Peach for the future: a specialty crop revisited

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Abstract

Peach is the most important temperate fruit crop worldwide in terms of production after apple. However, a descending trend has been registered over the recent years in several key producing peach countries, mainly due to the increased labor cost and the reduced revenue for the farmer. The present perspective review aims to shed light on the current trends on peach fruit production related to cultivar and rootstock breeding initiatives, appropriate training system selection and targeted integrated management of main diseases, most promptly *Monilinia* spp. Cultivar breeding programs should focus on the most relevant outcomes about the main drivers of consumer's acceptance. In the near future, a contribution from the breeding sector should be expected in the reduction of the trade-off between quality and yield, towards selection of elite cultivars with enhanced aroma (a pool of compounds still scarcely known), with appreciable nutritional properties and extended market life. Such cultivars need an appropriate rootstock and canopy architecture to facilitate efficient cropping systems. The training/cropping system selection is of equal importance with rootstock selection as it can also determine efficiency and potential for mechanization. A tendency for the future is that several semi- and dwarfing *Prunus* hybrid rootstocks aligned with the innovations on peach tree architecture will lead to higher planting densities, reduced tree height and thus enhanced peach production with reduced labor cost. With the aim to advance peach fruit production and consumption, there is an urgent need to dissect solutions to valorize on the market the exceptional peach diversity and flavor potential, already present in the varietal landscape. The development of sophisticated non-destructive tools that will allow in cost-effective manner to determine fruit quality and maturity stage is expected to facilitate consumer eating experience and storage requirements with minimum risk of chilling injury symptoms development. Lastly, the phytosanitary protocol of small-sized wall-grown

plants would most likely be more effective and would require reduced quantities of pesticides while simultaneously responding to the needs of a market that is increasingly attentive to fruit healthiness and environment protection. Phytosanitary issues can be addressed by controlling diseases and/or by improving genetic resistance.

Keywords: breeding; cultivar; rootstock; training system; disease management; non-destructive; dry matter content; *Monilinia* spp., chilling injury; *Prunus persica*

1. Introduction

Peach is the second most produced temperate fruit crop in the world following apple. However, in terms of production trends, peach cultivation seems to have taken the avenue of the sunset in the Western world, slowly and progressively relegating this species within the secondary fruit crops. The global peach production is currently largely dominated by China, mostly destined for the internal market **(FAOSTAT, 2022)**. In contrast, peach production in historically important countries, such as Italy and USA, has decreased over 30% in the last decade (2008 – 2018), from about 1.6 to 1.1 and from 1.3 to 0.9 Mt, respectively **(FAOSTAT, 2022; USDA-NASS, 2021; Anthony and Minas, 2021)**. More recently, the same decreasing trend is also overwhelming Spain, the first exporter and the second worldwide producer with ca. 1.3 Mt in 2020. Although difficult to establish and often controversial, various hypotheses have been raised about the causes of this descending trend in key peach production countries, such as: (i) the competition with other fruit crops like grapes, kiwifruit, soft or tropical fruits (e.g. bananas and pineapple), now available year-round; (ii) the poor eating quality of peach sold through the wholesale system (iii) the saturation of the EU and US market, due to declining demand by the consumers; (iv) the lack of an aggregate supply, due to the high fragmentation of the producers (particularly evident in Italy and Greece); and (v) the increasing labor shortage and cost.

As a general consideration, if market is not remunerative, the grower will shift towards more profitable fruit crops. Therefore, there is an urgent need the peach marketing to be re-organized in a way that will generate profits at the 'farm-gate' stage. Improved packaging and more information on the characteristics of the product offered might retain consumer satisfaction at higher premium prices. It must also be taken into consideration that the fresh peach market mechanism is not always governed by the law of demand and supply. Indeed, in China peach production is decreasing in the last few years, and this is not causing an increase in price premiums, similar to what observed for Spain, Italy, and other countries. In the USA and Chile instead, a different trend is observed, showing an increase in price corresponding to a production decrease (**USDA-NAAS, 2021**). However, it is highlighted that the price for a given product, whether it is food or not, will be determined by consumers on the basis of its quality.

The main cultivation management operations (pruning, thinning and harvesting) in peach are labor intensive and routinely performed by hand, representing the major portion of the production cost. Constant increase in labor cost as well as labor shortages are further reducing profit margins and shrinking cultivation areas across many peach producing countries in the world. Thus, the future success and profitability of peach culture in the world is going to be linked to the research activity and the innovations introduced, i.e. mechanization (mechanical summer pruning-topping and hedging-, mechanical/assisted flower thinning and/or mechanical harvesting) towards reduction of labor needs and production costs. Overall, improved consumer satisfaction with supply of high-quality fruit and appropriate marketing that can improve price premiums together with the reduction of the production cost through improved productivity and mechanization should be the main goals of the peach industry for a successful future that are addressed herein.

2. The role of cultivar breeding programs

Several public and private research institutions have been working on peach breeding. Such programs are focusing on the development of cultivars with enhanced qualitative attributes (size, appearance, internal quality, resistance to chilling injury disorders), disease resistance [e.g. powdery mildew, brown rot, bacterial spot, plum pox virus (PPV)], improved productivity and environmental adaptation, particularly related to cold hardiness or low chilling requirements. These efforts have led to the yearly release of dozens of new cultivars and the availability on the market of white and yellow flesh, flat and round, peach and nectarine fruits, from May until late September, expanding cultivation from subtropics to Canada.

Rather than focusing on objectives and results from the past and ongoing peach breeding programs, a general and critical evaluation of the actual role of breeding is more urgently needed than in the past, particularly in the light of the long lasting crisis affecting the peach market worldwide. Indeed, the inability of peach industry to meet consumers' expectations is almost unanimously identified as the key factor behind the large loss of market share (**Kelley et al., 2016**). Consequently, the battle horse of several breeding programs is the enhancement of fruit internal quality (**Cirilli et al., 2016**). Thus, raising the fruit eating quality is of primary importance also in light of other crucial breeding objectives such as yield efficiency, enhanced disease resistance and tolerance to abiotic stress conditions.

Several studies have demonstrated how the increase of consumers' degree of liking is mainly associated with the increase of sugars in the fruit and their estimation by the soluble solids concentration (SSC or º Brix), irrespective of the cultivar considered. However, the specific SSC threshold to reach a certain level of satisfaction is affected by titratable acidity (through SSC/TA ratio), depending on the consumers' segment (**Crisosto and Valero, 2008; Delgado et al., 2013**). Therefore, the overall liking cannot be solely explained by sugars or SSC/TA ratio, as some other physicochemical parameters, such as aroma and texture, possess a pivotal role in flavor preferences (**Kelley et al., 2016**). As for the sugars, these parameters are deeply influenced by the orchard management (e.g., fruit load per tree, maturity degree at harvest), as well as by the intrinsic potential of the cultivar considered (**Minas et al., 2018; Anthony et al., 2020**). However, the range of 10-12 % SSC (often even lower) in which fall the majority of the peaches currently found on the retail counters (**Fallahi et al., 2009; Drogoudi et al., 2016; Belisle et al., 2018**) leaves little doubts about the actual bottleneck for consumer eating quality, which also leads some researchers to invoke a revision of the minimum marketing standards for peaches (currently, 8 ºBrix) according to EU Commission Regulation No. 1861/2004). In fact, in a three-year study, SSC values of 94 peach cultivars (84 non-melting type) exhibited an average value of 15 ºBrix, ranging from 12 to 18 ºBrix, when they were harvested at commercial maturity (**Font i Forcada et al., 2014).**

Interestingly, much of the initial success of flat peaches can be partially explained by their higher SSC level compared to the round-shape fruit cultivars. At the end, rather than going to the root of the matter (i.e. the need to rethink the whole peach supply chain, starting from the orchard management at the preharvest stage), the problem has quickly slipped into the breeders, as the primary subject for providing an effective short-term solution.

The concept 'breeding for improving fruit quality' has become the mantra of several public or private programs. Indeed, observing the tremendous evolution occurred from ‘Elberta’ (the founder of the early USA breeding efforts, back around 1870s), or even from the first ‘walnut-peach’ (as nectarines were firstly marketed in Italy), it can be seen how fruit flavor has been the cornerstone of many peach breeding programs. Some examples are the intense flavor of obsolete cultivars such as ‘Redhaven’ (released in 1942) or ‘Dixired’ (1945), or the floral aroma of many old white-fleshed peaches or the excellent taste of some nectarines released around the ‘90s, with the case of ‘Big Top’ being the most emblematic. This revolutionary cultivar has outlined one of the dominant ideotype on which the peach community is still focusing: low acid taste, yellow fleshed with fully, deep red skin and longer ‘fruit-keeping’ potential and shelf life, due to the slow softening texture (**Ghiani et al., 2011**; **Manganaris et al., 2017; Ciacciulli et al., 2018**). Indeed, its low acid taste confers a sweetness sensation even at no elevated SSC content and ensures an ‘acceptable’ edibility even when harvested early. However, the fully red overcolor phenotype could be deceptive for the consumer and could induce growers to harvest immature fruits, also due to the lack of green background color (**Drogoudi et al., 2016; Minas et al., 2018**).

Cultivars with fully red overcolor blush are often subjected to significantly premature-harvesting compared to standard bi-colored ones that background color can be assessed easily even at advanced harvest (**Figure 1**). In summary, instead of exploiting on the most valuable features of such cultivars (i.e. appealing appearance and slow softening trait) to keep the fruit longer on tree (thus allowing the SSC increase and better flavor development), the supply chain in large has opted for maximizing the post-harvest life, selling a physiologically immature and substantially tasteless fruit. This ‘production style’ has been very often applied to the whole peach industry and the value chain itself has created the need for increasing yield to compensate for the low prices and increased production costs. Therefore, there is a trade-off between the high quality demanded by consumers, expressed as medium-large sized fruits with SSC over 12% and a fully expressed aroma and the current need of the growers for increased commercial yields, i.e. higher than 30 tons per hectare. In the near future, a contribution from the breeding sector could be expected in the improvement of the trade-off between quality and yield, in the selection of cultivars with enhanced aroma (a pool of compounds still scarcely known) and nutritional value, or in a further improvement of postharvest life (**Infante et al., 2011**). For this last goal, the *stony hard* (SH) texture deserves a special mention for its intrinsic potential to enhance long-life span on-tree and during postharvest, as this trait hampers flesh softening even when the fruit is fully ripe (**Tatsuki et al., 2006**). Even if known since a long time (**Yoshida, 1976**), SH trait has been very scarcely incorporated at the commercial level, at least in the Western hemisphere, mainly because of the low fruit quality of many accessions that are characterized by unacceptably low acidity, poor color and aroma as well.

Recent breeding efforts and availability of molecular markers have allowed a remarkable improvement of several organoleptic characteristics, shedding a renewed perspective on this texture type to facilitate pre- and post-harvest management (**Liverani et al., 2017; Cirilli et al., 2018**). For the same reasons, the *non-melting* (NM) texture (nowadays mostly used for the canning industry) is also attracting some interest for the fresh market (**Beckman et al., 2008**). However, as for the slow softening texture, even the SH or NM traits are not a solution to the problem and, in the current situation, they would probably be classified as failures long before being able to express their most valuable potential, i.e. the improvement of maturity degree at harvest.

Due to their relatively short postharvest life, peaches and nectarines are not being sold by cultivar name to allow extension of the harvesting and supply windows with many different cultivars that are ripening at different times through a sequence during the growing season. As a result, every year new cultivars are being released into the market and consumers hardly know the characteristics and even the name of the cultivars. This hinders the attempts on promoting a given peach cultivar to build consumers loyalty, as it is happening for instance with apple. Their choice is to buy white or yellow pulp peaches or nectarines. Over the past decades, peach breeding programs worldwide provided a tremendous number of new releases that are ripening through an extended window during the season with superior qualitative attributes. At the same time, peach market share and grower profitability has been constantly shrinking. Thus, the extent that cultivar breeding can efficiently tackle the supply chain attitude and raise the peach market share or improve profitability needs to be further elucidated, eventually by strengthening the relations among the actors of the whole value chain.

3. Improvement of peach productivity through rootstock selection

Rootstocks represent an invaluable genetic tool that optimize fruit tree adaptability in different growing regions, control tree vigor and facilitate cropping arrangements that can improve yield efficiency and productivity (**Anthony and Minas, 2021**). Previous experience from other fruit crops have taught us that in orchard production systems no revolution in grower profitability can result from cultivar breeding programs, but from rootstock breeding and cropping systems innovation (**Minas et al., 2022**). The use of precocious, dwarfing and productive rootstocks has transformed apple and sweet cherry production by allowing the development of high-density cropping systems and the adoption of two-dimensional (2D) canopy architectures for increased efficiency, productivity, mechanization and uniform fruit maturation and quality (**Autio et al., 2020; Musacchi et al., 2015; Lang, 2019; Robinson et al., 2013**).

The main challenges peach producers face worldwide are associated with soil including texture issues, high pH, drought, waterlogging and nematodes (**Pinochet et al., 1999**), fungal and bacterial pathogens that cause the orchard replant disease syndrome (**Anthony and Minas, 2021**). These global challenges have defined objectives for rootstock breeding programs; thus, producers can overcome these limitations through targeted selection for specific pedoclimatic conditions and cropping systems.

Traditionally, peach has been planted into low-density plantings utilizing vigorous peach seedling rootstocks. However, the use of such rootstocks has been increasingly discontinued due to their inability to withstand the main soil associated challenges in a continuously diminishing land suitable for fruit production and to control tree vigor (**Reighard and Loreti, 2008; Minas et al., 2018**). The development of new rootstocks coming mainly from peach seedlings and interspecific *Prunus* hybrids from crosses between peach, almond, plum, prune and apricot domesticated and wild species to overcome these abiotic and biotic challenges that limit peach cultivation has been the main direction for breeders over the last decades (**Anthony and Minas, 2021**). Several new *Prunus* rootstocks have been selected from breeding programs directed by universities, research institutions and private entities in specific countries, namely USA, Spain, Italy, Russia and France. These new *Prunus* rootstocks of varying vigor classification are available for use in the main peach production areas of the world (**Table 1**).

Nematode resistance was a large research priority as well, in which popular peach rootstock cultivars like 'Nemaguard' and 'Guardian®' were developed and released in the USA. Peach × almond hybrids like GF677 that was bred in France are commonly used in Mediterranean countries because they tolerate calcareous (with high pH) soils and lime-induced iron chlorosis, and they are also replant tolerant, graft-compatible with peach cultivars and can be easily propagated in the nurseries (**Reig et al., 2020**). Almond hybrids are characterized for their high vigor and adaptability in poor soils and dry conditions like the western US and Mediterranean region (**Mestre et al., 2015; Reig et al., 2020; Font i Forcada et al., 2020; Reighard et al., 2020**). More recently, 'Garnem', a peach × almond hybrid with similar characteristics to GF-677 was selected in Spain for its root-knot nematode resistance (**Felipe, 2009; Reig et al., 2020**). In the USA, the most recent almond hybrid that was selected by the University of California at Davis rootstock breeding program was 'Hansen 536'. Similarly, private US entities such as Bright's Nursery, Inc. released their Bright's Hybrid® series and Zaiger Genetics, Inc. released other complex interspecific rootstocks, like 'Viking™,' and 'Atlas™' (**Reighard and Loreti, 2008**). In general, all of these rootstocks are characterized for their extreme vigor that helps withstand issues with soil biotic and abiotic challenges. However, excessive peach tree vigor inhibits exploiting the advantages of higher-density plantings, creating the need for heavier pruning practices that can increase canker incidence and tree decline, lowering fruit quality as well (**Minas et al., 2018; Pieper et al., 2022**).

Rootstocks of semi-dwarfing to vigorous classifications like 'Adesoto®101' and 'Cadaman®' and 'Ishtara®' which were selected in Spain and France, respectively, for their lower vigor compared to GF-677 (ca. 30, 10 and 5% of vigor reduction, respectively), good adaptation to heavy and calcareous soil conditions, tolerance to iron chlorosis and root asphyxia, and resistance to root-knot nematodes (**Moreno, 2004; Font i Forcada et al., 2012; 2014; Reig et al., 2020**). Currently, 'Krymsk®86' a Russian peach x plum hybrid rootstock of standard size (30% of the size of vigorous almond hybrids like 'Atlas™') is dominating the new peach and almond planting decisions in the USA due to the high graft compatibility to both species, good adaptation to heavy and calcareous soil conditions, increased anchorage, tolerance to iron chlorosis, root asphyxia due to waterlogging, cold hardiness, productivity, and good fruit size and quality (**Minas et al., 2022**).

Less vegetative growth favors light distribution and interception in the canopy and thus consequently improving photosynthesis. Conversely, excessive shading in the canopy negatively affects fruit quality like size, color, sugar and phytochemical concentration and antioxidant activity (**Font i Forcada et al., 2012; Gullo et al., 2014; Marini et al., 1991**). Xylem anatomy and exchange of endogenous plant hormones among the plant organs are the primary mechanisms of rootstock/scion interactions that affect plant productivity and fruit quality, modifying the sink rate from the fruit to the shoot (**Tombesi et al., 2010**). Percentage of dry matter partitioned to fruit decreased with increasing rootstock vigor even under increasing fruit sink (number of fruit) demand due to crop load (**Caruso et al., 1997; Inglese et al., 2002**). Dwarfing rootstocks can generally translocate more sugars (photosynthesis products) to fruits because of the lower competition from the vegetative organs (**Font i Forcada et al., 2012; Gullo et al., 2014**). Indeed, less vigorous rootstocks, as the hexaploid *P. insititia* plum, seems to induce higher fruit concentrations of soluble sugars, organic acids and antioxidants (phenols, flavonoids). However, other more vigorous interspecific plum-based rootstocks greatly influenced some important biochemical fruit traits due to the fact that they had a greater expected plum genetic background, even from other plum species, compared with typical vigorous peach-almond hybrids **(Font i Forcada et al., 2019).**

Apple and sweet cherry production have been dramatically transformed due to the availability and the use of precocious, dwarfing and efficient rootstocks that facilitate the development of high-density cropping systems (**Autio et al., 2020;**

Musacchi et al., 2015; Lang, 2019; Robinson et al., 2013). The primary focus of recent rootstock breeding efforts for peach is tree size control with a number of dwarfing and semi-dwarfing genotypes that have been selected. However, since the vigor control mechanism in most of these genotypes is governed by restrictions in xylem vessel diameter and sap flow, effective tree canopy size control is usually accompanied with reduced fruit size (**DeJong et al., 2014; Minas et al., 2018**). Two series of *Prunus* interspecific hybrid rootstocks that have demonstrated promising size controlling genotypes are the Controller™ series from UC-Davis, USA and the Rootpac® series from Agromillora Iberia S.L., Spain (**Table 1**). Extensive evaluation of these new rootstock selections for their responses to different pedoclimatic conditions and intensive cropping systems that utilize simplified canopy architectures for improved productivity and labor efficiency, is highly needed (**DeJong et al., 2005; Reighard and Loreti, 2008**). Several of these new rootstock genotypes are currently under evaluation across different peach growing regions in North America under the guidance of the USDA's multistate project NC-140 (**Minas et al., 2022**).

4. Training system selection towards enhanced peach production

Peach training systems vary from low- to medium-density complex 3D canopy architectures, with multiple leaders and sub-scaffolds per tree, to modern high-density 2D planar designs with single or multiple leaders per tree. The change to modern orchard design is facilitated by genetic (e.g., low-vigor cultivars, semi- and dwarfing rootstocks, etc.) and horticultural manipulations (e.g., summer pruning, multiple leaders per tree, etc.) that control or diffuse tree vigor, respectively, to increase planting density, efficiency, productivity per unit of growing area, light interception and distribution and fruit quality (**Anthony and Minas, 2021; Iglesias and Echeverria, 2022**). Some of the main training systems for peach include: low- to medium-density multi-leader systems that utilize vigorous and standard size rootstocks such as open vase, Quad-V and Hex-V, along with higher density systems that require semi- and dwarfing rootstocks like Y-shaped (e.g., KAC-V, bi-axis), and single leaders (e.g., Fusetto, tall spindle axe, TSA, slender spindle axe, SSA) (**Figure 1**) (**Anthony and Minas, 2021; Minas et al., 2018**).

Traditional multi-leader 3D systems, like the open vase (**Figure 2**), can yield a higher amount of fruit per tree, given the larger canopy volume, but these systems intercept less light and produce less on a per land area basis given their lower densities (200-550 trees per ha) (**Iglesias and Echeverria, 2022**). Additionally, these canopies may intercept a higher amount of light at the top/exterior portions of the tree, but often the bottom/internal portions are shaded. The result of shade in these interior portions of the canopy leads to reduced tree performance, yields and fruit quality (reduced color and SSC) (**Anthony and Minas, 2021**). Subsequently, this can lead to lower crop loads in the lower/interior parts of the canopy and an excessive vegetative vigor response in the form of waterspouts growing in the center of the tree, which can only exacerbate the problem of poor light distribution, unless summer pruning (or other vigor control) interventions are used. Additional drawbacks of this system include the lack of **fruiting/precocity**, the need for ladders during management operations (as tree heights exceed 4 m) and the excessively complex canopies. This complexity renders it difficult to increase labor efficiency and the potential for mechanization. However, when this system is managed properly, it can produce large quantities of high-quality fruit (**DeJong et al., 2008**).

Medium-density plantings (MDP, 600-1,000 trees/ha) utilize multi-leader training systems that can diffuse vigor, decrease tree height (~3.0 m) and reduce canopy complexity (**Figure 2**). These multi-leader systems include the Quad-V (4 leaders) and Hex-V (6 leaders) (**Day et al., 2005**). Reduced tree heights and canopy complexity, allow planting closer, achieving a larger number of trees and/or leaders per hectare. The benefit of shifting from the Quad-V to the Hex-V is that the increased number of leaders further help diffuse the tree vigor to promote smaller canopies (<2.5 m in height) without the need for excessive summer pruning and/or waterspout removal. Therefore, such trees that can be managed more easily and in some cases without ladders (**Day et al., 2005**). An alternative way of diffusing tree vigor in medium-density systems has been through a central leader system such as the palmette that represent a very tall (4-5 m) **main** leader with up to six permanent fruiting structures that can be a free-standing or trellised hedgerow or fruit wall (**Corelli-Grappadelli, 1998**). These systems are a great compromise for growers who wish to increase land unit production without excessive orchard establishment costs.

Training systems utilized in high-density (1,000 – 2,000 trees/ha) plantings include slender spindle iterations (Fusetto, TSA, SSA) and Y-systems (**Figure 2**) that are precocious and maximize land area production and light interception while facilitating uniform light distribution and crop loads across the canopy. Precocity and higher crop loads may interfere with fruit size, but uniform light distribution in the tree allows for improved color and internal quality (**Anthony and Minas, 2021**). The up-front cost for the higher number of trees and trellising may be a potential financial barrier of entry for growers, but these costs may be recouped quickly due to increased fruiting/precocity and early yields obtained in these systems. Furthermore, high-density systems require more intensive horticultural management (e.g., summer pruning, plant growth regulators, PGRs) and size-controlling rootstocks, but the simple design improves the potential for mechanization, use of platforms and robotics to reduce labor time/cost.

The Fusetto system is an Italian adaption of the slender spindle (SS) system, which is widely popular central leader system in apple production. Trees are grown to heights of 2.8 – 3.5 m, ensuring not to exceed the length of inter-row spacing. In contrast, the Tall Spindle Axe (TSA) is typically grown to taller heights (3.0-3.7 m), although the TSA retains a similar canopy architecture to the Fusetto. Both the Fusetto and TSA are trained in a conical fashion, with larger, more dominant branches in the basal portion of the tree, while branches recede in size as they reach the apex portion of the canopy (**Loreti and Massai, 2001**). These systems are very precocious in terms of fruiting as the central leader from the nursery stock is never headed back. However, they are not recommended without the use of size-controlling rootstocks or the use of summer pruning and PGRs that are necessary to reduce tree vigor, to ensure optimal light interception, penetration, and distribution in the tree canopy to maintain productivity. However, the USA and EU regulations restrict the use of many PGRs (e.g., paclobutrazol) and thus underlying the need for efficient genotypic (e.g., size-controlling rootstocks) or horticultural (e.g., diffusion of vigor) control of tree vigor.

The Y-shaped systems are characterized by two scaffolds that extend over the inter-row (i.e., tractor alleyway) with increased planting densities and light interception (**DeJong et al., 1994**). One of the most popular iterations of the Y-shaped systems was the Kearney Agriculture Center-V (KAC-V) system, which was developed at UC Davis, as a hybrid of the traditional open vase system and the Tatura trellis (**DeJong et al., 1994**). One major benefit of the KAC-V system is the lack of trellis requirement, as the two scaffolds are developed to be strong and free-standing, however, it is difficult to mechanize tasks parallel with the alleyway, as well as in the internal portions of the canopy (**DeJong et al., 1994**).

The bi-axis is a similar Y-shaped system but it maintains two leaders in the parallel direction of the tree-row and can therefore create a homogenous, continuous and thin fruiting wall (70-90 cm in depth) to optimize light relations in the tree (uniform light distribution and high light penetration in the canopy) and the orchard (high light interception), thus, allowing future use of mechanization and/or robotics to reduce labor costs (**Anthony and Minas, 2021**). The bi-axis is a combination of the KAC-V and the Fusetto providing a major benefit for growers wishing to reduce upfront orchard establishment costs for the development of a fruit wall (**Anthony and Minas, 2021**). A primary advantage of all bi-axis systems is the ability to split the vigor into two leaders, which can help minimize tree height and maximize labor efficiency, when compared to single-leader systems. The use of semi-dwarfing rootstocks is recommended for these training systems to reduce the need for summer pruning in the internal/basal portion of the canopy.

Cordon systems have been developed and implemented in several other tree fruit species, such as the cherry UFO (or Bi-UFO) and the apple Super-Vee (**Lang, 1999; Tustin et al., 2016**). Cordon systems have been developed for peach production systems as well to achieve uniform canopy shapes, induce high early yields and potentially reduce the need for ladders by diffusing tree vigor in multiple upright leaders (**DeJong et al., 1999**). Cordon systems are typically developed with one or two leaders (‘cordons’) that are bent towards the horizontal after the first growing season in which upright growing fruiting shoots emanate from (**DeJong et al., 1999**). However, it has been noted that trying to fruit on vigorous uprights is difficult in peach, unlike cherry, and so the system has been modified recently to develop short fruiting shoots on the semi-permanent upright scaffolds that originate from the cordon (**DeJong et al., 1999**). Several iterations of the cordon systems are now being developed in Spain, Greece and Colorado, USA on vigorous and semi-dwarfing rootstocks, experimenting with various numbers of uprights per cordon (**Anthony and Minas, 2021**).

Collectively, semi- and dwarfing *Prunus* hybrid rootstocks with tolerance to both abiotic and biotic stress factors are expected in the near future to facilitate the advancement of training system innovation, through increment of planting densities towards cost-effective peach production. However, the ideal training system for a given rootstock and planting spacing can achieve optimum diffusion of tree vigor through the selection of the number of leaders and tree height to optimize balance between vegetative and reproductive potential, light interception (60-70 %) and yields for adequate light distribution and enhanced/uniform fruit quality.

5. Peach disease management concepts and phytosanitary-related issues

The main cause of postharvest losses of peach fruit worldwide are **due** to fungal pathogens as *Monilinia* spp., *Rhizopus* spp. *Mucor* spp. and *Botrytis cinerea* (**Mari et al., 2019**). In turn, and probably associated to both rising summer temperatures and elevated efficacy of control strategies mainly focused on *Monilinia* spp., a new scenario has appeared in some producing areas, for instance in Spain and specifically in Catalonia and Extremadura, when the presence of sour rot caused by *Geotrichum* spp. has increased since few years ago. Thus, geographic distribution records of fungal pathogens of peach at each producing area are the basis for phytosanitary decision-making (**Carstens et al., 2011**).

Although all these fungi can cause phytosanitary issues in peach production, currently the major losses are associated with brown rot, caused by *Monilinia* spp., that is considered the most important pathogen in the major peach production areas worldwide. Hence, many of the control strategies, treatments and measures are mainly focused on this disease and, perhaps, this could be one of the explanations of the recent increase of other fungal diseases that have been undermined in the past. Additionally, brown rot is caused by different species as *Monilinia laxa*, *M. fructigena* and *M. fructicola*; the latter being the most destructive. This species is common in North and South America, Australia, and New Zealand, but only twenty years ago was detected in Europe (**Lichou et al., 2002**). Thus, a detection survey complemented with protocols to appropriately identify any pathogen in a new area is essential to promptly implement phytosanitary measures once the presence of the pathogen is confirmed.

All these pathogens can infect fruit under field conditions, but the symptoms of the disease usually appear after harvest, thus, phytosanitary measures must be implemented from orchard to the packinghouse to avoid losses. In parallel these measures have to provide healthy, environmentally sustainable and high-quality peaches. The European Green Deal covers, among others, the use of sustainable pesticides and aims at developing more organic farming systems within a new Farm to Fork Strategy which will prepare a roadmap towards a fair, healthy and environmentally friendly food system (**European Commission, 2019**). Hence, efforts must be directed on reducing the use of chemical pesticides to control peach diseases and on employing the most cost-efficient approaches.

Disease management start with a program of fungicide applications in the field. However, and due to different reasons as high inoculum pressure, weather conditions and/or susceptibility of cultivar, preharvest treatments are not enough for an appropriate postharvest control. Hence, many efforts are now focusing on developing complementary strategies, both at preharvest and/or postharvest stage, to find a wide control of fungal diseases. One of the key aspects to reduce, or at least minimize, peach diseases is defining the epidemiology of fungal pathogens. These studies aimed for better combinations of cultural practices, including tree management such as training and pruning, removing natural inoculum sources, and fungicide application in the field. Overall, the goal is to minimize the dissemination of conidia to healthy fruit, especially close to the harvest date. In turn, careful handling during harvest, and packing operations are also crucial to avoid or reduce mechanical injuries, which make the fruit more susceptible to pathogens, followed at certain cases by a postharvest treatment. Actually, all of them should be integrated to design an optimum control strategy for *Monilinia* spp. (reviewed in **Casals et al., 2022**).

The application of most synthetic fungicides for controlling *Monilinia* spp. begin at flowering, especially in rainy springs, and are being intensified prior to harvest (**Gotor-Vila et al., 2017**). However, these treatments are not always efficient alone, especially when favorable weather conditions for the infection and development of the disease occur. In addition, the list of active fungicides available for field application (particularly close to harvest), is becoming increasingly shorter due to both legislative issues and expectations from the distribution chains and consumers.

Another obstacle to the management of diseases by fungicide application is the development of resistance to synthetic fungicides that can lead to control failures. *Monilinia* spp. is classified as moderate resistance-risk pathogen by the Fungicide Resistance Action Committee (**Malandraskis et al., 2012**). The sensitivity to fungicides depends on the pathogen, but also on the isolates; this is the reason why monitoring is vital and must start early, to determine whether resistance is the cause of lack of disease control, and to check whether resistance management strategies are effectively working. Thus, detection of location-specific resistance profiles should be a powerful tool to prevent application of ineffective fungicides, improve control of diseases, and minimize the risk of fungicide resistance occurring in orchards where the pathogen is still sensitive to one or more fungicides (**Schnabel et al., 2015**).

Finally, other ongoing control strategies are breeding strategies for biotic resistance, which consist in the research for resistance regions against pathogens in the genome of stone fruit crops. Hence, significant efforts are being invested in characterizing and enhancing fruit resistance to brown rot to the cultivars' breeding programs. To this aim, an important challenge is to agree on the methodology applied for assessing the incidence and severity of brown rot on peach fruit through a reliable phenotyping. Several research groups worldwide have developed methodologies that consider different factors that are required to fungal development (reviewed in **Mustafa et al., 2021**). In general, it has been demonstrated that the current commercial cultivars are susceptible (at different degree) to brown rot and non of them is resistant. The breeding for brown rot resistance should focus on the search for new sources of potential suppliers of genes to improve fruit resistance against *Monilinia* spp. and, for that, breeders and pathologists have to work together, to obtain new cultivars that will be tolerant and/or resistant to pathogens.

6. Improvement of consumer quality is the assurance for a sustainable peach industry

Consumer preference studies have associated the reduced peach consumption rates with immature, tasteless and/or overripe fruit, which results from inappropriate harvest decision making, as well as a variety of textural problems associated with interrupted ripening due to postharvest physiological disorders (**Manganaris et al., 2006; Minas et al., 2018**). Therefore, it is critical for fruit quality to be maintained after harvest in order to maximize consumer satisfaction and ensure a sustainable peach industry. Peach fruit quality can only be built-up in the orchard, through optimizing preharvest factors, while proper postharvest management can only assure maintenance of harvested fruit quality (**Minas et al., 2018**). To revert the negative trends in peach consumption, the selection of cultivars with improved softening rates, storability, sensorial and nutritional characteristics is critical. On the other hand, optimization of cultural management at the orchard level is necessary to achieve balanced yields and cost efficiency with acceptable fruit quality. In addition, harvest and postharvest handling should focus on optimum maturity to facilitate consumer eating experience and storage/shipping requirements with minimum risk of CI symptoms development. Thus, fine tuning between preharvest, harvest and postharvest management through optimum decision making across these rings of the supply chain is critical for successful and consistent delivery to the market of high-quality peaches, year after year to build consumer trust and secure repeat sales.

The peach fruit *per se* develops CI symptoms upon prolonged cold storage (**Manganaris et al., 2019**). This physiological disorder is triggered by exposure to cold storage temperatures (0 to 5 °C), and affects several organoleptic attributes, such as texture, flesh color and juiciness. Externally, peach fruit with CI appears sound and the symptoms usually are not noticed until the fruit reaches retailers and consumers. The major symptoms of CI in peach fruit (**Figure 3**) are characterized by a lack of juice or flesh mealiness (pectins in intercellular spaces absorb free water thus, ripe fruit have a dry grainy feel when chewed), flesh browning (occurs when enzymes such as polyphenol oxidase act on phenolic substrates) and flesh bleeding (visualized as red pigmentation in fruit flesh area near the stone which can be present at harvest) (**Lurie and Crisosto, 2005; Manganaris et al., 2005**). The progression of flesh mealiness and browning symptoms is associated with reduced perception of normal peach flavor and with development of off-flavors. This type of sensory damage underscores the effect of CI complex on consumer preference and the commercial impact on fresh peach consumption.

Chilling injury symptoms in peach develop during maintenance at room temperature following 2 to 3 weeks of cold storage depending on the cultivar and maturity status (reviewed in **Lurie and Crisosto, 2005**). Temperature management during storage and transportation is critical as CI symptoms are more severe in temperatures between 4 and 7 ºC and less severe at 0 ºC. Maturity status prior exposure to cold storage conditions **is** highly influential on the velocity and severity of CI symptoms development. Tree ripe fruit (FF=~25 N) are more susceptible to CI symptoms development than commercially harvested fruit (FF=45 N) following 3 weeks of cold storage (**Tanou et al., 2017**).

Several treatments to delay and limit development of CI have been tested in peach, such as plant growth regulators, controlled atmosphere, heat treatments and delayed fruit cooling after harvest (pre-conditioning). **The latter,** when is properly applied, delays CI symptom expression for 10 to 12 days, enough to improve the quality of some peach cultivars on arrival (reviewed in **Lurie and Crisosto, 2005; Tanou et al., 2017**). However, the benefits of most of such treatments have been erratic, and when postharvest life has been extended, the time of extension has been too short to have a commercial impact (**Manganaris et al., 2019**).

Genotypic tolerance/resistance is particularly variable across peach cultivars and could provide a long-term solution by phenotypic selection in breeding program progenies. In general, clingstone nectarine cultivars are less susceptible to CI than peach cultivars and non-melting flesh cultivars have reduced CI than melting flesh cultivars. Clingstone non-melting flesh peaches, which are primarily used in canning are largely free of CI. Melting flesh cultivars vary in susceptibility to CI, with some cultivars exhibiting symptoms in all fruit after only one week of cold storage (0°C), while others appear tolerant even following six weeks at 0°C. However, the inheritance of symptoms has not been effectively quantified, and strategies for genetic improvement through breeding would be greatly aided by knowledge of the underlying mechanisms of genetic control (**Crisosto et al., 2009**).

Effective decision making across the different rings of the fresh peach supply chain requires large scale and efficient assessment of fruit internal quality and maturity to determine optimum preharvest conditions, harvest time as well as proper postharvest handling strategies (e.g. storage conditions and duration, shipping conditions and distance) to assure consistency in peach fruit quality for the consumers. Precise assessment of maturity and internal quality is essential, but it can be time-consuming, using standard destructive methodologies (**Drogoudi et al., 2016; Minas et al., 2021**). In addition, most destructive methodologies are not friendly for real-time large-scale data acquisition in the orchard to improve fruit quality and determine harvest time or at packinghouse receiving to determine postharvest handling and/or shipping/storage time (**Minas et al., 2021**).

Non-destructive techniques can enable rapid and real time peach maturity and quality assessments in a single scan (**Minas et al., 2021**). These methods can facilitate growers for determining harvest time, but also packers and shippers so that appropriate sorting is performed, and optimum storage duration is decided (**Spadoni et al., 2016; Costa et al., 2017**). Among the different technologies applied, near infrared spectroscopy (NIRS) is a non-destructive option with the most reported applications to determine the peach fruit industry's standard quality and maturity indices (**Minas et al., 2021**). Visible light radiation (Vis) and NIRS have been combined (Vis-NIRS) to create a new non-destructive peach index that has demonstrated a correlation with the onset of endogenous ethylene synthesis and determines physiological maturity/ripening status of peaches and nectarines (**Costa et al., 2009**). More precisely, this index calculates the absorbance difference (index of absorbance difference, I_{AD}) between two wavelengths (670 and 720 nm) near the absorption peak of chlorophyll-*a* (A_{670nm}-A_{720nm}; **Ziosi et al., 2008**). A factory calibrated ("closed-type") handheld Vis-NIRS sensor (DA-meter, T.R. Turoni srl, Forlì, Italy) can take rapid non-destructive fruit scans (i.e., I_{AD} measurements) that correspond to chlorophyll concentration (i.e., ground color) a few millimeters below the skin which provides an estimate of fruit physiological maturity and consumer acceptance (**Costa et al., 2017**). This handheld sensor is particularly useful for fully red overcolored cultivars, where harvest time is difficult to estimate due to excess red overcolor on the fruit's skin that obscures the background color, which is normally used to estimate fruit maturation and harvest time (**Drogoudi et al., 2016**).

Although optimum I_{AD} value for harvest time determination varies based on cultivar and flesh textural typology (**Anthony et al., 2021**) it has been effectively integrated into robustly calibrated 'open-type' handheld Vis-NIRS sensors to enable simultaneous assessments of both physiological maturity (I_{AD}) and internal fruit quality [dry matter content (DMC) and SSC] in a single scan (**Figure 1; Minas et al., 2021**). This non-destructive technology allows for a novel pomological experimental approach by selecting fruit of equal maturity to appropriately understand the 'true' impact of preharvest factors on quality without the confounding variable of maturation. Large-scale non-destructive maturity and quality data can be paired with '-omic' tools to better understand the biological foundation of fruit quality development (**Minas et al., 2021)** while assessing the direct influence of preharvest factors (**Anthony and Minas, 2022)** such as fruit position in the canopy (**Anthony et al., 2021)**, cultivar/rootstock genotype (**Minas et al., 2018; Pieper et al., 2022)** and crop load management (**Anthony et al., 2020**).

In a recent study, two cultivars of variable vigor (low vigor: 'Sierra Rich'; high vigor: 'Creshaven') were assessed for light availability and fruit maturity (I_{AD}) and quality (DMC) at two canopy positions (top and bottom) using a robustly calibrated 'open-type' handheld Vis-NIRS sensor (**Anthony et al., 2021**). The results demonstrated that the fruit positioned in the top, in both cultivars, received higher levels of light and were of advanced maturity and quality (i.e., DMC) at harvest. However, it was not clear whether the impact on fruit quality was a result of maturity advancement/delay or the amount and quality of fruit's growing light environment.

When compared fruit of equal I_{AD} (e.g., maturity control), ΔDMC between positions in the low vigor cultivar was non-significant due to uniform light distribution and availability across the canopy. On the other hand, ΔDMC remained widely variable at 2.1% across positions in the high vigor cultivar that had minimal light availability in the bottom portion of the canopy (**Anthony et al., 2021**). These results support the hypothesis that fruit quality development is influenced more by the attributes of the light environment it is developing in, rather than the canopy position alone. This has often been the case with rootstock studies as well, since rootstocks create distinct canopies which indirectly influence fruit quality development. Non-destructive Vis-NIRS fruit quality assessments on 'Redhaven' trees grafted onto vigorous ('Atlas^{TM}' and 'Bright's Hybrid #5'), standard ('Krymsk$^{®}$86' and Lovell) and dwarfing (Krymsk$^{®}$1') rootstocks that were of equal crop load (same fruit number per cm^2 of trunk cross sectional area across rootstocks) as well as maturity (I_{AD}) revealed that peach fruit quality indicators (DMC and SSC) were improved as rootstock vigor decreased from vigorous to dwarfing (>3% ΔDMC and ΔSSC), demonstrating increased light availability in the dwarfed canopies compared to the vigorous ones (**Pieper et al., 2022**). Rootstocks with increased vigor produce more fruit due to increased leaf area, however, they may reduce light availability across parts of the canopy, promoting shading and non-uniform canopies, light distribution, and quality at harvest.

Crop load and thinning studies have demonstrated that reduced crop loads (or increased leaf-to-fruit ratios) enhance fruit size, color, DMC and SSC in peach (**Minas et al., 2018; 2021**). However, these studies also showed that maturation is advanced with reduced cropping density. Therefore, it is not clear whether the quality enhancements and detriments are a result of the crop load or a result of variable maturation status. In a follow-up crop load experiment with 'Cresthaven' peach, two thinning treatments [thinned (15 cm fruit-to-fruit spacing) and unthinned] were assessed non-destructively using Vis-NIRS at equal maturity (I_{AD}) for internal fruit quality development. Thinned (carbon sufficient) and unthinned (carbon starved) fruit quality phenotypes were very similar early in development (i.e., stage S2), while metabolite profiles were distinct and highly variable (**Anthony et al., 2020**). However, at harvest (i.e., stage S4), phenotypes between carbon supply treatments were widely different, when metabolite profiles had minimal differences (**Anthony et al., 2020**). The thinned treatment demonstrated superior quality attributes (e.g., increased fruit weight by 140 g, increased size by 21 mm, and increased DMC by 3% and SSC by 2.8%), when compared to the unthinned control at harvest (**Anthony et al., 2020**). It was hypothesized that early metabolite shifts may play a priming role at-harvest fruit phenotype and quality (**Anthony et al., 2020**). The use of non-destructive sensors that assess maturity and internal quality rapidly and accurately is expected to support informed optimization of preharvest and orchard factors that can lead to consistent delivery of high-quality peaches to the market and build on consumer trust and repeat sales.

7. Future perspectives: thinking out of the box

Significant advancements on peach tree production systems occurred, particularly over the recent years. Thus, it is questionable whether further increment in terms of yield can occur or if it needs to be grown in a different way compared to nowadays. The hypotheses reported below have been previously conceptualized on an experimental basis over 40 years ago in Israel (**Alper et al., 1980; Erez et al, 1981, 1998)** and were based on a completely different idea of the actual peach growing, under three perspectives: (1) realization of very high density-planting or even a meadow orchard (up to 15,000-20,000 trees/ha) and instead of scions, trees are propagated by hardwood cuttings or by micropropagation, (2) reduction of planting costs through the development of “protected orchards” under greenhouse, plastic or net tunnel with the additional aim to produce super early ‘off season’ product in a period where no peaches from both hemispheres are on the market, (3) a full cultural portfolio available to the growers to control size of the trees, allowing a maximum height from the ground of about 2 m in order to perform all management operations from the ground. This type of orchard, being characterized by small trees, can even be harvested mechanically by a robot.

These orchards have been experimentally realized in very hot dessert areas and were named “mobile orchards” since the trees were grown in container and moved into coolers to meet their chilling requirements. While for several vegetable crops, for instance tomato under greenhouse, a 5-fold increase in production was monitored, to what extent this initiative can be also commercially viable for peach fruits need to be investigated, considering additionally the limitations of cultivating own-rooted peach trees.

8. Conclusions

High density planting orchards designed by small size trees might result in reduction of the production cost and an increase of the orchard sustainability. The “new orchard” has to be assisted by all the recent advances of precision horticulture such as sensors and modern devices to monitor production and diseases suggesting inputs for nutrition, irrigation and phytosanitary guidelines and to fulfill the consumers and society expectations as far as intrinsic quality and health-promoting properties of the fruits. To this aim, breeding possesses a pivotal role searching for disease tolerant cultivars that are characterized by high intrinsic fruit quality. The development of standardized non-destructive determination of fruit quality and maturity stage is expected to facilitate consumer eating experience and storage/shipping requirements with minimum risk of CI symptoms development. Lastly, the employment of smart and efficient irrigation strategies under abiotic stress conditions due to climate change as well as the need for sustainable fertilization due to the accumulating cost of raw material stand as significant challenges that need to be additionally considered. The creation of a new concept of "peach orchard" may seem too original or impractical, but substantial changes have already been achieved. When Giulio Verne wrote 20,000 leagues under the sea he conceived a submarine which, however it did not yet exist!

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Tables

Table 1. Most important peach rootstock genotypes, coming from various breeding programs around the world and their genetic origin and vigor classification. Vigor classification is bracketed as follows: vigorous rootstocks are >110% the size of 'Lovell' with the size estimated by trunk cross-sectional area (TCSA); standard size rootstocks are 110-90%; semi-dwarfing rootstocks are 60-90% and dwarfing rootstocks are <60% (Reighard et al., 2020).

Rootstock	**Breeder, Country of Origin**	**Genetic Origin**	**Vigor Classification**
GF-677	INRAE, France	*P. amygdalus* × *P. persica*	Vigorous
Ishtara® (Ferciana)	INRAE, France	*(P. cerasifera* × *P. salicina)* × (*P. cerasifera* × *P. persica*)	Vigorous
Cadaman® (Avimag)	INRAE, France/Hungary	*P. davidiana* × *P. persica*	Vigorous
Empyrean®2 (Penta)	CREA, Italy	*P. domestica*	Semi-Dwarfing
Empyrean®3 (Tetra)	CREA, Italy	*P. domestica*	Semi-Dwarfing
Krymsk®1	KEBS, Russia	*P. tomentosa* × *P. cerasifera*	Dwarfing
Krymsk®86	KEBS, Russia	*P. cerasifera* × *P. persica*	Vigorous
Adesoto®101	CSIC, Spain	*P. insititia*	**Semi-Dwarfing**

Garnem	CITA, Spain	*P. amygdalus* × *P. persica*	Vigorous
Rootpac®R	Agromillora Iberia, Spain	*P. cerasifera* × *P. amygdalus*	Vigorous
Rootpac®70	Agromillora Iberia, Spain	*P. persica* × *(P. amygdalus* × *P. persica)*	Vigorous
Rootpac®40 (Nanopac)	Agromillora Iberia, Spain	*(P. amygdalus* × *P. persica)* × *(P. amygdalus* × *P. persica)*	Semi-Dwarfing
Rootpac®20 (Densipac)	Agromillora Iberia, Spain	*P. besseyi* × *P. persica*	Dwarfing
Lovell	G.W. Thissell, USA	*P. persica*	Standard
Controller™5 (K146-43)	UC-Davis, USA	*P. salicina* × *P. persica*	Dwarfing
Controller ™6 (HBOK 27)	UC-Davis, USA	*P. persica* × *P. persica*	Semi-Dwarfing
Controller ™7 (HBOK 32)	UC-Davis, USA	*P. persica* × *P. persica*	Semi-Dwarfing
Controller ™8 (HBOK 10)	UC-Davis, USA	*P. persica* × *P. persica*	Semi-Dwarfing
Hansen 536	UC-Davis, USA	*P. amygdalus* × *P. persica*	Standard
Nemaguard	USDA, USA	*P. persica* × *P. davidiana*	Vigorous
Guardian®	Clemson University/USDA, USA	*P. persica*	Vigorous

MP-29	USDA-Georgia, USA	*P. umbellata* × *P. persica*	Dwarfing
Bright’s Hybrid® #5	Bright’s Nursery, Inc., USA	*P. amygdalus* × *P. persica*	Vigorous
Atlas™	Zaiger Genetics, USA	Hybrid of *P. persica*, *P. amygdalus*, *P. cerasifera*, *P. mume*	Vigorous
Viking™	Zaiger Genetics, USA	Hybrid of *P. persica, P. amygdalus, P. cerasifera, Prunus* × *blireiana*	Vigorous

CSIC=Consejo Superior de Investigaciones Científicas;

INRAE=Institut National de la Recherche pour l’agriculture, l’alimentation et l’environnement;

KEBS=Krymsk Experimental Breeding Station, Krasnodar Region, Russia;

CITA=Centro de Investigacion y Tecnologıa Agroalimentaria de Aragon

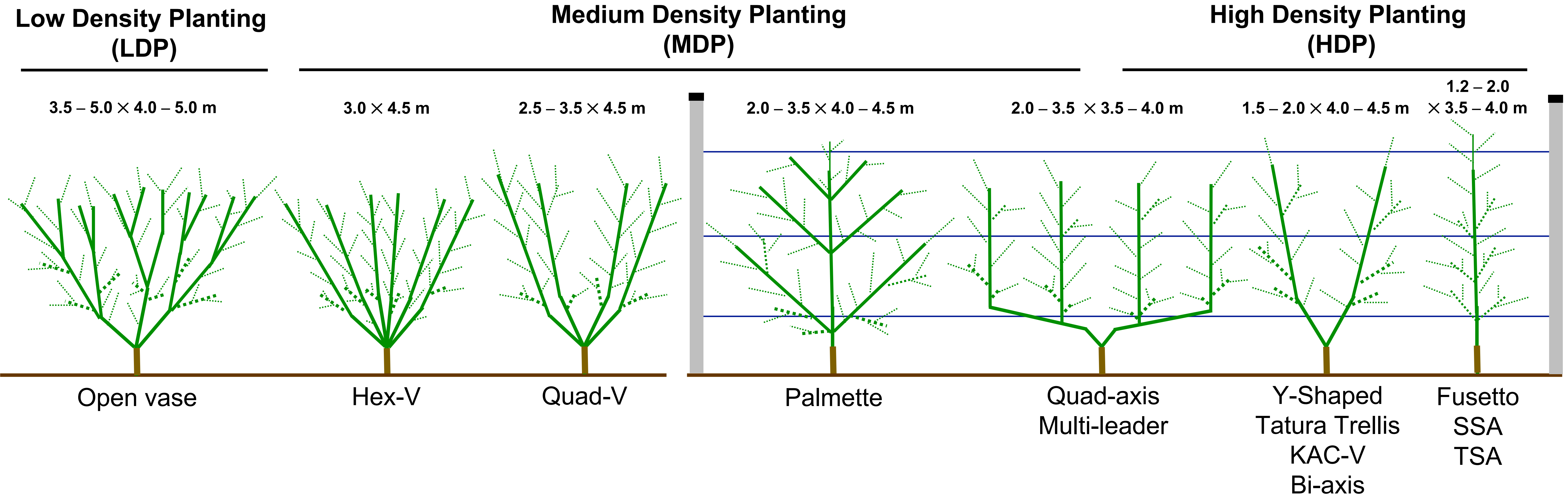
Figure captions

Figure 1. Phenotypic appearance of two distinct peach cultivar typologies during maturation ‘on-tree’. (A) ‘Cresthaven’ a late-ripening bi-color cultivar and (B) ‘Sierra Rich’ early-ripening fully red overcolored cultivar. Non-destructive Vis-NIRS assessment of (C) ‘Cresthaven’ and (D) ‘Sierra Rich’ using an ‘open-type’ handheld sensor that has been calibrated with robust models to simultaneously predict fruit internal quality (DMC and SSC) and physiological maturity (I_{AD}) in a single scan (Minas et al., 2021).

Figure 2. Canopy architectures of the most widely used training systems in peach and their planting densities. Spacings listed as: intra-row x inter-row (Adopted from Anthony and Minas, 2021).

Figure 3. Chilling injury (CI) symptoms due to prolonged storage make consumers stay away of peaches. Internal appearance of ‘Zee Lady’ peaches following storage of 4 weeks at 0ºC plus 2 days at 20ºC.


A
C
DM
Saving...
13.17
SSC
11.09
Lot/Sample: 1/1
Created: 07/28/2016 20:32:39
Filename: UNTITLED_1
Location: Reading GPS...
F-750 Produce Quali
B
D
DM %
Saving...
14.16
SSC % 12.78
Lot/Sample: 1/1
Created: 08/08/2016 22:07:43
Filename: UNTITLED_12
Location: 0, 0
F-750 Produce Quality


Low Density Planting
(LDP)
Medium Density Planting
(MDP)
High Density Planting
(HDP)
3.5 – 5.0 × 4.0 – 5.0 m
3.0 × 4.5 m
2.5 – 3.5 × 4.5 m
2.0 – 3.5 × 4.0 – 4.5 m
2.0 – 3.5 × 3.5 – 4.0 m
1.5 – 2.0 × 4.0 – 4.5 m
1.2 – 2.0
× 3.5 – 4.0 m
Open vase
Hex-V
Quad-V
Palmette
Quad-axis
Multi-leader
Y-Shaped
Tatura Trellis
KAC-V
Bi-axis
Fusetto
SSA
TSA

Healthy

Flesh bleeding

Flesh browning

Flesh mealiness