red Fuji apple grafted on B.9 and M.9 rootstocks showed significantly decreased soil-to-leaf hydraulic conductance, palisade/spongy parenchyma ratio and stomatal density. They suggest that the reduced hydraulic conductance caused decrease in net photosynthesis, which resulted a decrease in immediate whole-canopy photosynthetic assimilation.

Uptake and translocation of water and minerals

Dwarfing rootstocks are less effective than vigorous ones in uptake of water and nutrients and their supply to shoots. The low vigour that Riparia Gloire rootstock usually confers on scions may be due to a combination of decreased nitrogen translocation to shoots and a larger allocation of biomass toward roots (Rossdeutsch *et al*., 2021). It was determined that dwarfing rootstocks may be less effective in soil nutrient absorption. The decline in nutrient uptake ability in certain rootstocks may be due to decreasing root volume (Ben Yahmed *et al*., 2016).

Nonetheless, the results of numerous research assessing rootstock influences on water/solute absorption and transport demonstrate inconsistency. A few of these variations were likely due to the diverse genera, species and cultivars studied, variances in the ages of the trees tested and issues with methods employed to collect xylem sap.

Phytohormones

Plant hormones, also known as phytohormones, are naturally occurring small organic molecules or chemicals that regulate physiological processes in plants at extremely low concentrations (Davies, 2010). Auxins are the main hormones affecting scion/stock interactions. Less auxin flow take place through bark of dwarf rootstock as compared to vigorous ones. The dwarfing rootstock had a lower intensity of polar auxins transfer (PAT) through micro-propagated stem tissue than more invigorating rootstocks (Else *et al*., 2018). When compared to MM 106 trees, root-and shoot-specific abscisic acid (ABA) deliveries in M 9 composite trees were considerably greater and the increased ABA import corresponded briefly with earlier shoot growth cessation in M 9 composite trees (Else *et al*., 2018). Dwarfism in crabapple plants is induced by a decrease in indole-acetic acid (IAA) concentration and variations in the IAA:ABA (abscisic acid) content ratio (Rudikovskii *et al*., 2019). The 'Nantong-xiaofangshi' interstock influences water conductance and gene expression in the grafted scion associated to IAA and Gibberellic acid (GA) metabolism and transduction, hence regulating phytohormone levels and causing dwarfing (Shen *et al*., 2019). Abscisic acid and abscisic acid glucose ester levels were higher in the roots, xylem exudate, rootstock stem below the graft union and scion above the graft union of dwarfing rootstock M 9 than in MM 111. Decreased gibberellin (GA19) was discovered in the xylem exudate and roots of apple cv. Gala grafted on M 9 rootstocks rather than MM 111 rootstocks. These findings confirm the idea that hormone signals from rootstocks govern tree growth; however, time after planting, phase of development and environmental elements are expected to interact to alter the growth impacts of size-controlling rootstocks (Tworkoski and Fazio, 2016).

Bark of the rootstock

Because auxins are degraded by several enzymes, plants with thick bark are dwarf. Harrison *et al*. (2016) examined the root bark percentage of M 116 and M 27 rootstocks grown in pots and grafted with apple cv. Royal Gala and cultivated for three years. The root bark percentage of the dwarfing rootstock M 27 was 85.3 percent, while the semi-vigorous rootstock M 116 had a lower root bark percentage of 62.6 per cent. The percentage of shoot bark was found to have a negative correlation with plant growth (Yang *et al*., 2016).

Reduced root system of dwarfing rootstocks

The root systems of dwarf rootstocks are small and restricted. Formation of fine roots and mortality in Red Fuji apple trees cultivated on dwarfing M 9 and Shao series no. 40 rootstocks were much less than in trees cultivated on vigrous *Malus robusta* Baleng Crab (BC) rootstock. In comparison to Baleng Crab rootstock, the utilization of M 9 and SH 40 as interstems resulted in a significant reduction in fine root formation and mortality. About half of the fine roots in a Red Fuji apple tree growing on dwarf rootstock M9 were distributed within the top 0-20 cm of top soil, signifying a shallow root system in M9, whereas 55.15 % of fine roots in trees growing on standard Baleng Crab ootstock were scattered among 100 and 150 cm soil depth, implying a deep root architecture (An *et al*., 2017). The Red Fuji apple trees on dwarfing rootstock Shao series no. 40 had smaller root system volume, projected area, surface area, less root number and short length of root system than on vigorous rootstock Baleng Crab (Zhang *et al*., 2021). The number of roots could be the deciding element in the variations between the two root systems (Zhang *et al*., 2021).

Depletion of solutes in xylem sap of scions by dwarfing rootstock

The graft union affected the ionic composition of the xylem sap. Passage through the M.9 graft union at extremely low flow rates reduced sap osmolality and Ca2+ ion concentration (Else *et al*., 2018). In comparison to vigorous rootstocks, leaf Ca and Fe concentrations of Granny Smith apple on semi-dwarfing rootstock M.26 were lower below the optimal range (Jobir, 2017).

Dwarfing root stocks induce restricted canopy development of scion variety

Many studies have demonstrated that when branches are oriented towards the horizontal, whether naturally or by tree training, they grow less vigorously (Webster, 2004). Dwarfing rootstocks accelerated the cessation of primary axis growth (Foster *et al*., 2016). Apple cv. Fuji trees on dwarf rootstock M 27 developed short primary axis, low cross trunk sectional area and less number of sylleptic shoots than on vigorous rootstock M793 (Foster *et al*., 2016). It has been claimed that trees grown on dwarfing rootstocks have accelerated leaf production cessation, as well as faster leaf senescence and abscission (Marini and Fazio, 2017). At eight years of age, a decrease in canopy volume of Valencia Orange by 77% were observed on dwarfing rootstock Flying Dragon in comparison with most vigorous rootstocks. The number of new flushes was also lower on dwarfing rootstock Flying Dragon (Rodrigues *et al*., 2020). Grafting of cherry cultivars on dwarfing rootstock Gisela 5 reduced the average length of annual growth. Tree grafted on Gisela 5 rootstock generated less long fruiting branches and much more short fruiting branches than on vigrous rootstock Mahaleb (Pal *et al*., 2017).

Use of bioregulators

Paclobutrazol is an effective growth retardant to reduce the tree size in high density planting. Paclobutrazol helps in restricting vegetative growth of tree by retarding tree growth by inhibiting the biosynthesis of gibberellic acid. Paclobutrazol can be applied through foliar application and soil application. However, drenching of paclobutrazol in soil around the tree trunk is the most effective one. The Paclobutrazol (PBZ) treatments inhibited vegetative growth while enhancing reproductive growth in cashew. The Paclobutrazol treatments changed the physiology of the cashew tree by reducing vegetative growth, increasing flowering and producing a greater quantity of fruits and nuts (Mog *et al*., 2019). When sprayed as a foliar spray, paclobutrazol and chlormequat were significantly efficient in vegetative growth inhibition. Foliar application of paclobutrazol inhibited growth by increasing proline accumulation while decreasing gibberellin content in leaves (Ajmi *et al*., 2020). With paclobutrazol application, plants pruned to 50% of current season growth had lower shoot length, plant height, tree girth and canopy spread, compared to trees pruned to 50% of previous season growth and unpruned trees (Srilatha *et al*., 2016). Root pruning combined with paclobutrazol treatment could be the most effective technique for reducing tree size and enhancing flowering in a pear orchard (Raja *et al*., 2018). In non-irrigated 'Hass' avocado trees, the use of gibberellin biosynthesis inhibitors significantly inhibited shoot development above indeterminate inflorescences (Brogio *et al*., 2018). In rain-fed conditions, growth retardants have a high potential for enhancing cropping parameters, suppressing growth and optimizing water relations. When applied as a soil drench in November, PP333 (4 g a.i per tree) decreased growth, internode length, leaf area, stomatal size, water potential, transpiration rate, endogenous GA content, stomatal conductance and increased leaf thickness, leaf chlorophyll content and photosynthesis of the olive cultivar Leccino under rain-fed conditions in Himachal Pradesh, India (Kumar and Sharma, 2016). The use of 125 mg/dm-3 prohexadione-calcium inhibited vegetative growth of Golden Delicious apple trees while having no influence on fruit quality or yield parameters (Atay and Koyuncu, 2017).

Use of incompatible rootstocks

Dwarfness can be imparted by the use of incompatible scion and stock. However, it is not commercially exploited. Certain incompatibility symptoms were observed in pear cultivars grown on Quince C dwarf rootstock, like small leaf size and early leaf yellowing that could be attributed to vascular discontinuity at the graft union (Askari-Khorasgani *et al*., 2019). Ber scion cultivars grafted on *Zizyphus nummularia* rootstock may cause dwarfness due to graft incompatibility (Saroj and Singh, 2018). At 64 months following planting, visual signs of incompatibility between the 'Pera' orange grafted onto the Flying Dragon can be observed. Dwarfism and graft incompatibility are connected to vessel size and frequency, as well as the size and disarrangement of the cambial zone (de Carvalho *et al*., 2018). At 10 and 21 days after grafting, *ParPAL1* (phenylalanine ammonia-lyase) transcripts were three times more abundant in incompatible unions of *Prunus spp*. than in compatible unions, but *ParPAL2* transcripts were upregulated in graft incompatible unions (Irisarri *et al*., 2016).

Induction of viral infection

Dwarfing can be induced by inducing viral infection, although, it is not commercially adopted. Citrus dwarfing viroid (CDV-d) infection of navel orange trees produced on trifoliate orange rootstock has previously been observed to lower canopy volume by 50%. (Vidalakis *et al*., 2011). The gene expression of CDVd-responsive miRNAs suggests that these miRNAs are involved in regulating essential citrus tree growth and development processes, which may contribute in the cellular changes observed in *C*. *sinensis* on *C*. *trifoliata* rootstock dwarf phenotype (Dang *et al*., 2021). In Shine Muscat grapevines, Infection with viral pathogens such as hop stunt viroid, Grapevine geminivirus A, Grapevine yellow speckle viroid 1 and Grapevine fabavirus produced severe dwarfing and leaf malformation by graft inoculation from the mother vine (Chiaki *et al*., 2020). Due to infection with the Milk vetch dwarf virus (MVDV), symptoms of leaf yellowing and dwarfism were seen in papaya trees grown in Yesan, located in the western part of the Korean peninsula (Lal *et al*., 2018).

Pruning and Training

Dwarfing can be achieved through pruning and it has been observed that slow growing trees responds more. A dwarf tree is achieved by removal of shoot apical portion which stimulate lateral bud growth. Tree size control trough pruning is limited to grape, apple and some temperate crops. In apple cv. Topaz grafted on M9 rootstock, trees trained as modified slender spindle had lower canopy volume compared to slender spindle and demonstrated better tree size control (Mészáros *et al*., 2017). Trees of cherry cv. 0900 Ziraat grafted on Gisela 5 rootstock and trained as spindle bush had lower tree height (Aglar *et al*., 2016). Guttingen V training system reduced tree vigour of the apple trees and accommodated higher planting density (3000 tree/ha), compared to the Geneva Y trellis system (1680 tree/ha) (Dadashpour *et al*., 2019). The number and percent of spurs improved while the number and proportion of long and medium shoots reduced as branch bending angles increased in Fuji apple (Zhang *et al*., 2017).

Use of phenols

Phenols reduce vegetative growth by inhibiting cell division, mitosis, cell elongation and increased oxidative decarboxylation of IAA. Some phenols also restrict sugar and auxin translocation or function via controlling polar auxin transport *e.g*. Coumarin, phloridzin. Li *et al*. (2014) investigated seventeen Chinese dwarf cherry cultivars and found higher phenol concentration (851–1899 mg/100 g FW) than that of blueberry, red raspberry, strawberry and blackberry. Whether grafted or not, Mango rootstock Hybrid 13/1 has the highest phenol content, followed by Sabre, Gomera 3 and Socaria rootstocks in descending order. It is obvious that Socaria rootstock, which is regarded a vigorous rootstock, has the lowest phenol level, whereas Hybrid 13/1, which is regarded a dwarfing rootstock, has the highest phenol level. As a result, it is possible to conclude that there is a negative correlation between phenol content and growth vigour (Zayan *et al*., 2020). Semi-vigorous rootstocks (MM106) were found to have higher total phenolic levels than the other two dwarf rootstocks. The concentrations of p-coumaric acid and p-hydroxy benzoic acid in semi-vigorous rootstock were higher than in dwarf rootstock (Yıldırım *et al*., 2016).

In vitro techniques

Khattak *et al*. (2007) subjected embryos of three apple cultivars to different concentrations of BA for somaclonal variation via *in vitro* techniques. BA @ 60 µM induce dwarfing in apple cultivars Golden Delicious and USDA 4-20 with 100 % survival of embryos. In cultured tissues subjected to TDZ, compact shoots and impeded shoot elongation were observed (Varshney and Anis, 2012; Zaytseva *et al*. 2016) and inhibited rooting, stunted and thickened root systems were also observed (Dobránszki and da Silva, 2010). Ganapathi *et al*. (2016) irradiated several shoot cultures of Giant Cavendish banana with gamma radiation at 10 Gy and analysed their performance in the field. They discovered that two clones, TBM-2 and TBM-6, were dwarf in comparison to the control and late flowering, but matured considerably earlier than the control plants. Nagaraja *et al*. (2019) treated multiple in vitro shoot cultures of two banana cultivars, Grand Naine (AAA) and Rajapuri (AAB), with EMS (Ethyl Methane Sulphonate) at various concentration to induce genetic variability via mutation. They discovered that Rajapuri plantlets treated with 0.5 percent EMS produced the most dwarfing mutants. Sales and Roca (2016) investigated the influence of long subculture and high 2, 4-D dosage on yield and other postharvest features of banana cv 'Lakatan' somaclones. They discovered that long-term culturing and the addition of a high concentration of 2, 4-D resulted in both positive and negative changes. Higher bunch weight, earlier flowering, better shelf life and a greater number of hands all showed positive variation, resulting in higher income. Dwarfism, delayed blossoming and a smaller number of hands were examples of negative variation.

Genetic engineering

Shao *et al*. (2020) used the CRISPR/Cas9 technology to alter *MaGA20ox2* genes in 'Gros Michel' and produced semi-dwarf mutants. Various genes, such as *Ipt*, *OSHI* and *rolA, B, C*, have been discovered in fruit cultivars that can cause dwarfism. Overexpression of the Arabidopsis *gaai* gene resulted in a reduction in stem length and node number in apples. The transgenic expression of a hairpin construct to silence *GID1c* gene in plum resulted in dwarf phenotypes comparable to brachytic dwarfism trait peaches. The degree of *GID1c* silencing correlated with the degree of dwarfing in general (Hollender *et al*., 2016). Feng *et al*. (2017) discovered changes in cytokinin metabolic pathway gene expression and root trans-zeatin concentration among dwarfing and vigorous rootstocks of apple. They discovered reduced *IPT5b* gene expression with high levels of methylation in the promoter region, resulting in poor root trans-zeatin synthesis in the M 9 rootstock and possibly dwarfing. MdKNOX15, an apple KNOX transcription factor gene, was shown to be more abundant in the scion of Fuji grafted on M 9 trees, which show dwarfism with early flowering, than in self-rooted Fuji trees (Jia *et al*., 2021). Jia *et al*. (2018) investigated the function of *MdNAC1*, a novel NAC transcription factor (TF) gene in apple that is associated with plant dwarfing. Transgenic apple plants with the gene overexpressed had a dwarf phenotype. Their reduction was showed by shorter, thinner stems and roots, as well as a decreased leaf area. Transgenics also had shortened internodes and less stem cells. Endogenous brassinosteroid (BR) and abscisic acid (ABA) levels were reduced in transgenic plants and expression of genes involved in the biosynthesis of those phytohormones is reduced. All of these results showed that *MdNAC1* has a role in plant dwarfism, most likely through regulating BR and ABA production. Pang *et al*. (2019) created 22 positive transgenic pear lines by transferring the *PbPAT14*, *phosphinothricin acetyltransferase* (*PAT*), gene utilising cotyledons from *Pyrus betulifolia* seeds by Agrobacterium-mediated transformation. According to sequencing studies, six of these lines had homozygous mutations and showed the dwarf yellowing phenotype. The mutant lines had increased levels of endogenous abscisic acid (ABA) and transcript levels of ABA pathway genes, indicating that the *PbPAT14* function was related to the ABA pathway. Liu *et al*. (2017) stated that qRT-PCR analysis of various citrus rootstocks revealed that expression levels of *ARF1*, *ARF8*, *GH3* and *IAA4* genes were negatively linked with growth vigour and IAA content. The dwarf phenotype of autotetraploid apple plants may be caused by the accumulation of miR390 after genome doubling, which leads to upregulation of apple *trans-acting short-interfering RNA 3* (*MdTAS3*) expression, which in turn down regulates *MdARF3* expression. Overall, the indoleacetic acid (IAA) and brassinosteroid (BR) signal transduction pathways are partially disrupted (Ma *et al*., 2016).

Ringing or girdling

Ringing or girdling impeded the flow of carbohydrates down to the roots, which causes accumulation of carbohydrates above the girdle, causing a difference in root development which result in differences in shoot growth. In apple, 2 cm girdling in August month significantly decrease tree vigour and improve fruit quality (Matsumoto *et al*., 2021). Choi *et al*. (2018) recommended early July scoring at the trunk to control tree vigor and to improve fruit quality of persimmon cv. Fuyu.

CONCLUSION

Dwarfing in fruit crops can be accomplished through a variety of methods, including the use of dwarfing rootstock, the selection of spur type scion cultivars, use of interstock, pruning, root pruning, various training systems, girdling, scoring, bark invasion and the application of growth retardants. Paclobutrazol is one of the most effective and extensively used growth retardants. The mechanism of dwarfing is obscure, although it involves morphological, physiological and biochemical changes that affect the vigour of the tree. Dwarfing effects are most likely caused by disruptions in auxin:cytokinin metabolism and translocation within the compound tree. Dwarfing rootstock is crucial for managing tree size and inducing precociousness in fruit plants. Although viroid induction causes dwarfing in citrus, it is not used economically. The use of various training systems such as modified slender spindle, spindle bush and Guttingen V aids in the regulation of tree size. The use of chemicals or hormones such as BA, TDZ, EMA and 2,4-D and gamma irradiation during micro-propagation aids in the production of dwarf plants *in vitro*. Recombinant DNA technology has recently expanded the gene pool that can be managed to cause dwarfism and maximize benefits in horticulture crops.

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