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Tree Canopy Architecture and Engineering: Physiological and Molecular Aspects

Sujeet Kumar Patel [a++], Vipin Kumar [a++], Divyansh Mishra [a++], Avdhesh Kumar [a++*], Prabhat Kumar [a++], Durge Dansena [b#], Imran Ali [a++], Brijesh Patel [a++] and Abhishek Sonkar [a++]

[a] Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (UP), India.
[b] Hort. Fruit Science, PSB, Visva- Bharati, Sriniketan, West Bengal, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The fruit industry is a vital part of the agricultural economy, and the quality and quantity of crops depend heavily on the science of tree canopy architecture and engineering. The canopy is the most important part of a fruit tree as it affects photosynthesis, fruit quality, and yield. The study of canopy architecture and engineering increased in importance due to the need for efficient agricultural practices that optimize fruit production while reducing the environmental impact. Factors that influence canopy architecture, such as light, water, and nutrient availability, genetic makeup of the plants, hormones, management practices and innovative engineering techniques

[++] Research Scholar;
[#] M.Sc. (Ag.) Horticulture;;
**Corresponding author: E-mail: avdheshk05797@gmail.com;*

can optimize orchard management. Canopy can managed by the using different types of pruning (Proper pruning can enhance light penetration, airflow, and disease management, ultimately leading to higher yields and healthier fruits), thinning, by using dwarfing rootstocks and training (such as central leader system, modified central leader system and open Centre system etc.) and also by using the growth retardant & regulators and through gene regulation for higher yield as well as quality improvement.

Keywords: Fruit crop; fruit quality; light; photosynthesis.

1. INTRODUCTION

Fruit crop development and yield are greatly influenced by the design of the tree canopy. It includes how the branches, leaves, and fruits are arranged, distributed, and composed overall inside the canopy [1,2]. The tree canopy acts as a dynamic contact between the plant and its surroundings in fruit crops. The distribution of nutrients, water, and light within the canopy is determined by the configuration of the branches and leaves [3,4]. This in turn impacts the tree's overall productivity as well as the growth and development of individual fruits [5-7]. Because of the dynamics of growth and development, the spatial arrangement of canopy components, or plant architecture, is liable to change throughout time [8-10]. An arrangement of leafy plants with a specific spatial distribution and variety of angle orientations makes up a plant canopy [11-14]. Aggregate of all crowns, or the whole of all leaves, twigs, and branches within a stand of plants.

2. PRINCIPLES AND OBJECTIVES OF THE UNDERSTANDING THE TREE CANOPY ARCHITECTURE

- **Maximum utilization of light**
  Growers can improve the total efficiency of photosynthesis, which raises sugar production and improves fruit quality, by optimizing canopy architecture. This can be accomplished by using a variety of methods that help to form the canopy and guarantee sufficient light penetration, like training, thinning, and pruning.
- **Avoidance of built-up microclimate congenial for diseases and pest infestation**
  The architecture of the canopy affects disease management as well. Improved air circulation from a well-structured canopy lowers humidity and lowers the chance of fungal illnesses. Additionally, it makes pest management easier to reach and enhances spray coverage, which results in more efficient pest control.
- **Maximizing productivity with quality fruit production**
  The quality of the fruit is also influenced by how light is distributed within the canopy. When opposed to fruits that are shaded, those exposed to direct sunlight typically have superior flavor, a higher sugar content, and better colors. To ensure uniform fruit development and desired quality qualities, the best canopy architecture should increase light penetration into the lower regions of the canopy.
- **Obtaining the required canopy architecture**
- **To facilitate cultural practices**
- **To increase input use efficiency**
- **Efficient use of pesticide and fungicide**

3. BASIC COMPONENTS OF TREE CANOPY ARCHITECTURE

There are three components of tree canopy architecture.

3.1 Branches

These are the woody projections from the tree's trunk that project outward. They act as channels for water, nutrients, and energy within the tree in addition to supporting the leaves and other elements of the tree.

3.2 Leaves

A tree's main organ for photosynthetic processes is its leaves. They are essential to the growth and survival of the tree because they absorb sunlight and use it to produce energy through the process of photosynthesis.

3.3 Trunk/ Stem

The primary structural components of a tree are its stems. They give the tree stability, move nutrients and water throughout it, and act as conduits for the products of photosynthesis to reach different areas of the tree.

4. TYPES OF CANOPY ARCHITECTURE

4.1 Round

The lower branches are spreading type, while the upper branches grow upward and outward. The main trunk has a sympodial branch pattern, which implies that eventually the main trunk growth stops and lateral branches emerge. Ex. Mango. A spherical canopy indicates unimpeded development, but a canopy with a flat top indicates wind-related obstruction of vertical growth, which includes air pollution.

4.2 Oblong/ Cylindrical

Taller than broad canopy trees fall under this category. The main stem is both sympodial, with short, ascending lateral branches, and monopodial, which implies the main branch grows upward from a single location. Ex. Jackfruit.

4.3 Umbrella Shaped

Main trunk is periphery-like, always sympodial. Ex. *Delonix regia.*

4.4 Conical Tree Canopy

The monopodial main trunk has branches that progressively get smaller from the base upward. Ex. *Auracauria*.

4.5 Weeping Type

The main stem is sympodial (Ber) and monopodial (*Polyalthia*). There are a few branches that either dangle from the main trunk or spread outside. The weeping peach tree has the same canopy diameter as the regular, columnar, and semiwarf kinds, but it is the shortest due to its pendulous limbs.

4.6 Drooping Type

Additionally, the stem is both sympodial and monopodial, with downward-pointing branches. Ex. Asoka

4.7 Palm

Principal stem is straight and unbranched, but it has a caudex-style stem with leaves grouped on top. Ex. Palm.

5. FUNCTION OF TREE CANOPY ARCHITECTURE

5.1 Carbon Sequestration

In order for photosynthesis to occur, carbon dioxide (CO2) from the atmosphere must be absorbed by tree canopies. By lowering the amount of greenhouse gases in the atmosphere, this carbon sequestration aids in the mitigation of climate change.

5.2 Shade Provision

The amount of direct sunlight that reaches the ground is decreased by tree canopies. By reducing heat and assisting in the cooling of the surrounding area, this shade saves energy and improves comfort for people.

5.3 Habitat Creation

A wide variety of microhabitats are available for different creatures due to the intricate structure of tree canopies. The canopy provides food, shelter, and nesting places for birds, insects, and other animals, promoting biodiversity and ecological balance.

5.4 Rainfall Interception

Rainfall is intercepted by tree canopies, which keeps it from falling directly to the ground. This interception helps keep Rivers and streams' water quality stable, decreases soil erosion, and improves water infiltration.

5.5 Air Quality Improvement

As filters, tree canopies collect airborne contaminants such dust, particulate matter, and toxic gasses. They enhance human health and the quality of the air by absorbing toxins and releasing oxygen.

5.6 Aesthetics and Cultural Value

Urban spaces, natural settings, and landscapes are all improved visually by tree canopies. They offer a sense of peace and a connection to nature, adding to the cultural and recreational value of outdoor places.

6. FACTORS INFLUENCING CANOPY SHAPE AND SIZE

6.1 Genetic Factors

One of the key factors influencing canopy architecture is the genetic makeup of the tree.

Different fruit tree varieties have inherent growth habits that influence the shape, size, and branching patterns of their canopies. Some varieties naturally have a more open canopy structure, with well-spaced branches that allow for better light penetration and airflow. Others may have a more compact or dense canopy, which can lead to reduced light exposure and increased susceptibility to diseases.

6.2 Environmental Factors

Environmental factors also play a significant role in shaping tree canopy architecture. Light availability, temperature, humidity, and wind conditions can all impact how a tree develops its canopy. In regions with abundant sunlight, trees may grow taller with a more upright growth habit to compete for light. Conversely, in areas with intense wind or extreme temperatures, trees may develop shorter, more compact canopies to reduce the risk of damage.

6.3 Management Factors

Human interventions, such as pruning, tree training, and selective cutting, can influence canopy shape and size. Cultural practices, including irrigation, nutrition, and pest management, can also affect tree canopy architecture. Proper irrigation and nutrient management can promote healthy growth and canopy development. Effective pest and disease control measures can prevent damage to the canopy and maintain its structural integrity.

7. CANOPY MANIPULATION TECHNIQUES

7.1 Pruning

Pruning is the selective removal of branches to control tree size, shape, and overall canopy structure. Pruning can help maintain tree health, improve light penetration, and enhance aesthetics. Removing half of the terminal shoots resulted in the highest number of flowering shoots, number of panicles per tree, length of panicles, perfect flowers percentage, fruit retention, and yield. It also recorded the highest reserve of total sugars and C/N ratio in the leaves at the time of flower bud differentiation. The greatest number of emerged shoots per pruned shoot was achieved by removing half of the terminal shoots. For the high-density "Amrapali" mango orchards, moderate pruning (removal of almost 20 cm shoot apex from top) following fruit harvesting in July may be a feasible choice for sustained output.

7.2 Training

Training involves guiding tree growth through the use of stakes, wires, or other supports. Training techniques help shape the canopy, promote desired growth patterns, and prevent structural weaknesses. Training methods includes central leader system, modified central leader system, open vase system, dwarf pyramid system etc.

7.3 Thinning

Thinning involves the selective removal of branches or foliage to reduce the density of the canopy. Thinning can improve air circulation, light penetration, and reduce wind resistance.

7.4 By Use of Plant Growth Retardant

Plant growth retardant is chemical substances that able to slow the growth rate of plants by inhibiting the gibberellins biosynthesis. Over the course of three years, paclobutrazol (15 mg/litre) dramatically decreased shoot length in plum, sour and sweet cherries, apricot, and pear trees, and TIBA (Triiodobenzoic Acid) (3.5 mg/tree) in plum and sour cherry trees, respectively. Ethephon at higher concentration (500-3000 ppm) effectively reduces plant height and increases flower production. ABA (Abscisic Acid) inhibits shoot growth in water stressed condition.

8. PHYSIOLOGICAL ASPECTS

8.1 Photosynthesis

The process of turning light energy, carbon dioxide and water into sugars is called photosynthesis, and it may be optimized to boost a plant's productivity and fitness. Canopy development is directly linked to photosynthesis. As leaves capture sunlight, they convert it into energy through photosynthesis, enabling growth and development of the tree. The availability of light and nutrients can influence photosynthetic rates, thereby affecting canopy development. Trees in more favorable conditions tend to have fuller and denser canopies.

8.2 Transpiration

The loss of water vapor through the stomata of leaves is another important process that occurs within the canopy. It helps regulate leaf temperature, nutrient uptake, and the movement of water and nutrients within the tree. By understanding the factors that affect transpiration, such as humidity, temperature, and airflow, growers can implement irrigation strategies that optimize water use efficiency and minimize water stress.

8.3 Dwarfing Rootstocks

It maintains the dwarfness of the plants which helps in the proper management like training, pruning thinning etc. Tree size can also be controlled by rootstock. The ‘Paradise’ apple, as dwarfing rootstock, has been known since the time of Alexander the Great and the Romans. A second important dwarfing apple rootstock, French Doucin, was mentioned for the first time in 1519. The quince has been used for many centuries as a dwarfing rootstock for pear. Compared to other tree phenotypes, peaches have the maximum number of second order branches per cent of first order branches, very short internodes, and narrow branch angles. The dense canopy is a result of these two characteristics.

9. MOLECULAR ASPECTS

9.1 Genetic Regulation of Canopy Development

Canopy development is regulated by various genes that control growth, cell division, and differentiation. Genes involved in the regulation of leaf initiation, expansion, and senescence play a crucial role in canopy development. Genetic variations in these regulatory genes can result in different canopy architectures, such as differences in branching patterns, leaf size, and overall canopy shape. In apple rootstock M26 using *rolAc* genes which slow shoot growth. Down regulation of *GA20 oxidase* in transgenic fruit trees resulted dwarf plants. *rolC*: Reduce internode length, *GA2*-oxidase: Control production of GA, dwarfing in apple tree.

9.2 Hormones Involved in Canopy Growth and Branching

Several hormones play important roles in canopy growth and branching, including auxins, cytokinins, gibberellins, and abscisic acid. Auxins are involved in apical dominance, where the main terminal bud suppresses lateral bud growth. The balance between auxin and cytokinins regulates lateral branching and canopy architecture. Gibberellins promote elongation of shoots, promoting canopy growth and influencing internode length. Abscisic acid is involved in stress responses and can affect canopy development under adverse environmental conditions. Regulation of GA biosynthesis by genetic manipulation is a better alternative to control plant size. For both root and shoot growth in plants, auxins are required.

9.3 Role of Transcription in Controlling Canopy Architecture

Transcription factors are proteins that bind to specific DNA sequences and regulate the expression of genes. Transcription factors play a critical role in controlling canopy architecture by modulating the expression of genes involved in cell division, cell expansion, and branching. Synthesis of RNA from DNA is called transcription. DNA is the genetic materials that give instructions for the development and function of the living things. It provides the genetic code for the synthesis of proteins. It also controls the gene expression, play in various enzymatic, structural and functional roles (photosynthesis, biosynthesis etc.).

10. CONCLUSION

Tree canopy architecture refers to the structure and arrangement of branches and leaves in a tree's uppermost layer and it plays a crucial role in the overall function and health of a tree as well as affects photosynthesis, fruit quality, and yield. Factors that influence canopy architecture, such as light, water, and nutrient availability, genetic makeup of the plants, hormones, management practices and innovative engineering techniques can optimize orchard management. Canopy can manage by the using different types of pruning (Proper pruning can enhance light penetration, airflow, and disease management, ultimately leading to higher yields and healthier fruits), thinning, by using dwarfing rootstocks and training (such as central leader system, modified central leader system and open centre system etc.) and also by using the growth retardant and regulators as well as through gene regulation for higher yield and quality improvement.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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