The Pharma Innovation Journal 2022; SP-11(3): 664-667

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(3): 664-667

www.thepharmajournal.com
Received: 10-01-2022
Accepted: 12-02-2022

Astha
Department of Horticulture Naini Institute of Agriculture, Faculty of Agriculture, Sam Higginbottom University of Agriculture, Technology and Sciences Prayagraj, Uttar Pradesh, India

Vijay Bahdur
Department of Horticulture Naini Institute of Agriculture, Faculty of Agriculture, Sam Higginbottom University of Agriculture, Technology and Sciences Prayagraj, Uttar Pradesh, India

S Narayan
Division of Vegetable Science, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu & Kashmir, India

Raj Narayan
ICAR-ATARI, Zone-II, CAZRI Campus, Behind AIIMS, Jodhpur, Rajasthan, India

FA Khan
Division of Basic Sciences & Humanities, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar, Jammu & Kashmir, India

Corresponding Author
Astha
Department of Horticulture Naini Institute of Agriculture, Faculty of Agriculture, Sam Higginbottom University of Agriculture, Technology and Sciences Prayagraj, Uttar Pradesh, India

Dwarfism in fruits crops: A way to produce new canopy architecture

Astha, Vijay Bahdur, S Narayan, Raj Narayan and FA Khan

Abstract
Dwarfing is an alteration in the normal growth pattern. A dwarf plant is that which is smaller than normal size at full maturity and possess other characteristics like precocity, canopy architecture and time of flowering and altered fruit size. As fruit trees generally have a large size, the production of small or even dwarf trees are of great interest for most of fruit crops. In this review, some of the main tropical, subtropical and temperate fruit trees that have small or even dwarfing cultivars are approached. The causes of dwarfism, although the use of dwarfing rootstocks, is the main theme of this review. The factors that affect the size of the fruit trees are also approached, as well the dwarf cultivars of banana, papaya and cashew, and the dwarf rootstocks for guava, mango, anonaceae, loquat etc. The principle is to make the best use of vertical and horizontal space per unit time and to harness maximum possible returns per unit of inputs and natural resources. The mechanisms underlying involves anatomical, physiological and biochemical changes. The various methods to induce dwarfism include: use of dwarfing root stock/ interstock or use of dwarfing scion; Use of bio regulators; Use of incompatible root stock; Induction of; viral infection; Pruning and training; Nutrients; Phenols; In vitro techniques; Genetic engineering; Ringing or girdling and Others. Some important dwarfing rootstocks of fruit crops include: Apple: - M27, M9, EMLA 26; Pear: - Quince C; Peach: - Siberian C, St. Julien X, *P. besseyi* and Rubira; Plum: - St. Julien A, St. Julien K, Pixy; Cherry: - Giesela series, Stockton Morello, Oppenheim, Charger; Mango: - Olour, Vellaikolumban; Citrus: - Trifoliate Orange, Flying Dragon; Guava: - Pusa Srijan, *P. friedrichesthalianum*; Ber: - Jhar ber. Dwarfing in fruit crops can be achieved through various approaches like use of dwarfing rootstock, root pruning, training, use of growth retardants, control of nutrient elements etc.

Keywords: Dwarfing, canopy, fruit crops, scion, interstock, bioregulator

Introduction
Dwarfing is an alteration in the normal growth pattern. A dwarf plant is that which is smaller than normal size at full maturity and possess other characteristics like precocity, canopy architecture and time of flowering and altered fruit size ref. As fruit trees generally have a large size, the production of small or even dwarf trees are of great interest for most of fruit crops. Although, there are different causes of dwarfism, the use of dwarfing rootstocks, is the main theme of this review. The factors that affect the size of the fruit trees as well the dwarf cultivars of banana, papaya and cashew, and the dwarf rootstocks for guava, mango, Annonaceae, loquat etc. are also discussed, Fruit trees are propagated by grafting the desired variety to a rootstock. By selecting special rootstocks, it is possible to grow all of our apple varieties and many pear varieties as so-called "dwarf" or miniature trees. Peaches, plums, and cherries may also be dwarfed if grown on the proper dwarfing rootstock. Dwarf apple trees require a rootstock known as Malus EM IX, whereas apple trees of intermediate size are grown on Malus EM VII. Pears are generally dwarfed by grafting on quince rootstock such as Angers quince, but not all pear varieties will grow on quince. The following varieties are entirely compatible with quince and can be grown as dwarfs: Duchess d' Angouleme, Beurre Hardy, Flemish Beauty, and Beurre Diel. Anjou, Bartlett, Claps Favourite, Dana Hovey, and Tyson might survive, but the trees will break easily at the point of union and should therefore always be supported by a stake. Bose, Seckel, and Sheldon will grow poorly or not at all on quince rootstock. They can be dwarfed, however, by double-working. Peaches can be dwarfed by grafting the desired varieties either on *Prunus besseyi* or *Prunus tomentosa* rootstocks. Certain plums and prunes, such as Beauty, Pearl, and Pacific plums and Italian and Stanley prunes, can also be grown as dwarf trees on *Prunus besseyi*. The dwarfing effect of certain rootstocks used for cherries, such as Mahaleb cherry seedlings and certain Morello cherries, is somewhat less than that of rootstocks used for apples peaches, pears, or plums.

Principle
To make the best use of vertical and horizontal space per unit time and to harness maximum possible returns per unit of inputs and natural resources.

Physiology of dwarfism
Mechanism - involves anatomical, physiological and biochemical changes. Auxins are produced by shoot tips and translocated basipetally downwards to the roots through phloem. Dwarfing rootstock controls tree Size-by controlling the auxin passing through the bark of the rootstock. Large number of vessels and twice as many xylem fibres are produced in vigorous rootstocks than dwarfing ones (Beakbane *et al.,* 1974) [3]. A greater number of non-functioning phloem has been found in rootstock with thick bark (M9) than those with thin bark i.e., MM106 or M7 (Chu and Simons, 1984) [30].

Methods to achieve dwarfism
Dwarfness can be achieved by various ways such as use of dwarfing root stock/ interstock or use of dwarfing scion; use of bio regulators; use of incompatible root stock; induction of viral infection; pruning and training; nutrients; phenols; *in vitro* techniques; genetic engineering; ringing or girdling, etc.

Use of dwarfing root stock/interstock
Use of vigour controlling root stocks is one method used to promote early fruit bearing, reduce vigour and increased yield. Various studies suggested a correlation between early flowering and smaller tree size (Costes and Garcia, 2007). Apple dwarfing rootstocks induce two most important effects i.e., precocity and reduction in tree size (Lauri *et al.,* 2006) [12].

Correlations for predicting dwarfing capacity of rootstocks
Percentage of live tissues of root cross section; bark: wood ratio; percentage of ray tissues in root cross section; high stomatal density on leaves; bark is the key factor as it reduces translocation of auxins, sugars and other compounds; genes exert their effect on dwarfness.

Physiological processes of root stock inducing dwarfness
Anatomy of dwarfing rootstock
Smaller xylem vessels and less xylem fibers; have a higher percentage of living tissues than lignified cells; higher percentage of bark and wood ray tissues

Nutrition
More carbohydrates are directed to fruiting structure and less to tree frame by dwarfing rootstock

Hydraulic conductivity
Reduced root hydraulic conductance helps to induce dwarfism (Nardini et al; 2006) [14].

Translocation of water and minerals
Less effective in uptake of nutrients and water; partial blockage at graft union affects water and nutrients translocation e.g., Reduction in translocation of P and Ca (Bukovac *et al.,* 1958).

Phytohormones
Less auxin flow take place through bark of dwarf rootstock; lower concentration of IAA and ABA are observed in dwarfing rootstock while vigorous rootstock showed higher cytokinin concentration in root pressure exudate and shoot xylem sap. Lack of ability to produce soluble sugars result in reduced growth e.g starch hydrolysis. NAA suppress the conversion while IAA promotes it that is why NAA cause dwarfing

Bark of the rootstock
Thicker the bark lesser the height as auxins get destroyed by several enzymes. e.g.- dwarfed avocado trees had 22.7 % of bark compared to 12.9 % in tall ones. Greater thickness in the bark of dwarf trees is associated with a higher degradation of auxins by IIA oxidase, peroxidase and phenolic compounds present in the bark (Lockhard and Schneider, 1981).

Reduced root system of dwarfing rootstocks
Dwarf rootstocks have small and limited root systems. More dwarfing a rootstock the smaller is its root system e.g.- M9 has limited root system compared to seedling rootstock (Fernandez *et al*.,)

Depletion of solutes in xylem sap of scions by dwarfing rootstock
It has been observed that dwarfing root stocks and inter stocks lead to depletion of xylem sap with respect to N, P, K, Ca and Mg (Jones 1976).

Dwarfing root stocks induce restricted canopy development of scion variety
Induce wider crotch angles to lateral branches and spreading habit in scions. Horizontal branches show both decreased vegetative growth and enhanced flowering and fruiting (Crabbe, 1984). Reduce the growth of both vertical and horizontal branches and effects being greater on vertical branches (Webster, 1995) [34].

Precocious and heavy fruiting at the expense of vegetative growth
Trees on dwarfing root stocks show a higher ratio of fruit yield to vegetative growth than those on vigorous root stocks.

Reduced carbohydrates transport from leaves to root
Dwarfing rootstock have been found to block the transport of carbohydrates from leaves to roots.

Some important dwarfing rootstocks of fruit crops
- Apple: - M27, M9, EMLA 26.
- Pear: - Quince C
- Peach: - Siberian C, St. Julien X, P. besseyi and Rubira.
- Plum: - St. Julien A, St. Julien K, Pixy.
- Cherry: - Giesela series, Stockton Morello, Oppenheim, Charger.
- Mango: - Olour, Vellaikolumban
- Citrus: - Trifoliate Orange, Flying Dragon
- Guava: - Pusa Srijan, P. friedrichesthalianum
- Ber: - Jhar ber

Use of bio regulators
A wide varieties of growth regulators re being used to regulate the growth rate of the fruit trees. Paclobutrazol inhibit the GA synthesis and thereby retards growth, shorten elongation and reduced internodal length.

Dwarfing mechanism due to PBZ is based upon
Shorter internodes due to less GA in tissues; reduces ABA levels in shoot tips (Kurian *et al*; 1993); reduces the levels of cytokinins (Kurian *et al;* 1993); enhances the total phenolic content of terminal buds (Kurian *et al;* 1993) [23].

Gibberlins biosynthesis inhibitors
Onium compounds- CCC, Mepiquat chloride, Phosphon-D; Triazoles- Uniconazole, Tripenthenol, Paclobutrazol; Pyrimidines- Inhibit synthesis of gibberlins; New molecules- Tetcyclasis, morphactins

Pruning and training
Slow growing trees responds more to pruning. A compact and bushy tree achieved by removal of apical portion. Limitation: - grape, apple and some other temperate crops. Of the various training systems being followed in apple e.g. spindle bush and single vertical axis raised on M9, M7 and M4 root stocks has been found promising for HDP w.r.t size control and higher yield per unit land area (Gyuro, 1978). Spindle Bush system Vertical axis system

Nutrients
Moderately vigorous trees utilize less nitrogen. Vigorous one uses more nitrogen.

Phenols
Phenols reduce vegetative growth by inhibiting mitosis, cell division, cell elongation and increase IAA oxidation. Some phenols also inhibit translocation of sugar and auxin or act by regulating polar auxin transport eg. Coumarin, phloridzin

In vitro techniques
Seeds are subjected to different level of BA (Benzyle adenine) and TDZ (Thidiazuron). The plants produced with TDZ and BA were slower in growth and dwarf in size thannon treated plants (Khattak *et al.*, 2004) [4].

Genetic engineering
DNA coding of sorbitol-6-phosphate dehydrogenase (S6PDH) which is the key enzyme of sorbitol biosynthesis introduced into Japanese induced dwarfism. The physiological mechanism behind this dwarfism effect has been attributed to accumulation of sorbitol which might have caused an osmotic imbalance between cytosol and vacuole (Deguchi *et al.*, 2004) [4].

Ringing or Girdling
With the removal of bark, the flow of carbohydrates down to the roots restricted and, therefore carbohydrates accumulate above the girdle producing differential effect on root development. This in turn, leads to differential effect on shoot growth.
Cutting and Lyne (1993), supported the hypothesis that less cytokinins and gibberellins above the girdle are likely to reduce meristematic activity and cell elongation, leading to reduction in vegetative growth.

Thrust Areas
Understanding the physiology of dwarfing rootstocks and their effect on scion vigour. Commercializing the use of incompatible rootstocks and use of viral infections for dwarfing. Need to develop dwarf rootstocks for evergreen subtropical fruit crops for HDP. Need to develop dwarf rootstocks which does not affect the fruit quality of scion cultivar. Opportunities will also exist to modify the root growth of crops for which no dwarfing rootstocks exist presently. Screening of dwarf cultivars for dwarfing genes in fruit plants e.g. S6PDH, GID1c from brachytic dwarf peach.

Conclusion
Dwarfing-canopy and rootstocks are suitable for a variety of fruit crop production techniques, particularly high-density plantings. Some tropical, subtropical, and temperate fruit species, primarily dwarfing-rootstocks, are available for this purpose, allowing for fruit production in both covered and open fields. Dwarfing in fruit crops can be achieved through various approaches like use of dwarfing rootstock, root pruning, training, use of growth retardants, control of nutrient elements etc. Paclobutrazol are most effective and widely used growth retardant. Dwarfing rootstock plays important role in controlling tree size and induce precocious bearing in fruit plants. Pruning practices like tip pruning, pinching, removal of apical buds, heading back, etc. control the tree size. Ringing and girdling control the tree size by restricting the flow of carbohydrates and auxins to the roots. Recently genetic engineering has widened the gene pool which can be manipulated to induce dwarfism and harvest maximum benefits in horticultural crops.

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