Fruit Growing Research, Vol. XXXX, 2024 DOI 10.33045/fgr.v40.2024.23
https://publications.icdp.ro/index.php

TEHNICI DE ALTOIRE ÎN CREȘTEREA PRODUCȚIEI DE POMI FRUCTIFERI DE MANGO (*MANGIFERA INDICA* L.) – SINTEZĂ
GRAFTING TECHNIQUES IN ENHANCING PRODUCTION OF MANGO (*MANGIFERA INDICA* L.) FRUIT TREES – A REVIEW

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Abstract

Mango (*Mangifera indica* L.) is a highly valued tropical fruit known for its exceptional flavor and nutritional benefits. Grafting is a key practice in modern horticulture, significantly boosting fruit yield and quality, as well as enhancing resilience to various biotic and abiotic challenges. This article emphasizes the impact of grafting on mango trees for accelerating flowering, and fruit production, improving yield, and enhancing overall orchard efficiency. Furthermore, the key aspects of grafting such as grafting compatibility, selection of suitable rootstocks, and the influence of environmental factors on successful grafting discussed. This study also focused on the adaptability of grafted mango trees to diverse environmental conditions, offering insights into their resilience against abiotic challenges such as temperature extremes, drought, and salinity stress. This literature review provides a comprehensive and up-to-date analysis of mango grafting offering valuable insights for researchers, horticulturists, and growers engaged in mango cultivation.

Cuvinte cheie: altoire, mango, portaltoi, pui, înmulțire vegetative.
Key words: grafting, mango,rootstock, scion, vegetative propagation.

1. Introduction

Mango (*Mangifera indica* L.) is one of the most economically important tropical fruit crops, valued for its outstanding flavor and nutritional content (Kuganesan et al., 2017). Mangoes are considered the king of fruits (Alam et al., 2006) in the tropical regions of the world due to exhibiting higher vitamins (A and C), antioxidants (*i.e.,* β-carotene, quercetin, fisetin, isoquercitrin, astragalin, gallic acid, and methyl gallate) (Lemmens et al., 2013; Choudhury and Ghosh, 2021), minerals (mainly sodium, potassium, calcium, magnesium, iron, zinc, and manganese), and fiber (Fowomola, 2010). Mango production is increasing worldwide and India ranks as the world's largest mango producer followed by China (Minja et al., 2017). According to Balaganesh and Makarabbi (2023), India has produced around 20.772 billion Kg during 2021 – 2022 and it accounts for more than 40% of global mango production. Mangoes are also grown in different countries such as Pakistan, Brazil, Mexico, the Philippines, Indonesia, Thailand, and Sri Lanka (Khushi et al., 2019).

Mango is mainly propagated by two basic propagation methods, including sexual (seed propagation) and asexual (vegetative) methods (Galan Saúco, 2021). Mango crops are highly heterozygous and commonly propagated vegetatively (Choudhury and Ghosh, 2021). Vegetative propagation reduces the juvenile phase of plants, enabling mango trees to enter the productive stage much earlier and it is a key objective for mango growers. Vegetative propagation is essential for preserving the distinct characteristics of a genotype and maintaining the genetic makeup of offspring (Yadav et al., 2019a; Yadav et al., 2019b). Seedling plants have a long juvenile phase (6-10 years) and their flowering and fruit setting initiate very late. The vigorous growth habit of seedling plants causes various problems in management practices, including pruning, training, bagging, pest/disease control, harvesting, and so on. Moreover, sexually raised plants produce heavy crops with inferior fruit size and quality which reduces the market demand and value.

Vegetative propagation techniques are practiced obtaining the true-to-type progenies in mango propagation. The advantages of asexual propagation are early bearing/fruiting, maintaining the desirable characteristics of the mother plant, and easier in all field management practices and harvesting. The various vegetative propagation techniques including grafting, budding, air layering, and cutting are used in mango propagation. Grafting is the most common vegetative propagation technique for mangoes and has shown higher success rates compared to other methods (Ghosh et al., 2015; Choudhury and Ghosh, 2021).

Grafting, one of the oldest vegetative propagation techniques, is widely practiced for the multiplication of true-to-type mangoes. Grafting mango trees involves transferring a mature, bearing tree or scion to a separate plant known as a rootstock. Mango cultivation often involves the use of grafting techniques to increase production, improve quality, and solve numerous propagation obstacles. The scion must come from a tree proven to bear better quality fruits, and the rootstock to be used should be healthy, vigorous, and disease-free. The scion becomes the canopy of the tree and the rootstock the lower trunk and root system (Beshir et al., 2019). Grafting is the most reliable and economical method of mango propagation. It provides the opportunity to utilize the favorable traits of rootstocks for the scion and favorable traits of the scion for the rootstock which would not be possible in a non-grafted plant (Adhikari et al., 2022). Grafting is also an effective technique for preserving genetic characteristics by ensuring the transfer of quality traits from the parent plant to its offspring, maintaining the true-to-type nature of the desired variety, and it alters the characteristics of the plant, making it superior to its mother plant (Beshir et al., 2019; Naik and Kumar, 2020). Additionally, when compared to sexual propagation methods, grafting enhances production by providing fruits in a short time (Naik and Kumar, 2020). Various techniques for grafting, including cleft, epicotyl, wedge, whip, side, soft-wood, splice, and veneer, have been explored by researchers to achieve efficient, speedy, and commercially viable mango propagation (Yadav et al., 2019b). Cleft and splice grafting are considered the most effective and widely accepted methods for mango propagation (Pinto et al., 2018). Among various grafting techniques, soft-wood grafting using the cleft method was found to have the highest success rate when conducted between July and October (Yadav et al., 2019a).

Several reviews have been conducted on mango grafting. However, none of these reviews sufficiently described the role of grafting on fruit yield and quality. Therefore, the objective of this study was to review the existing knowledge on the impact of grafting on mango fruit yield and quality by exploring the complex interactions between scion and rootstock. Understanding the importance of grafting in mango cultivation is not only essential for the optimization of orchard management but also holds the key to addressing challenges such as pest resistance, environmental stress, and fluctuations in fruit characteristics.

Overview and Importance of Mango Grafting

Grafting is a conventional horticultural technique that is essential for modern horticulture (Beshir et al., 2019). Fruit trees have been grafted since the beginning of civilization due to the difficulties in propagating by cuttings and the superiority and high value of the grafted crops (Abewoy, 2021). This technique was used a long time ago to increase the uniformity, vigor, and resistance to the biotic and abiotic stresses of vegetatively propagated plants (Leonardi and Romano, 2004).

Grafting can be done successfully within closely related species and the principal factor of grafting is compatibility. If both the scion and rootstock are compatible new shoots begin to grow (Naik and Kumar, 2020). Differences in graft success could be due to different levels of compatibility between the rootstock and scion, which can affect the healing process of the graft union (Ajal and Kizito, 2015). Scions are selected for grafting based on characteristics associated with yield, and they are typically grafted onto rootstocks known for their resilience to both biotic and abiotic environmental factors. The rootstock primarily impacts the vigor of the scion and its water-related functions (Rasool et al., 2020). Achieving successful grafting involves a complex biochemical and structural process that establishes a connection between scion and rootstock. Successful grafting involves the rejoining of tissues, including the formation of vascular connections between the rootstock and scion (Choudhury and Ghosh, 2021). Several factors contribute to the success and survivability of mango grafts, including the specific varieties involved, the time of the grafting operation, the selected grafting technique, the period of scion defoliation, the age of the scion, as well as leaf and node retention on rootstock (Khushi et al., 2019).

Grafted mango trees often show an accelerated onset of fruit production compared to mango trees which are grown from seedlings (Adhikari et al., 2022). This aspect is essential for commercial orchards where timely fruiting is vital for economic returns and overall orchard management (Adhikari et al., 2022). Yadav et al., (2019a) highlighted that mango grafting accelerates fruit production, ensuring faster returns on investment. For commercial growers, grafted mango trees offer a practical advantage for achieving prompt economic gains. The advantages include early flowering and the production of smaller mango trees (Singh et al., 2018; Beshir et al., 2019). The use of dwarf mango rootstocks allows to production of more manageable orchards, facilitating easy harvesting and overall orchard efficiency (Karna, 2018).

Grafting enhances the vigor of the tree and it extends the harvesting period (Lee et al., 2010). This technique improves the yield and the quality of the fruits (Huang et al., 2009) and also produces fruits with an extended postharvest life (Zhao et al., 2011). Moreover, grafted trees can tolerate some stress conditions such as high and low temperatures (López-Marín et al., 2013; Li et al., 2016), drought conditions (Schwarz et al., 2010), flooding conditions (Bhatt et al., 2015), and salinity stress (Penella et al., 2016). Furthermore, grafted plants have a higher water use efficiency (Cantero-Navarro et al., 2016), and grafting provides mango trees with improved resilience against environmental challenges (Habibi et al., 2022).

Abewoy (2021) highlighted the critical role of grafting in maintaining genetic consistency and preserving desirable traits. Grafting allows the production of mango trees with specific qualities such as superior taste, aroma, and fruit characteristics. Naik and Kumar (2020) highlighted the role of grafting in propagating unique mango varieties. It is essential for preserving and disseminating rare and distinct mango cultivars with specific and desirable attributes.

Grafting into disease resistance rootstocks becomes a strategic approach for mitigating the impact of prevalent mango diseases and pests (Louws et al., 2010; Fallik and Ilic, 2014). The selection of an appropriate graft combination is important for proper nutrient uptake, water potential, plant vigor, fruit quality, and yield efficiency (Shivran et al., 2023).

The Influence of Grafting on the Vigor of Mango Plants

Several factors contribute to the vigor of a scion, including the impact of the rootstock, soil fertility, water availability, soilborne diseases, and the genetics of the scion itself (Fazio et al. 2014). In the context of the orchard, A, if T represents the size of a grafted scion (S) on a rootstock (R), the ultimate size of the tree at maturity (T) can be expressed as $T = A_{fertility} + A_{water} + A_{disease} + A_{system} + S_{vigor} + R_{dwarfing}$. Here, $A_{fertility}$ represents soil fertility, A_{water} signifies water availability, $A_{disease}$ accounts for disease impact on scion vigor, A_{system} includes the orchard system used, S_{vigor} denotes the inherent vigor of the scion, and $R_{dwarfing}$ reflects the rootstock's genetic potential for dwarfing the scion (Fazio et al., 2014). The genetic makeup of the rootstock interacts with all these factors since it acts as a conduit for nutrients and water and can be susceptible to or resistant to diseases (Fazio et al., 2014). The growth vigor of different mango varieties, assessed through height, canopy diameters, and canopy volume measurements, was notably impacted by both the scion variety and rootstock individually, as well as their combined interaction (Dubey et al., 2021). Abirami et al., (2011) reported that phenolic contents, bark percentage, and chlorophyll fractions were highly effective in predicting the vigor of mango rootstocks during the nursery stage.

According to a study conducted by Dubey et al., (2021) on the long-term performance of mango varieties grafted onto five rootstocks in subtropical conditions, ‘Pusa Arunima’ exhibited the highest measurements for tree height, canopy diameter, and tree volume among the scion cultivars, while ‘Amrapali’ showed the reverse responses. Srinivas et al., (2022) investigated the impact of various rootstocks on grafts of different scion varieties of mango under nursery conditions. Their findings revealed that polyembryonic rootstocks such as ‘Nekkere’, ‘Bappakai’, ‘Muvandan’, ‘EC-95862’, and ‘Mylepelian’ exhibited elevated seedling vigor, while ‘Starch’, ‘Peach’, and ‘Kitchner’ demonstrated comparatively lower levels of seedling vigor. Kubar et al., (2023) conducted a study to investigate the influence of scion and rootstock on the establishment and vigor of mango seedlings. This study involved three distinct mango scion varieties, namely ‘Sindhri’, ‘Chaunsa’, and ‘Neelum’, grafted onto three different rootstocks, ‘Ratam’, ‘Pado’, and ‘Sindhr’. Among the rootstocks, ‘Pado’ demonstrated remarkable results, with its seedlings exhibiting the highest seedling vigor index (5158.74), followed by ‘Ratam’ at 3529.33, while’ Sindhri’ displayed the lowest vigor index at 3398.52. According to Galán Saúco, (2016) in Brazil, 'Coquinho' is not recommended as a rootstock for 'Tommy Atkins' and 'Van Dyke' mango cultivars due to its tendency to impart high vigor to the grafted plants. ‘Vellaikulumban’ rootstock was found as a vigorous rootstock in terms of stomatal index (Patil et al., 2008). Besides, an experiment was carried out to evaluate the impact of various rootstocks on the success of softwood grafting. The rootstocks tested included ‘Amrapali’, ‘Sindhu’, ‘Sindhura’, ‘Beneshan’, and ‘Nekkare’, while ‘Alphonso’ was used as the scion. When grafted ‘Alphonso’ scion was with ‘Sindhura’ rootstock, maximum sprout height, number of leaves, and graft diameter were achieved (Patil et al., 2008). A study was conducted to compare the growth and fruiting characteristics of 'Dashehari' grafted onto both 'Dashehari' seedling stock and various polyembryonic rootstocks. The findings revealed that grafts on 'Dashehari' seedlings exhibited the most vigorous growth and produced the highest yields (Reddy and Raj, 2015). Reddy et al., (2003) reported that results from a 21-year study on the performance of 'Alphonso' conducted at IIHR, Bangalore, showed that nucellar seedlings of 'Muvandan', 'Bappakai', and 'Olour' were vigorous rootstocks, with 'Muvandan' being the most vigorous, followed by 'Bappakai' and then 'Olour'. A study was conducted to evaluate the performance of a local desi variety of mango in nursery conditions by grafting to different other mango cultivars (‘Rampur Gola’, ‘Chausa’, ‘Alphonso’, ‘Amrapali’, ‘Dusehri’, ‘Langra’, ‘Mallika’, ‘Benganpali’, ‘Malda’ and ‘Totapari Red Small’) in India. This study found that ‘Dusehri’ scion grafting using the wedge grafting technique between late July and late August exhibited superior performance in early sprouting, grafting success, survival rate, scion girth, growth, leaf count, taproot length, root count, primary root diameter, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, and overall vegetative growth (Kaur, 2017). The grafting technique has been used to improve the vigor of the mango plants (Leonardi and Romano, 2004).

The Influence of Grafting on Flowering Physiology and Fruit Set in Mango

Rootstocks of fruit trees can trigger early flowering in scions (Habibi et al., 2022). Rootstocks of fruit trees influence flowering time due to changes in the chilling requirements of different rootstocks (Atkinson and Else, 2001). The impact of rootstocks on flowering dates of fruit trees could also be linked to considerations of low-temperature injury (Atkinson and Else, 2001). Flowers that bloom later in the spring are more likely to escape harm induced by frosts or low temperatures in fruit trees (Atkinson and Else, 2001). Grafted mango trees often exhibit early flowering and sometimes even within the first year of growth, leading to the formation of fruits (Mulinge 2015). The early flowering can be avoided by removing the inflorescences. Generally, it is advisable to allow mango trees to bear fruit from the third or fourth year onwards (Mulinge, 2015).

Rootstocks can affect fruit set, the precocity of fruiting, and the overall yield of fruit trees (Habibi et al., 2022). The use of dwarfing rootstocks often results in early fruiting, whereas vigorous rootstocks tend to delay fruiting (Habibi et al., 2022). However, achieving optimal performance in fruit trees requires an optimum balance between vegetative growth and fruiting. Excessive vegetative growth of fruit trees can lead to a reduction in both fruiting and overall yield (Habibi et al., 2022). Grafting improves the fruit-setting capacity of flowers by increasing flower quality, affecting the longevity of ovules, and extending the effective pollination period (EPP) in fruit trees. Rootstocks can influence the induction of the number and size of the flower spurs in fruit trees. The number of spur leaves in fruit trees has an impact on flowering and it can modify the fruit set (Atkinson and Else, 2001).

The Influence of Grafting on Yield and Productivity of Mango

Fruit yield and productivity are crucial factors in crops such as mango, especially considering that productivity is generally low in many mango-growing countries (Reddy and Raj, 2015). Grafting is a significant practice with a substantial impact on enhancing both yield and quality across various horticultural crops (Abewoy, 2021). There are examples of high yields reported in grafted mango, such as 'Keitt' in Costa Rica using 'Jamaica', and Floridian cultivars grafted on the ‘Gomera’ types in Spain (Galán Saúco, 2016). Smith et al., (2003) reported that the yield and yield efficiency of ‘Kensington Pride' mango were highest when grafted onto the 'sg. Siput' rootstock and yield were lowest when grafted onto the 'Saber' rootstock. This suggests the potential to enhance mango scion productivity by selecting the appropriate rootstock genotype. Quijada et al., (2008) found that the 'Criollo de Mara', 'Manzana', and 'Sensation' mango cultivars, when grafted onto 'Sinamaica' rootstock, exhibit the highest adaptability to the agro-ecological conditions of the Maracaibo plain in Venezuela, resulting in increased yield and production efficiency.

Dubey et al., (2021) investigated the fruit yield performance of different mango scion varieties ('Amrapali', 'Pusa Arunima', and 'Pusa Surya') when grafted onto various rootstocks ('Kurakkan', 'Olour', 'K-3', 'K-5', 'K-2') over five years. 'Amrapali' and 'Pusa Arunima' had higher yields in different years, with 'Amrapali' consistently performing well, especially in 2017 and 2018. Among the rootstocks, 'Kurakkan' and 'Olour' showed higher yields during the initial three fruiting seasons, while 'K-3' and 'Olour' were more productive in 2018. However, the combination of 'Pusa Surya' with 'Kurakkan' and 'Olour' consistently demonstrated high-yield performance throughout the study, except in 2018. Grafting compatibility is a critical factor influencing the overall performance and yield of grafted fruit trees (Adhikari et al., 2022).

A study has been conducted by Rebolledo-Martínez et al., (2019) to assess the growth, yield, and fruit quality of 'Manila' mango trees grafted onto various rootstocks. 'Manila' mango scions were grafted onto rootstocks of varying heights, including short ('Thomas' and 'Julie'), medium ('Esmeralda', 'Irwin Morado', 'Gomera 1', and 'Chauza'), and tall ('Criollo') rootstocks and concluded that mango rootstocks directly impact tree growth, flowering, and fruit production. According to a study conducted using 'Tommy Atkins' as the scion and 'Rosinha' as the rootstock resulted in a yield of 7700 Kg per hectare (Vargas Ramos et al., 2004). It was 7040 Kg per hectare when the scion was 'Tommy Atkins' and the rootstock was 'Comum' (Vargas Ramos et al., 2004). 'Winter' × 'Extrema' has produced mango fruits around 7620 Kg per hectare after eight years (Vargas Ramos et al., 2004). Dayal et al., (2016) conducted a study to investigate the potential impact of polyembryonic rootstocks on the tree growth, yield, and physiological aspects of five different mango cultivars ('Pusa Arunima', 'Pusa Surya', 'Amrapali', 'Mallika' and 'Dushehari') with three polyembryonic rootstocks ('K-5', 'Kurakkan', and 'Olour'). The 'Kurakkan' rootstock resulted in the highest yield for 'Amrapali' and 'Pusa Surya', while both 'Kurakkan' and 'Olour' were effective for 'Pusa Arunima'. Additionally, 'K-5' and 'Kurakkan' demonstrated higher productivity for 'Mallika'. A study using the mango cultivar 'Osteen' grafting with 'Gomera-1' and 'Gomera-3' rootstocks and results showed that 'Gomera-1' gave a higher fruit yield whereas 'Gomera-3' produced fruits with increased width and weight (Durán-Zuazo et al., 2005). The study conducted by Hamed et al., (2021) investigated the influence of mango rootstocks ('Succary' and 'Balady') on the performance of 'Keitt', 'Naomi', and 'Haydi' mango cultivars. The fruit number per tree and yield per year (Kg) were higher in 'Keitt' × 'Succary' compared to other combinations. Reddy et al., (2003) conducted a study to investigate the performance of 'Alphonso' mango by grafting on eight different rootstocks and the findings highlight the diverse influences of specific rootstocks, such as the vigorous 'Muvandan' and 'Olour', leading to higher cumulative fruit yields, while the dwarfing 'Vellaikulamban' rootstock demonstrates enhanced yields per unit canopy volume and per unit land area. A study was conducted to assess the performance of mango cultivars 'Osteen' and 'Keitt' when grafted onto 'Gomera 1' and 'Gomera 3' rootstocks, specifically focusing on fruit yield. The results showed that the combinations of 'G1-Ost' and 'G3-Kt' produced the highest fruit yield, indicating their potential to improve mango productivity in subtropical areas (Durán-Zuazo et al., 2006).

An experiment conducted in India, in 1980 aimed to assess the long-term effects of various rootstocks on the growth, yield, fruit quality, and leaf mineral composition of mango 'Bombai'. The rootstocks tested included 'Mylepalian', 'Puttu', 'Kurukan', 'Kalapady', 'Latra', 'One tree seedling', and 'Random seedling'. Results revealed that 'Bombai' grafted onto one tree seedling produced the highest fruit yield, while the lowest yield was observed with 'Latra' rootstock (Singh and Singh, 2004). Reddy and Raj, (2015) reported that the grafting of 'Manila' onto 'Irwin' as an interstock with 'Irwin' served as the rootstock resulting in the highest yield efficiency recorded at 216%. A study in Madhya Pradesh, India, assessed the performance of mango 'Langra' on various rootstocks, including 'Bappakai', 'Chandrakaran', 'Muvandan', 'Vellaikolamban', 'Olour', 'Kalepad', and random stock. The highest number of fruits per plant was recorded for 'Langra' grafted onto 'Bappakai' rootstock, followed by 'Vellaikulumban' and 'Chandrakaran' (Singh and Kanpure 2006). A study was conducted by Fumuro, (2019) to compare the growth and productivity of 'Aikou' mango trees propagated through air layering versus conventional grafting. It was found that the yield per tree increased with tree age, plateauing after 8 years. The average yield per unit land area over 6 years was calculated as 2.9 Kgm^{-2} for own-rooted trees and 3.1 Kgm^{-2} for grafted trees. The yield performance is influenced by both the scion variety and rootstock, as well as their interactions (Dubey et al., 2021).

The Influence of Grafting on Mango Fruit Quality

The grafting of cultivars with superior characteristics onto adaptive and available rootstocks results in quality fruits with superior characteristics. Consumers typically look for qualities such as attractive colors, good flavor, pleasant taste, and regular bearing when selecting mango varieties (Tadda et al., 2019). Reddy et al. (2003) conducted a study to investigate the performance of 'Alphonso' mango by grafting on eight different rootstocks 'Open pollinated Alphonso', 'Vellaikulumban', 'Bappakai', 'Chandrakaran', 'Kurukan', 'Muvandan', 'Mylepelian' and 'Olour') for 21 years and concluded that there is no significant effect on quality parameters by these rootstocks.

Saeki and Iwasaki, (2020) and Minja et al., (2017) conducted studies to explore the influence of grafting on mango fruit characteristics. These studies showed that grafting positively affects tree growth, flowering, and yield subsequently leading to fruits with improved size, color, taste, and overall fruit quality. Grafting is frequently utilized as a method to improve disease resistance in mango trees (King et al., 2008). Shivran et al., (2023) conducted extensive scion/rootstock interaction studies using five mango varieties ('Mallika', 'Amrapali', 'Dashehari', 'Pusa Arunima', and 'Pusa Surya') by grafting into three different rootstocks ('Olour', 'Kurukkan', and 'K-5'). They analyzed 25 physicochemical parameters, including fruit weight, yield efficiency, soluble solids content (SSC), titratable acidity (TA), and peel thickness, revealing alterations induced by scion–rootstock interaction. Among the varieties, ‘Olour’ rootstock was identified as the most effective in enhancing fruit quality and shelf life through grafting. The study also identified specific markers associated with shelf-life, demonstrating polymorphism among genotypes and providing valuable insights into the genetic diversity and associations between simple sequence repeats (SSRs) markers and physiological traits such as yield efficiency and fruit weight. According to the study conducted to investigate the influence of mango rootstocks ('Succary' and 'Balady') on the performance of 'Keitt', 'Naomi', and 'Haydi' mango cultivars, the carotene content of the fruits was high in 'Haydi', compared to 'Keitt' and 'Naomi'. Rootstocks also showed an effect on the carotene content of the mango fruits, and it was high in 'Balady', compared to 'succary'. SSC was high in 'Keitt' with both rootstocks. However, the 'succary' rootstock gave a higher TA in all mango cultivars used in the study (Hamed et al., 2021). 'Manila' mango scions were grafted onto different rootstocks ('Thomas', 'Julie', 'Esmeralda', 'Irwin', 'Morado', 'Gomera 1', and 'Chauza' and 'Criollo') and observed an effect on the total soluble solid content of mango fruits (Rebolledo-Martínez et al., 2019). Furthermore, a study conducted by Vazquez-Luna et al., (2011) investigated the impact of the 'Criollo' rootstock on the 'Manila' mango cultivar. The comparison between grafted and non-grafted 'Manila' mango trees revealed that grafted plants exhibited enhanced fruit firmness, elevated levels of 3-carene, and higher content of main flavonoids in the fruits. Consequently, this increased resistance in 'Manila' mangoes made them less susceptible to infestation by *Anastrepha obliqua*. The selection of appropriate scion and rootstock combinations is essential to improve the fruit quality (Shivran et al., 2022).

Influence of Grafting on Pest and Diseases of Mango

Grafting is an efficient alternative crop management technique to overcome problems related to pests and soil pathogens (Alvarez-hernandez, 2019). The incorporation of grafting as part of integrated pest management for controlling soil-borne pests and diseases holds promise for future low-input sustainable horticulture (Suansia and Samal, 2021).

Vegetative and floral malformations are significant mango diseases caused by *Fusarium* spp. Since this pathogen is present in the tissues of mango grafts in the nursery and in the inflorescence of adult plants, the use of these infected grafts should be prohibited to prevent the development of abnormal and diseased grafting plants (Pinto et al., 2018). According to Galán Saúco, (2019), grafting with particular rootstocks has shown a noticeable impact in diminishing the occurrence of a specific disease known as 'Seca' or 'Sudden Death of Mango. This disease is caused by the fungi *Ceratocystis fimbriata* in Brazil or *Ceratocystis manginecans* in Oman and Pakistan. It is transmitted by the vector insect *Hypocryphalus mangiferae*, which enters into the plant through either the aerial parts or the roots. The moderate size of 'Apple' mango trees allows farmers to effectively manage pests and diseases by facilitating chemical spraying, pruning, and maintaining underground hygiene (Mulinge, 2015). Generally, grafted plants have protection against soil-borne diseases and nematodes (Louws et al., 2010; Fallik and Ilic, 2014).

Influence of Grafting on Abiotic Stresses of Mango

Producing mango grafts year-round is essential to meet the demand for high-quality planting materials. This can be achieved by maintaining optimal temperature and relative humidity levels in propagation structures (Pinto et al., 2018). Grafting has the potential to influence tolerance to abiotic stress (Wang et al., 2017). Rootstocks of fruit crops play a crucial role in overcoming stress conditions (Satisha et al., 2020). Their deeper root systems enhance drought tolerance, while selective nutrient absorption mechanisms improve salt tolerance (Satisha et al., 2020). Additionally, rootstocks of fruit crops can induce early or late precocity, helping plants cope with heat or low-temperature stress (Satisha et al., 2020). These attributes make fruit crop rootstocks valuable for grafting onto commercial varieties, enabling them to thrive in challenging environments (Satisha et al., 2020). Pranava et al., (2014) conducted a screening of mango rootstocks for salinity tolerance and identified 'Olur', 'Terpentine', and 'Kurukkan' as the most tolerant cultivars. Conversely, 'Chandrakaran' was found to be sensitive to salinity stress. Studies in the Canary Islands have shown that the polyembryonic rootstock 'Gomera 1' (G-1) exhibits higher tolerance to salinity compared to other polyembryonic types tested, including 'Gomera 3', 'Gomera 4', 'Peach', 'Turpentine', and 'Kensington' (Galán Saúco, 2016). In contrast, in Colombia, 'Van Dyke', 'Irwin', 'Kent', and 'Tommy Atkins' cultivars exhibit enhanced resistance to dry conditions when grafted onto seeds of the 'Arauca' rootstock compared to when grafted onto the 'Hilacha' rootstock (Galán Saúco, 2016). Tolerance to salinity has been observed in several mango varieties, including 'Criollo de Cholucanas' from Peru, 'Hilacha' from Colombia, 'Piqueño' from Chile, *Mangifera kasturi* from Indonesia, 'Bau 6, 7, and 8' from Bangladesh, 'Gomera 1' from Spain, 'Sukkari' from Egypt, and '13/1' from Israel (Galán Saúco, 2016). The mango plants that showed tolerance to salinity had lower levels of ash, potassium, calcium, and sodium, but higher levels of chlorine. This suggests that the resistance to salinity in these plants is likely due to a tolerance of leaf tissue to chlorine rather than a selective uptake of this element (Galán Saúco, 2016). Van Hau et al., (2001) reported that the rootstock 'Chau Hang Vo' is affected only by salinity levels of 12 dS/m, whereas 'Buoi', the primary rootstock used in Vietnam, tolerates only 8 dS/m. Moderately tolerant polyembryonic rootstocks such as 'Bappakai', 'Olour', and 'Kurukkan' have been identified regarding salt stress in India (Dubey et al., 2007).

Shading during and after grafting has been found to have a positive impact on the success of mango grafting (Pinto et al., 2018). 'Mameyito' is not a suitable rootstock for 'Keitt' mangoes, as grafted plants tend to develop iron chlorosis when grown in alkaline soils in the Dominican Republic. The cultivars 'Criollo de Cholucanas', 'Hilacha', and 'Sabre' from South Africa are noted for their tolerance to flooding, while 'Criollo de Cholucanas', 'Jamaica' from Costa Rica, 'Mango de racimo' from Guatemala, 'Arauca' from Colombia, 'Kaew' and 'Ta-Lub-Nak', 'Bau 6, 7 and 8', 'Tsar-Swan', 'Kohuamba' from Sri Lanka, 'Cat head' and 'Long mouth' from Ivory Coast, and '13-1' are reported to be tolerant to dry conditions (Galán Saúco, 2016). Mango growers can effectively tackle problems associated with drought, salinity, and unfavorable soil conditions by using suitable rootstocks (Habibi et al., 2022).

Future Scope

Grafting has the potential to be a strategy to develop products with better quality and higher yield. In addition, it minimizes the usage of chemicals in a safe and green way (Shivran et al., 2022). Extensive research is necessary to mitigate post-grafting losses. Development and accessibility of effective grafting machinery and robotic grafting systems are crucial for accelerating the grafting process, enhancing the survival rates of grafted plants, and reducing the elevated cost associated with grafted seedlings (Suansia and Samal, 2021). Furthermore, limited attention has been given to understanding the effects of grafting on essential nutritional compounds. Addressing these knowledge gaps is crucial for advancing the understanding of grafted plant physiology and improving overall fruit quality (Fallik and Ilic, 2014).

Moreover, it is necessary to explore the molecular aspects of rootstocks, aiming to develop rootstocks that demonstrate tolerance to both biotic and abiotic stresses across various tropical, subtropical, and temperate fruit crops (Albacete et al., 2015), while extensive research has focused on the agronomical and physiological processes influencing the fruit quality of grafted plants, there is still a significant gap in understanding the biochemical and molecular mechanisms involved. Therefore, there is a critical need for in-depth investigations aimed at unraveling the biochemical and molecular processes, identifying biomarkers, and enhancing the understanding of rootstock/scion compatibility. This knowledge can contribute to creating optimal environmental conditions for successful rootstock and scion unions (Fallik and Ilic, 2014). Conducting more comprehensive studies that integrate multi-point time-course data encompassing anatomical, metabolic, and genetic assessments has the potential to provide conclusive answers in the future (Adhikari et al., 2022). Future researchers should focus on the exploration of epigenetic modifications, methylation patterns, and the identification of epigenetic markers, as well as the preservation of these alterations in various fruit trees (Habibi et al., 2022).

Significant additional research is required to comprehend the interactions involving the rootstock (R), the scion (S), and their environment (E) in terms of mobile signals, gene expression, as well as the genetic and epigenetic regulation of advantageous alterations in both above and below-ground plant components. A deeper understanding of the functionalities and significance of the natural and induced communication process between and within plants could bring new knowledge and agricultural applications through grafting. This involves identifying, creating, and exploiting new genetic biodiversity contributing to enhancements in crop vigor, quality, and sustainability, as well as increased resistance to pathogens, pests, and environmental stressors in food production (Albacete et al., 2015). A limited number of investigations have been conducted regarding the uptake and transport of essential nutrients in grafted plants. Consequently, more comprehensive studies are required to gain a thorough understanding of the sensing, signaling, uptake, and transport mechanisms in grafted plants. This knowledge will be important in breeding programs aimed at developing rootstocks with enhanced nutrient efficiency (Nawaz et al., 2016).

2. Conclusions

Grafting plays a crucial role in modern horticulture offering a significant impact on fruit yield, quality, and resilience to various biotic and abiotic challenges. This literature review emphasized the different advantages associated with grafting mango trees including enhanced fruit production, accelerated fruit quality, disease resistance, and tolerance to abiotic stresses. Growers can customize the grafting practices to optimize orchard management, increase economic returns, and overcome the inherent propagation obstacles in sexually propagated mango plants by careful selection of scion varieties and rootstocks. Moreover, Grafting is a promising solution that could help address significant issues such as pest resistance, environmental stress, and fluctuations in fruit characteristics. This could contribute to ensuring the sustainability and resilience of mango cultivation worldwide.

In conclusion, mango grafting is a valuable tool for modern horticulture and it offers a pathway toward sustainable fruit production and enhances food security and economic returns for mango growers. They can meet the growing demands of global mango markets while ensuring the long-term health and vitality of mango orchards by using the full potential of grafting techniques.

CRediT authorship contribution statement

A.K.A.N.W.M.R.K. Thamarsha: Conceptualization, Writing – original draft. **Jinwook Lee**: Writing – review & editing. **Jin Gook Kim**: Writing – review & editing. **Nishant Kumar**: Writing – review & editing. **H. M. P. C. Kumarihami**: Investigation, Conceptualization, Supervision, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the authors

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Figure

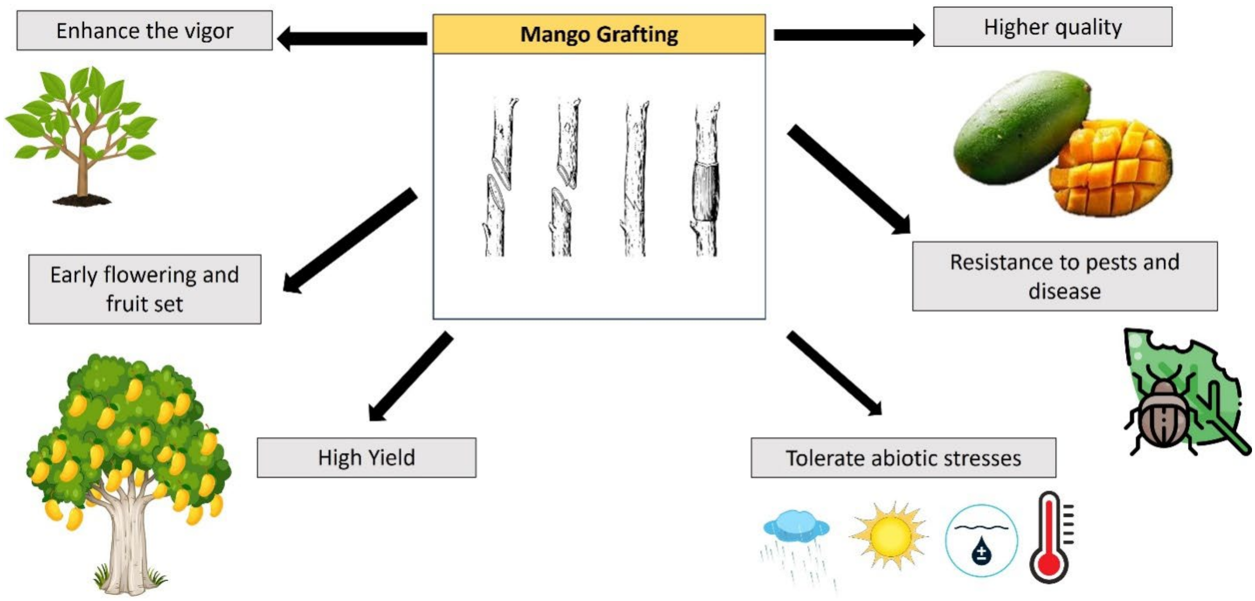

Fig. 1. Effect of grafting technique on yield and fruit quality of mango