Universidade Trás-os-Montes e Alto Douro

Eco-physiological evaluation of 'Vairo' cultivar grafted onto different rootstocks

-Final Version-

Dissertation of the master in Agronomic Engineering

Nuno Filipe Miranda Ribeiro Araújo

Professor Doctor Ana Paula Silva

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Vila Real, 2018

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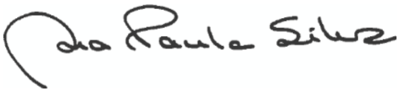

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IRTA

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"If you want to go fast, go alone. If you want to go far, go together", African proverb.

Abstract

Almond (*Prunus dulcis*) is the most important nut crop in terms of world production. New almond cultivars and rootstocks have been created to satisfy world increasing demand, consumption trends and new agronomic production models. The aim of this study was to understand the influence of eight different *Prunus* rootstocks on the behaviour of almond cultivar 'Vairo'. The study was carried out in an experimental orchard of IRTA located in Les Borges Blanques, Catalonia. The trees were planted in 2010 and the data used in this study were collected during the summer of 2017.

The rootstocks evaluated were: 'GF-677', 'ISHTARA', 'IRTA 1', 'IRTA 2, 'ROOTPAC-R', 'ROOTPAC-40', 'ROOTPAC-20' and 'Puebla de Soto'. Periodic measurements were carried out. Leaf chlorophyll concentration, quantum yield of PSII, shoot growth, stem water potential, stomatal conductance, canopy volume, photosynthetically active radiation, fruit volume, fruit weight and yield were the parameters analysed. A statistical analysis was made and showed significant differences between rootstocks.

'Vairo' cultivar seemed to be best adapted to the 'GF-677' rootstock. This combination was also the best suited to the site conditions, having the healthier trees, producing bigger and heavier fruits and with the highest yield. Regarding tree water status, 'Vairo' cultivar grafted onto 'ROOTPAC-40' presented the less stressed trees. Moreover, when grafted onto 'ROOTPAC-20' rootstock, 'Vairo' cultivar presented the smallest fruits, smallest kernels, lowest fruits weights, lowest kernels weights and lowest yield, making it the less suitable combination.

For a healthier and productive orchard, the right rootstock choice is one of the most important factors to consider. However, choosing a rootstock only by its main characteristics and discarding its adaptability to the soil and climate may not be the best approach.

Key words: Almond; *Prunus dulcis*; 'Vairo'; rootstocks; tree water status; fruit dimensions; yield.

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List of abbreviations

CEBAS	Centro de Edafología y Biologia Aplicada del Segura
CITA	Centro de Investigación y Tecnología Agroalimentaria de Aragón
CSIC	Consejo Superior de Investigaciones Científicas
CV	Canopy volume
FAO	Food and Agriculture Organization of the United Nations
GF	'GF-677'
INRA	Institut National de la Recherche Agronomique
IRTA	Institut de Recerca i Tecnologia Agroalimentàries
ISH	'ISHTARA'
NAN	'ROOTPAC-40'
MB	'IRTA 1'
MI	'IRTA 2'
MIR	'ROOTPAC-R'
PAC	'ROOTPAC-20'
PAR	Photosynthetically Active Radiation
PSII	Photosystem II
PUE	'Puebla de Soto'
SE	Standard Error
SPAD	Soil Plant Analysis Development
Ψstem	Stem Water Potential

General introduction

This work was done as an original thesis for the degree of Master of Agronomic Engineering. It resulted on a partnership between UTAD (Universidade de Trás-os-Montes e Alto Douro) and IRTA (Institut de Recerca i Tecnologia Agroalimentàries) located in Catalonia, Spain.

The study consisted on the eco-physiological evaluation of 'Vairo' cultivar grafted onto eight different rootstocks. The adaptability of the rootstocks to the site conditions and their compatibility with the almond cultivar were factors taken into consideration.

The choice of rootstocks and almond cultivar were related with an ongoing trial created by IRTA in one experimental orchard localized in the village of Les Borges Blanques, Catalonia. The measurements were collected between May and September of 2017. All the practical work was done in Spain.

This work is divided in four parts. The first is the literature review which starts with a contextualization of almond history. Botany and physiology of the almond tree are also described, and its economic importance and multiples uses. Moreover, 'Vairo' cultivar most important traits, rootstock types and parameters analysed are presented. The second part consists in the material and methods. In this chapter everything related to the trial is described. The third part is results and discussion. In this section all the results obtained are presented in figures and tables followed by a brief discussion. The last part is the conclusion where the rootstocks performance is debated, and final considerations are made.

1. Literature review

1.1. Almond, from ancient to modern times

Almond is an ancient crop. It has been recognized that almond was first domesticated in central and southern Asia during the third millennium BC [1]. Most of the wild varieties produced bitter kernels due to the accumulation of glucoside amygdalin [2]. Some of them were harmful to eat due to the hydrolyzation of the glucoside amygdalin to benzaldehyde and cyanide when exposed to the enzyme emulsin [3]. However, ancient civilizations discovered that some of the trees produced sweet kernels. The domestication of almond started by selection of superior traits. The most important factor was the development of sweet kernel [4]. After the domestication, almond started to be consumed by every ancient civilization in the central, southern Asia and in the Middle East region. Commercial routes like the Silk Road took the very important role of spreading almond [5]. Almond was an important crop in every civilization that was consumed, with references in the Greek mythology and in the Old Testament [4], [6].

An adaptation to severe climates combined with the ability to develop a deep and extensive root system has allowed almond to survive and thrive in a wide range of ecological niches [7], [8]. After arriving in to the Mediterranean area, almond quickly spread across Southern Europe and North Africa carried by explorers, conquerors and merchants [9]. The good adaptation to the area was mainly due to the climate conditions of these regions. Almond is well suited to the mild winter and dry, hot summer conditions typical of Mediterranean climates due to its low chilling requirement, rapid early shoot and high tolerance to summer heat and drought [10].

Almonds arrived in the United States of America brought by the early colonists, but it was only successfully planted in California, where the Central Valley's Mediterranean climate offered the perfect conditions for the earliest significant plantings [11]. It was only until middle of the XX century that almond started to become an important crop in the region and latter transforming California in the biggest producer of almond in the world [11].

Today, in the XXI century the demand for almond was never higher. Due to its health benefit and high nutritional value the consumption and world supply of almond is increasing. That means that, like in the prehistoric times, superior morphological traits need to be selected. Increasing yields, improvement of kernel quality and reduction of production costs are the main objectives of almond breeding programs to meet industry's demand [3]. But also, self-compatibility, resistance to different diseases and pests and late bloom to escape winter/spring frosts are the biggest challenges that the producers face today. To answer these challenges new varieties are being developed along with the combination of different rootstocks. Also new orchards production models like intensive and super-intensive are being tested.

Almond is at a stimulate turning point, where the production of almond kernels of very high organoleptic and nutritional quality, and produced under sustainable methods, will be required to satisfy the increasing world demand.

1.2. Botanical classification and physiology of almond tree

Almond [*P. dulcis* (Mill.) D.A. Webb; syn. *P. amygdalus* Batsch] is classified within the family of Rosaceae and belongs to the genus *Prunus* and subgenus *Amygdalus*. The *Prunus* genus includes all the stone fruits such as peach (*P. persica* (L.) Batsch), apricot (*P. armeniaca* L.), sweet cherry (*P. avium* L.), sour cherry (*P. cerasus* L.) and plum (*P. domestica* L.). Almond is a diploid species with n=8, the basic ploidy number of *Prunus* [3]. *Prunus* species are characterized by species that produce fruit known as drupe where the seed is enclosed in a hard, lignified endocarp referred to as the stone, and the edible portion is a juicy mesocarp. In contrast, almond is the only *Prunus* species where the seed or kernel is the most valuable part [3], [12]. Almond produces a drupe with pubescent exocarp, a thin and fleshy mesocarp (hull) that after the period of development becomes dry and dehiscent at maturity, and a distinct hardened endocarp (shell). The dehiscent of the hull distinguishes almond from other *Prunus* species [3]. The particularities of almond have surrounded the botanical classification with controversy and many synonyms have been reported since Carl Linnaeus began botanical systematics. Most of them were proved wrong and are not accepted today, such as: *Amygdalus communis* L.; *Amygdalus communis* Bunge; *Amygdalus dulcis* Mill. [13].

Almond is a deciduous tree and it’s the first fruit tree to bloom due its lowest winter chilling requirement [3]. Almond growth cycle follows its original Mediterranean or desert climate, where plants are dormant during winter and blooming when temperatures become mild [3]. During the early blooming period frost has an extremely negative impact on yield. Rain in early spring reduces flower pollination interfering with the main pollinator, *Apis melifera*.

Almond flowers are generally perfect and pentamerous, with five sepals, five petals, a variable number of stamens and a single pistil. Flower buds are variable in size, shape and colour depending on the cultivar. The number of flowers in a single bud is also a cultivar trait [13].

Genetic diversity of almond is very high and there is a wide variability for many traits within the species. The differences observed are much higher than in other closely related species, e.g. peach. Almond is a very heterogeneous species, not only its morphological and physiological traits, but also on the genetic structure of the different cultivars [13]. This heterogeneity probably results from the ancient origin of almond, the propagation method, growth habit in many diverse areas and local adaptation to different microclimates [3].

1.3. Economic importance and uses

Almond is the nut crop with the largest commercial production in the world. The worldwide production of almond with shell has increased from approximately 2.062.052 tonnes in 2006 to approximately 3.214.303 tonnes in 2016 (FAO 2018). In the other hand, the total area harvested has increased from approximately 1.659.614 ha in 2006 to approximately 1.865.633 ha in 2016 (FAO 2018) (Figure 1). Taking a closer look to the previous values an important observation can be made, almond production with shell has increased approximately 56% in the last decade but the harvested area has only increased approximately 12%. These values reflect how important almond has become and how different is the almond paradigm today. Almond is not a crop of rainfed and marginal conditions anymore. In the right conditions and with adequate agricultural practises almond can be presented has one of the most profitable and well-suited crops in the Mediterranean climate regions.

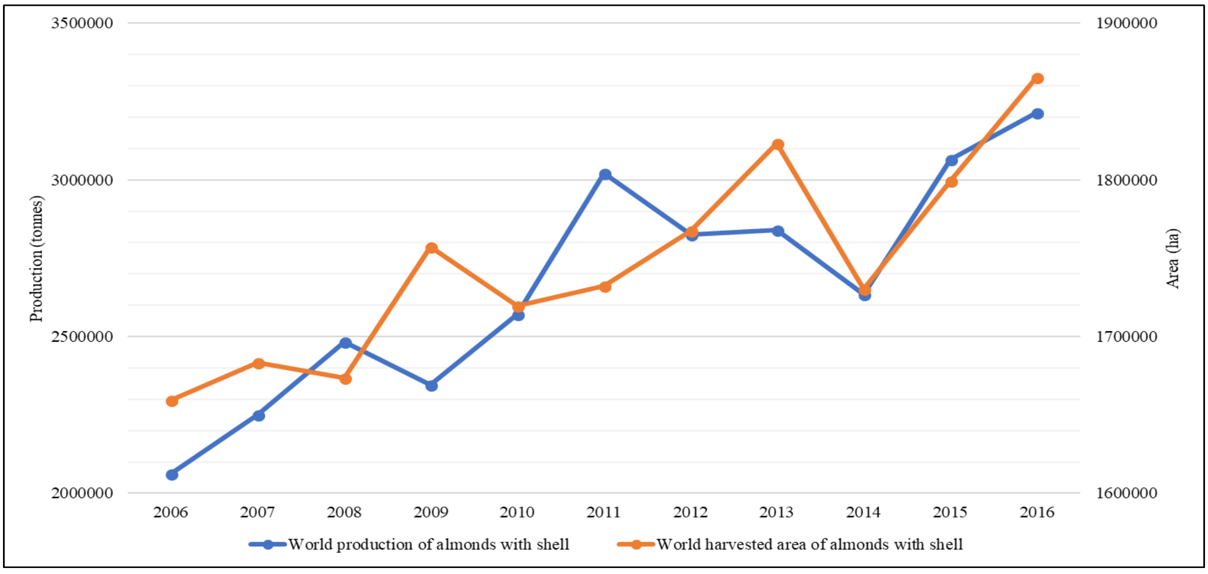

Figure 1. Total world production of almonds with shell (tonnes) from 2006 to 2016 and total world area harvested of almonds with shell (ha) from 2006 to 2016 (FAO 2018).

From the approximately 3.214.303 tonnes of almond with shell produced worldwide in 2016, 2.002.742 tonnes were produced in the United States of America corresponding to 62% of the world total production. The top 10 countries productions combined correspond to 91% of the total almond with shell production in the world (Figure 2). In Europe, Spain is the biggest producer with 202.339 tonnes in 2016, followed by Italy with a production of 74.584 tonnes. These are the only two European countries in the top 10. Portugal is the fourth biggest producer of almond with shell in Europe, with a production of 8.713 tonnes in 2016.

In the Iberian Peninsula almond was traditionally a crop for rainfed and marginal conditions, planted in places where most crops wouldn't survive. This fact is still visible when analysing the total production values and the total area harvested. In Portugal there were approximately 31.464 ha of area harvested in 2016 (FAO 2018). Meaning that Portugal had a medium yield of 0,28 tonnes/ha of almond with shell. In Spain, even though it's Europe's biggest producer and second worldwide producer of almond with shell a similar situation occurred. There were approximately 544.518 ha of area harvested in 2016 (FAO 2018). Meaning that Spain had a medium yield of 0,37 tonnes/ha of almond with shell. These values reflect a big different between countries like the United States of America and Australia with the rest of the almond producer countries regarding good agricultural practises and mentality. Despite the low medium yield values recorded in the Iberian Peninsula, a revolution is happening regarding varieties and rootstocks used and agricultural practises. These changes will make it possible for countries like Portugal to compete in the global market in a not so distant future.

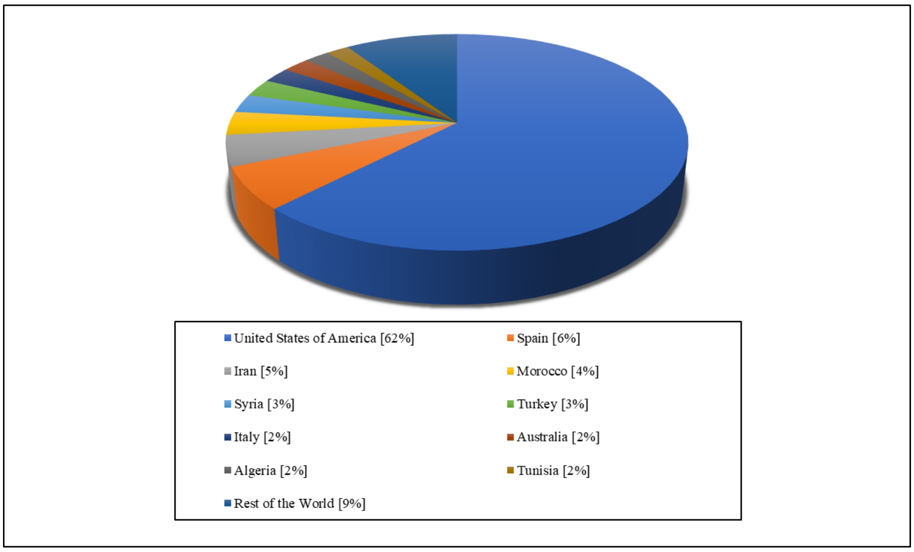

Figure 2. Top 10 countries producers of almond with shell in 2016 (FAO 2018).

Every year the production of almonds grows, fact only possible because the consumption is increasing. The main reason for this high demand is mainly because the nutritional value and health benefits that almonds present, making them part of many diets across the world. Not only is a good source of energy that contains macronutrients such as lipids (52,2%), carbohydrates (20,4%) and water-soluble sugars (4,4%), but also phytonutrients like vitamin E (α-tocopherol), folic and oleic acid [14], [15]. The main fatty acids are oleic (70-80%), linoleic (10-17%) and palmitic (5,5-6,5%) [16]. The high level of oleic acid has very importance because it is known that reduces low-density lipoprotein cholesterol that inhibits blood circulation [17]. The consumption of almonds in a regular basis maintains the levels of high-density lipoprotein cholesterol, lowers the level of low-density lipoprotein cholesterol and reduces central obesity [18]. Moreover, the consumption of almonds reduces the risk of heart diseases [19], increases the plasma concentration of polyphenols, raises the total antioxidant potential in the plasma and reduces lipid peroxidation [20]. Furthermore, the consumption of almonds reduces the risk of colon cancer [21]. Almond milk contains high percentage of monounsaturated fatty acids and have a balanced composition in terms of proteins, fats, fibre and vitamins and minerals and does not contain lactose [22]. It is suitable for those who suffer from lactose and milk protein intolerance [23]. Also, there are many products that uses almond in their composition. Almond is very rich in antioxidants and its oil has been used by the cosmetic industry [24].

1.4. Vairo cultivar

One of the basics factors for a successful crop plantation is the plant material used. The varieties panorama of almonds has experienced a remarkable renovation in the last 30 years. This renovation was only possible because of the diffusion of new varieties created in breading programs, first in France (INRA) and latter in Spain (CEBAS, CITA and IRTA) [25].

The IRTA almond breeding program, active since 1975, aims to solve some of the main problems within the almond crop in the Mediterranean Basin. The main agronomic and commercial features that the program is focused are: late bloom, self-compatibility, higher yields, tree vigour, growth and branching habit, training and pruning ease, disease resistance, and nut quality [26].

With those parameters in mind, in 1991 'Vairo' cultivar was obtained. Resulted from crosses between cultivars and selections with the desirable traits specifically from IRTA ('4-655') with INRA ('Lauranne'). 'Lauranne' is self-compatible, high yielding and shows good growth habit; '4-655' is vigourous and productive, with a good growth habit and good kernel appearance. Both cultivars are late-blooming [26]. ‘Vairo’ has inherited both parents traits and has been considered as one of the most promising varieties ever resulted from IRTA almond breading program. The most important and relevant traits present in ‘Vairo’ cultivar are:

- Bloom date: ‘Vairo’ flowers late, at a similar time as ‘Guara’ (Table 1);
- Self-Fertility: ‘Vairo’ is self-compatible. In almonds, the self-compatibility is genetically controlled by S-alleles. Specifically, S_f allele is responsible for self-fertility. Plus, S_f allele is dominant and when present pollen from the same cultivar has the potential to produce fruit [27] (Table 2);
- Vigour, yield potential and bearing precocity: ‘Vairo’ is a very vigorous cultivar, which allows it to maintain a good balance between production and growth. An important factor because a balanced tree produces earlier. Also, has a very high production capacity (Table 3);
- Disease tolerance: ‘Vairo’ has high tolerance to the main diseases that are responsible for the major economic losses in an almond orchard (Table 4). A very important trait to help increase orchard sustainability.
- Fruit Characteristics: ‘Vairo’ shows good nut features with hard shell; good kernel weight and yield; and with practically non-existent double kernels (Table 5). In the kernel chemical composition is important to mention the high oil yield that contains (Table 6).

Table 1. Bloom date of 'Vairo' and reference almond cultivars. Average full bloom date and number of days from 'Desmayo Largueta' full bloom (average: 3 of February) [26].

Cultivar	**Average bloom date**	**Average number of days from ‘Desmayo Largueta’**
‘Vairo’	1-March	26
Reference:		
‘Guara’	1-March	26
‘Ferragnès’	3-March	28

Table 2. Self-compatibility and S-genotypes of 'Vairo' and reference almond cultivars [26].

Cultivar	Self-compatibility	S-genotype
‘Vairo’	Yes	S_9S_f
Reference:		
‘Guara’	Yes	S_1S_f
‘Ferragnès’	No	S_1S_3

Table 3. Tree vigour, yield potential and bearing precocity of 'Vairo' and reference almond cultivars [26].

Cultivar	Vigour	Yield potential	Bearing precocity
‘Vairo’	Very strong	Very high	Early
Reference:			
‘Guara’	Mid	High – very high	Early
‘Ferragnès’	Strong	High – very high	Mid

Table 4. Tolerance of ‘Vairo’ and reference almond cultivars to *Phomopsis amygdali* Del. ("fusicoccum"), *Polystigma ochraceum* Whal. ("red leaf blotch") and Monilinia (“brown rot”) [26].

Cultivar	Tolerance to “fusicoccum”	Tolerance to “red leaf blotch”	Tolerance to “brown rot”
‘Vairo’	Tolerant	Tolerant	Very tolerant
Reference:			
‘Guara’	Susceptible	Very susceptible	Susceptible
‘Ferragnès’	Very susceptible	Tolerant	Mid

Table 5. Nut characteristics of 'Vairo' and reference almond cultivars: kernel weight (g), kernel yield (shelling percentage %), double kernels (%) and kernel appearance (scale 1 to 9, with 9 the highest mark) [26].

Cultivar	Kernel weight (g)	Kernel yield (%)	Double kernels (%)	Kernel appearance (scale 1-9)
‘Vairo’	1.20	29	0.1	7.0
Reference:				
‘Guara’	1.33	35	11.4	6.3
‘Ferragnès’	1.49	34	0.1	6.4

Table 6. Chemical composition of blanched kernels from 'Vairo' and reference almond cultivars [26], [28].

Cultivar	Oil (%)	Protein (%)	Soluble sugars (%)	Total fiber (%)
'Vairo'	52.7	24.5	3.0	9.0
Reference:				
'Marcona'	54.2	25.7	2.2	8.8
'Nonpareil'	45.5	25.3	2.1	9.7

1.5. Almond rootstocks

The importance of the rootstock is often underestimated. However, the agronomic performance of the fruit tree is highly influenced by it. The rootstock is part of the fruit tree and needs to interact with the scion to optimise fruit production and quality [29]. It provides a root system that will absorb water and nutrients and communicate important messages to the above ground components of the tree influencing stomatal conductance; shoot growth; fruit size; fruit yield; and bloom and harvest dates [29], [30]. A rootstock may also improve the water use efficiency by altering stoma size, transpiration, water potential and vegetative growth [31], [32]. Also, the adequate choice of the scion-rootstock combination is important in the adaptation of the fruit tree to the soil conditions and to specific training systems [33].

Because their recognized importance, the development of new rootstocks is the aim of several breading programs around the world, IRTA included [34]. Rootstocks can be either seedlings or vegetatively propagated (clonal) [35].The different types of rootstocks used for almond production are:

- Almond seedlings: The main characteristic of almond seedlings is their ability to develop a deep root system. They are also known by their hardiness and ability to grow in poor, high limestone content soils with little natural rainfall [36]. In the negative side, almond seedlings are not homogeneous in growth development and behaviour and are sensitive to handling and transplanting from the nursery to the field. They are also susceptible to soil pathogens such as nematodes; *Agrobacterium*; *Phytophthora*; *Armillaria*, and sensitive to neck and root asphyxia, making them unsuitable for cultivation under irrigated conditions, except with specific irrigation systems and in soils with good drainage [35]–[37].
- Peach seedlings: Suitable for cultivation under irrigated conditions and tolerance to certain species of nematodes are the main characteristics and advantages when

compared to almond seedlings. Also, peach seedlings typically give more homogeneous plants that come into bearing sooner. In contrast, they remain highly sensitive to some common pathogens such as *Agrobacterium*; *Phytophthora*; *Armillaria;* they are not tolerant to calcareous soils, subject to drought, or high in boron, and they induce a shorter tree life than almond rootstocks [10], [37].

- Plum seedlings: The root system of plum has a shallow development and generally the roots are smaller in number and thickness when compared to almond or peach. This root system gives them the ability to perform better in heavy soils, specifically in waterlogging conditions. When compared to almonds and peach, plum have more tolerance to certain soil pathogens, like nematodes and oak-root fungus. This type of rootstock has been extensively used in California. Due to its unsatisfied behaviour on rainfed soils, this type of rootstock should only be used under irrigated conditions. Plums also have big compatibility problems with almond cultivars, making them hard to use without prior experience [10], [35], [37].
- Clonal rootstocks: Even though it's a more expensive process than grafting to seedlings it offers the big advantage that the behaviour of the produced material is very homogeneous and consistent [37].
- Interspecific hybrids: Among the interspecific hybrids between *Prunus*, almond and peach are the best known and widespread. Specially in the Mediterranean area, as they are tolerant to lime induced Fe chlorosis and alkaline conditions [38]. The main advantages of this kind of hybrid are drought tolerance; high vigour; deep rooting; exceptional anchorage; and tolerance to calcareous soils [35]. They are also appropriate to poor dry soils and replanting situations [39]. The interspecific hybrids are still sensitive to some soil pathogens like *Agrobacterium* and *Armillaria*. Also, they can be difficult to propagate [37]. Micropropagation can increase the range of genotypes propagated, but it also increases the cost of nursery propagation. It also has shown promise for the direct rooting of the scion material [10].

In this study, eight different rootstocks were evaluated (Table 7). It was very important to have rootstocks coming from different parentages and types to see how they influence the tree and how well they perform. From the eight rootstocks evaluated, seven were interspecific hybrids and one was a clone selection from damson plum.

Nowadays, the most used almond-peach hybrid rootstock is 'GF-677', for both irrigated and non-irrigated conditions [15]. As first analysis, 'GF-677', 'IRTA 1' and 'ROOTPAC-40', being almond-peach hybrids, were the rootstocks that were expected to create bigger trees [35]. In contrast, 'ROOTPAC-R' and 'ROOTPAC-20' were especially created to meet the sector demand of restraining vigour, so they were expected to create the smaller trees [40].

Table 7. Origin and parentage of the rootstocks studied [40].

Rootstock	Parentage	Origin
'GF-677'	'*P. amygdalus*' x '*P. persica*'	INRA (France)
'ISHTARA'	('*P. cesarifera*' x '*P. salicina*') x ('*P. cesarifera*' x '*P. persica*')	INRA (France)
'IRTA 1'	('*P. dulcis*' x '*P. persica*') x ('*P. dulcis*' x '*P. persica*')	IRTA (Spain)
'IRTA 2'	'*P. cerasifera*' x '*P. dulcis*'	IRTA (Spain)
'ROOTPAC-R'	'*P. cerasifera*' x '*P. dulcis*'	Agromillora Iberia (Spain)
'ROOTPAC-40'	('*P. dulcis*' x '*P. persica*') x ('*P. dulcis*' x '*P. persica*')	Agromillora Iberia (Spain)
'ROOTPAC-20'	'*P. besseyi*' x '*P. cerasifera*'	Agromillora Iberia (Spain)
'Puebla de Soto'	Clone selection of '*P. insititia*'	CSIC Aula Dei (Spain)

1.6. Physiological parameters

In order to understand the influence of a rootstock on the 'Vairo' cultivar physiology, it is necessary to analyse some parameters, namely photosynthetic potential, water management in the plant and, consequently, the level of vigour. These parameters, in turn, will influence the growth of the shoots, canopy volume, the yield and the quality of the fruits. For this it is necessary to make measurements, namely:

- Leaf chlorophyll content: The leaf chlorophyll content or leaf greenness provides useful information about photosynthetic potential and primary production. Most of the leaf nitrogen is incorporated in chlorophyll, so quantifying chlorophyll gives an indirect measurement of tree nutrient status. A further area of application arises from the fact that several diseases directly lead to changes in pigmentation caused by a decrease in chlorophyll content [41], [42];
- Quantum yield of PSII: The quantum yield of photosynthesis is a definitive measure of the energetic efficiency of autotrophy. It provides useful information about the photosynthesis status [43];
- Stem water potential: The stem water potential is an indicator of tree water status. It provides useful information that allows adjustments on tree water incomes and detect water stressed trees [44];

- Stomatal conductance: The stomatal conductance is an indicator of foliar transpiration rate and consequently tree water status. To maintain adequate levels of water, stressed trees close the stomata and have low values of stomatal conductance [45];
- Photosynthetically active radiation: The photosynthetically active radiation is an indicator of the amount of light available for photosynthesis [46];
- Shoot growth: The shoot growth was measured on one year old shoots. It can be used as potential production information for the next years. Flowers form on shoots with more than one year [47];
- Canopy volume: The canopy volume is an indicator of the rootstock type. Bigger canopy volumes indicate vigourous rootstocks and smaller canopy volumes indicate dwarfing rootstocks;
- Fruit and kernel volume: The fruit and kernel volume measurement gave useful information to identify which rootstock produced bigger fruits and kernels. An important trait to meet the industry demand;
- Fruit and kernel weight: The fruit and kernel weight measurement identified which rootstock produced heavier fruits and kernels. An important trait to consider if having higher yields is a priority.

2. Materials and methods

2.1. Experimental trial

This study was carried out in an experimental orchard of IRTA, located in the Ebro Valley, north-east of Spain, in the village of Les Borges Blanques, Lerida (41°30'25.9''N051'09.2''E) during the summer of 2017. The climate of this region is considered Mediterranean climate, with very hot and dry summers and mild to cold winters. It is classified as Csa by Köppen and Geiger [48]. The orchard soil was composed by a clay-silt-loam texture.

The experimental orchard was planted in March of 2010 and the trees were spaced 5,5 m x 4,5 m (Figure 3). The total number of trees used in this study was 48 and the total number of different rootstocks evaluated was 8. The trees were organized in 6 different blocs, with each bloc having 8 trees grafted in 8 different rootstocks. In every block the rootstocks were positioned randomly.

Regarding the orchard management, the trees were conducted with a low pruned, traditional vase system, and managed and fertilized following current commercial practices. A drip irrigation system was used to supply water with an estimated application rate of 8000 m^3/ha per year.

Figure 3. Experimental orchard in Les Borges Blanques.

2.2. Climatic data

The climatic data were collected day by day from a meteorological station located in Les Borges Blanques from May 12th until September 1st. The data recorded was: daily temperature, maximum and minimum (Figure 4); daily relative humidity, maximum and minimum (Figure 5); and daily pluviometry (Figure 6).

The highest temperature value recorded occurred in July 7th and it was 37,5ºC. The total amount of pluviometry recorded in the studied period was 72mm. These values reflect how arid and dry the summer in Les Borges Blanques was.

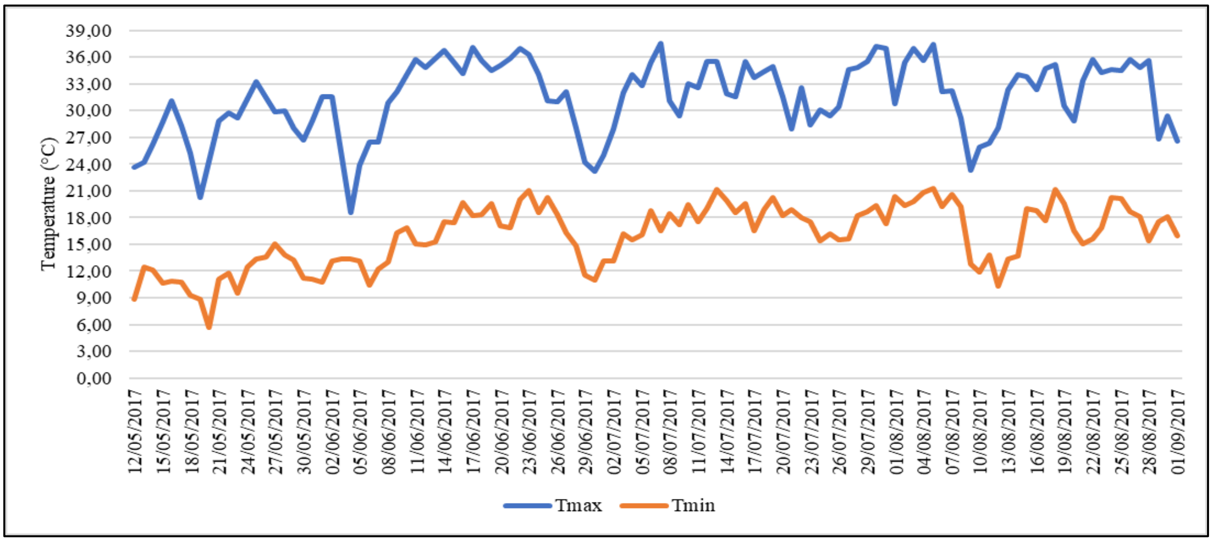

Figure 4. Daily maximal and minimal temperature between 12th of May and 1st of September.

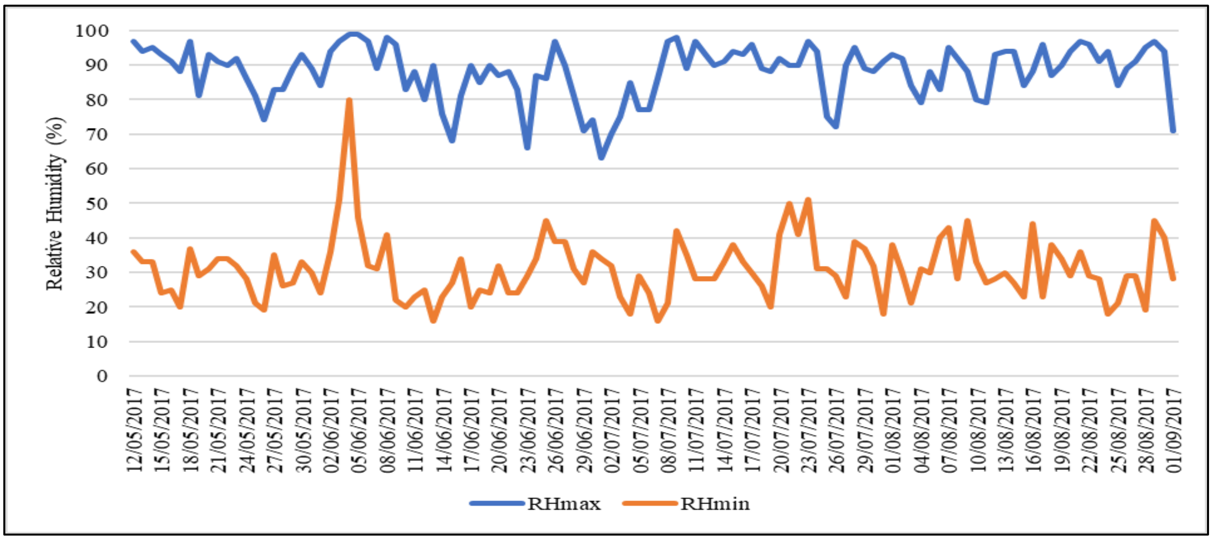

Figure 5. Daily maximal and minimal relative humidity between 12th of May and 1st of September.

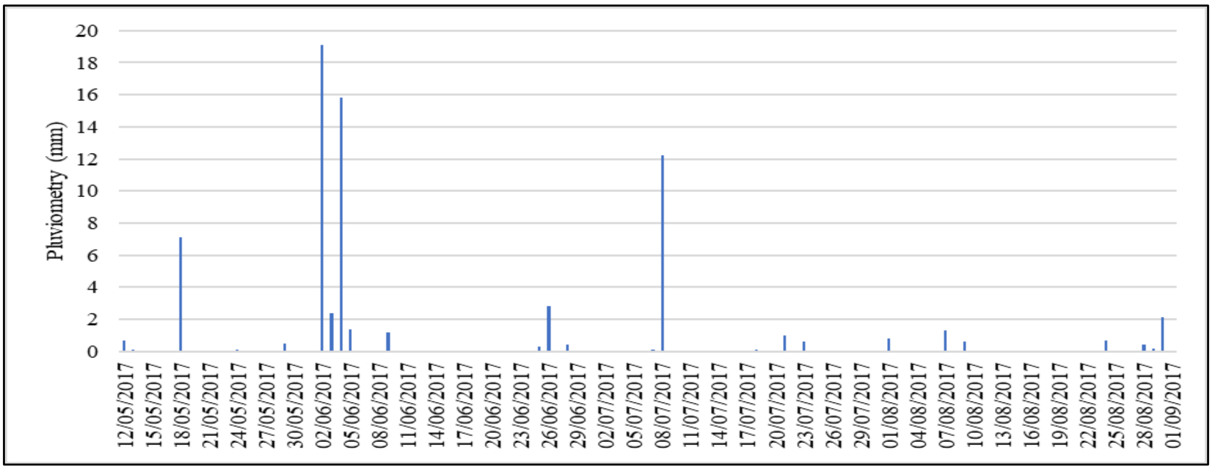

Figure 6. Daily pluviometry between 12th of May and 1st of September.

2.3. Plant material

This experiment focused on the agronomic performance, particularly the water use efficiency, of eight different rootstocks. The almond cultivar crafted in all the rootstocks was 'Vairo' ('4-665' x 'Lauranne'). It's a self-compatible cultivar developed by IRTA in 1991. The rootstocks evaluated were: 'GF-677'; 'ISHTARA'; 'IRTA 1'; 'IRTA 2'; 'ROOTPAC-R'; 'ROOTPAC-40'; 'ROOTPAC-20' and 'Puebla de Soto'.

2.4. Measurements

The measurements used in this study were taken between May and September of 2017. In total, nine different measurements were made, namely: leaf chlorophyll concentration, quantum yield of photosynthesis, shoot growth, stem water potential, stomatal conductance, canopy volume, photosynthetically active radiation, fruit volume and fruit weight.

2.4.1. Leaf chlorophyll content

For measuring the leaf chlorophyll concentration, a SPAD-502 meter hand-device was used (Konica Minolta SPAD-502 Plus) (Figure 6A). This device determines the chlorophyll content by measuring the leaf absorbance in red and near-infrared regions. The numerical SPAD value has no units and specifies the relative content of chlorophyll within the leaf [41], [49]. Also, SPAD analysis has been used as an indicator of iron chlorosis tolerance in *Prunus* trees [50].

Every two weeks, three random leaves per tree at the same height and development stage were selected and measured. Non-invasive measurement.

2.4.2. Quantum yield of PSII

The quantum yield of PSII, or else the effective quantum yield of photosystem II electron transport (ΦPSII), which represents the electron transport efficiency between photosystems within light adapted leaves was measured using a leaf fluorometer (FluorPen FP100 Photon Systems Instruments) (Figure 6B). The quantum yield of PSII is a definitive measure of the energetic efficiency of photo autotrophy. Every two weeks, three random leaves at the same height and development stage were measured, per tree [43], [51], [52]. Non-invasive measurement.

2.4.3. Shoot growth

The shoot growth was measured using a digital vernier caliper (Absolute Digimatic Caliper Mitutoyo) (Figure 6C). To monitor the trees shoot growth rate two shoots per tree with one-year old wood were selected and tagged with a blue stripe. The selected shoots were measured every two weeks. Non-invasive measurement.

2.4.4. Stem water potential

The stem water potential is used to check the tree water status. It was measured in two steps: first, two random mature leaves per tree were bagged in a black plastic covered with aluminium foil two hours before the measurements (very important step in order to prevent leaf transpiration and to eliminate the water potential gradient between the leaf and the stem). The second step consisted on picking the bagged leaves and measure the stem water potential using a pressure chamber (Digital pressure chamber SF-Pres type “Scholander”) (Figure 6E). The ΨSTEM was measured every two weeks between 12:30h and 14:30h [44], [53], [54].

2.4.5. Stomatal conductance

Stomatal conductance is an indicator of foliar transpiration rate and plant’s water status measured in mmol m^{-2} s^{-1}. It was measured using a leaf porometer (Decagon SC-1 Leaf Porometer) (Figure 6F) that determines the stomatal conductance by measuring the actual vapor flux from the leaf through the stomata and out to the environment. This measurement was made every two weeks in two leaves per tree between 12:30h and 14:30h [45]. Non-invasive measurement.

2.4.6. Canopy volume

Three measures per tree were taken with a normal meter scale: length; width and height (Figure 6D). The canopy volume was calculated using the mathematical formula: $CV = \frac{2}{3}\pi H(\frac{L}{2} \times \frac{W}{2})$, where H stands for height, L for length and W for width [55]. The CV was measured every four weeks. Non-invasive measurement.

2.4.7. Photosynthetically active radiation (PAR)

The photosynthetically active radiation is the amount of light available for photosynthesis and it's measured in µmol m^{-2} s^{-1}. PAR was measured every four weeks using a quantum sensor (SunScan type SS1) (Figure 6G) [46], [56]. Non-invasive measurement.

2.4.8. Fruit collection

Five fruits per tree were collected by hand to plastic bags every two weeks. The bags were tagged with the number of the tree and the bloc and were stored in a freezer until the measurements of volume and weight were made. The fruits were randomly selected, from different branches, around the tree.

2.4.8.1. Fruit and kernel volume

Using a digital vernier caliper, three linear dimensions were measured, length, width and thickness, both for fruit and for kernel (Figure 6I). To calculate the volume the basic ellipsoid volume formula was used: $V = \frac{4}{3}\pi LWT$, where L stands for length, W for width and T for thickness [55].

2.4.8.2. Fruit and kernel weight

A laboratory digital scale was used for this measurement (Figure 6H). Two measurements were taken: fruit weight and kernel weight.

Figure 7. Equipment's used for the different measurements. A – Konica Minolta SPAD-502 Plus; B – FluorPen FP100 Photon Systems Instruments; C – Absolute Digimatic Caliper Mitutoyo; D – Meter scale; E – Digital pressure chamber SF-Pres type "Scholander"; F – Decagon SC-1 Leaf Porometer; G – SunScan type SS1; H – Digital scale; I – Absolute Digimatic Caliper Mitutoyo

2.5. Statistical analysis

The data collected in the different measurements were analysed using the program STATISTIX 10.0 (Analytical Software, Tallahassee, FL, USA). The data were subjected to analysis of variance (ANOVA) and means were separated by Duncan's significant difference test when ANOVA indicated significance (P < 0.05) variable effects. The standard error was also recorded. The data are expressed as mean ± SE.

3. Results and discussion

3.1. Leaf chlorophyll content

SPAD values are proportional to the amount of chlorophyll present in the leaf [57].

During the measurements period, the medium value of SPAD had a growing tendency for all rootstocks. The leaf chlorophyll content was significantly affected by the rootstocks. However, in the 1st measurement there were no significant difference among rootstocks (Table 8).

The trees grafted in the 'GF-677' rootstock had the biggest average SPAD values followed by 'IRTA 1'. The trees grafted on the 'ISHTARA' rootstock had the lowest average SPAD values (Figure 8). The SPAD values measured ranged between 25,1 and 49,6. The highest value was recorded in 'GF-677' and the lowest in 'ROOTPAC-40'.

Pinochet classified rootstocks as susceptible to iron chlorosis for values bellow 35 SPAD units [58]. Due to the high SPAD values, 'GF-677' and 'IRTA 1' can be classified as tolerant to iron chlorosis. In the other hand, 'ISHTARA' can be classified as the most susceptible rootstock from all the rootstocks evaluated.

The results obtained are supported by Mestre *et al.* [59], which concluded that the good adaptation of the rootstock to the growing conditions favoured higher vigour, as well as higher N leaf content and SPAD values [59]. Also, Jiménez *et al.* [31] showed that 'ROOTPAC-20' rootstock presented lower leaf chlorophyll concentration than 'GF-677' and 'ROOTPAC-R' [31].

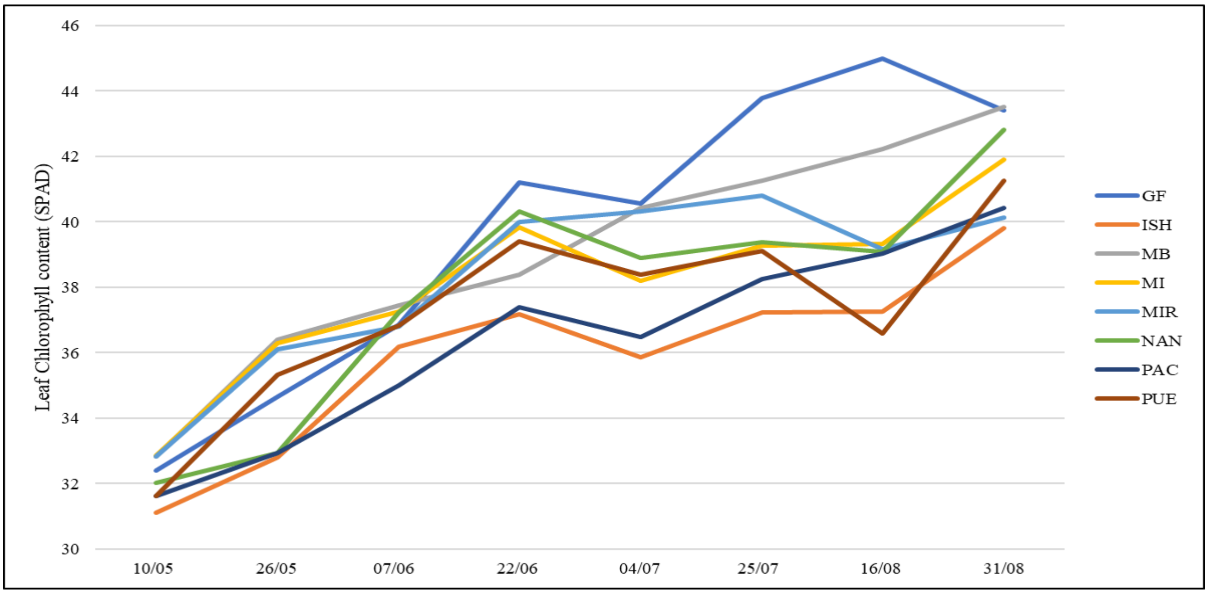

Figure 8. SPAD analysis of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 8. SPAD values (means ± standard errors) with different letters were significantly different (P<0.05). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	10/05	**26/05**	**07/06**	**22/06**	**04/07**	**25/07**	**16/08**	**31/08**
GF	32,40 ± 0,47a	34,66 ± 0,90ab	36,87 ± 0,70ab	41,19 ± 1,02b	40,57 ± 0,95c	43,78 ± 0,70d	45,01 ± 0,62c	43,41 ± 0,90b
ISH	31,11 ± 0,81a	32,79 ± 0,70a	36,18 ± 0,60ab	37,17 ± 0,92a	35,87 ± 0,88a	37,22 ± 1,02a	37,27 ± 1,00a	39,82 ± 0,93a
MB	32,82 ± 0,53a	36,40 ± 0,76b	37,45 ± 0,99b	38,39 ± 1,08ab	40,42 ± 1,13c	41,27 ± 1,31cd	42,24 ± 0,82b	43,52 ± 1,14b
MI	32,86 ± 0,40a	36,28 ± 0,66b	37,27 ± 0,57ab	39,84 ± 0,74ab	38,20 ± 0,87abc	39,27 ± 0,99abc	39,33 ± 1,25a	41,91 ± 0,84ab
MIR	32,82 ± 0,74a	36,11 ± 0,78b	36,81 ± 0,50ab	40,01 ± 0,91ab	40,33 ± 0,79c	40,81 ± 0,82bc	39,18 ± 0,95a	40,12 ± 0,90a
NAN	32,02 ± 0,80a	32,94 ± 0,88a	37,23 ± 0,52ab	40,32 ± 0,83b	38,89 ± 0,87bc	39,37 ± 0,98abc	39,08 ± 1,22a	42,83 ± 1,32ab
PAC	31,62 ± 0,45a	32,94 ± 0,86a	35,01 ± 0,95a	37,38 ± 0,86a	36,49 ± 0,91ab	38,26 ± 0,84ab	39,02 ± 0,91a	40,43 ± 0,88ab
PUE	31,61 ± 0,61a	35,33 ± 0,49b	36,84 ± 0,70ab	39,41 ± 0,80ab	38,40 ± 0,85abc	39,10 ± 0,58abc	36,58 ± 0,94a	41,27 ± 0,95ab

3.2. Quantum yield of PSII

There were significant differences in the quantum yield of PSII among rootstocks, except in the 4th and 5th measurement (Table 9).

The highest average values were registered on trees grafted in the ‘GF-677’ rootstock. The lowest amounts of chlorophyll fluorescence were observed in the ‘ROOTPAC-20’ rootstock (Figure 9). The quantum yield of PSII values ranged between 0,60 and 0,81. ‘GF-677’ had the highest recorded value.

The abrupt drop of the quantum yield of PSII values recorded in the 4th measurement, measured in 22nd of June can be justified by the atmospheric conditions. Even though there was no big difference in the climacteric data, previously analysed, when the 4th measurement was made it was under a cloudy day. The quantum yield of PSII depends on the light intensity. If the light intensity is high, stomata allows more CO_2 into the leaf for more photosynthesis, if not, the amount of fixed carbon drops, leading to a drop in quantum yield of PSII values, as recorded in the 4th measurement [43].

This results coincide with Yahmed *et al.* [60] that showed that the same almond cultivar grafted on different rootstocks presented different quantum yield values and the amount of chlorophyll fluorescence in the rootstock ‘ROOTPAC-20’ was lower than in ‘GF-677’ [60].

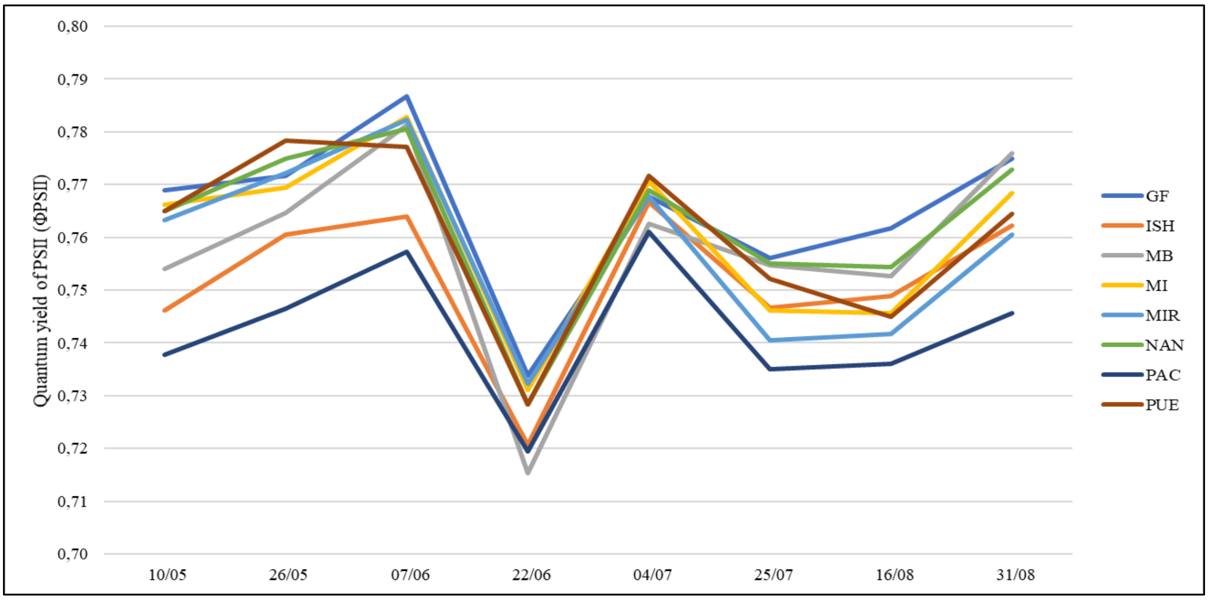

Figure 9. Quantum yield of PSII (ΦPSII) of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOtPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 9. Quantum yield of PSII (ΦPSII) values (means ± standard errors) with different letters were significantly different (P<0.05). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	10/05	**26/05**	**07/06**	**22/06**	**04/07**	**25/07**	**16/08**	**31/08**
GF	0,77 ± 0,0060c	0,77 ± 0,0051bc	0,79 ± 0,0034c	0,73 ± 0,0082a	0,77 ± 0,0056a	0,76 ± 0,0046b	0,76 ± 0,0036d	0,78 ± 0,0022de
ISH	0,75 ± 0,0062ab	0,76 ± 0,0050b	0,76 ± 0,0061ab	0,72 ± 0,0072a	0,77 ± 0,0037a	0,75 ± 0,0055ab	0,75 ± 0,0030bc	0,76 ± 0,0049bc
MB	0,75 ± 0,0066bc	0,76 ± 0,0055bc	0,78 ± 0,0054c	0,72 ± 0,0114a	0,76 ± 0,0073a	0,75 ± 0,0057b	0,75 ± 0,0032bcd	0,78 ± 0,0032e
MI	0,77 ± 0,0051c	0,77 ± 0,0045bc	0,78 ± 0,0051c	0,73 ± 0,0068a	0,77 ± 0,0044a	0,75 ± 0,0059ab	0,75 ± 0,0051abc	0,77 ± 0,0032bcde
MIR	0,76 ± 0,0039c	0,77 ± 0,0031bc	0,78 ± 0,0053c	0,73 ± 0,0029a	0,77 ± 0,0031a	0,74 ± 0,0048ab	0,74 ± 0,0036ab	0,76 ± 0,0033b
NAN	0,77 ± 0,0036c	0,78 ± 0,0031bc	0,78 ± 0,0060c	0,73 ± 0,0057a	0,77 ± 0,0024a	0,76 ± 0,0048b	0,75 ± 0,0034cd	0,77 ± 0,0024cde
PAC	0,74 ± 0,0071a	0,75 ± 0,0075a	0,76 ± 0,0072a	0,72 ± 0,0062a	0,76 ± 0,0048a	0,74 ± 0,0072a	0,74 ± 0,0033a	0,75 ± 0,0061a
PUE	0,77 ± 0,0034c	0,78 ± 0,0033c	0,78 ± 0,0036bc	0,73 ± 0,0049a	0,77 ± 0,0029a	0,75 ± 0,0035b	0,75 ± 0,0044abc	0,76 ± 0,0022bcd

3.3. Shoot growth

The shoot growth is significantly affected by the rootstocks since the growth rate highly depends on the type of rootstock used. The vigourous almond-peach rootstocks have high growth rate while dwarfing rootstocks are sceptically used to control and restrain tree vigour and size [60].

The results obtained in this measurement are very clear. The rootstocks can be divided in three groups (Figure 10), where the vigourous 'GF-677' register, by far, the highest values of shoot growth, and the dwarfing rootstocks like 'Puebla de Soto' and 'ROOTPAC-R' the lowest values (Table 10). The rest of the rootstocks presented medium shoot growth values. 'ROOTPAC-40', being an almond-peach hybrid and having the second biggest canopy volume presented low values of shoot growth.

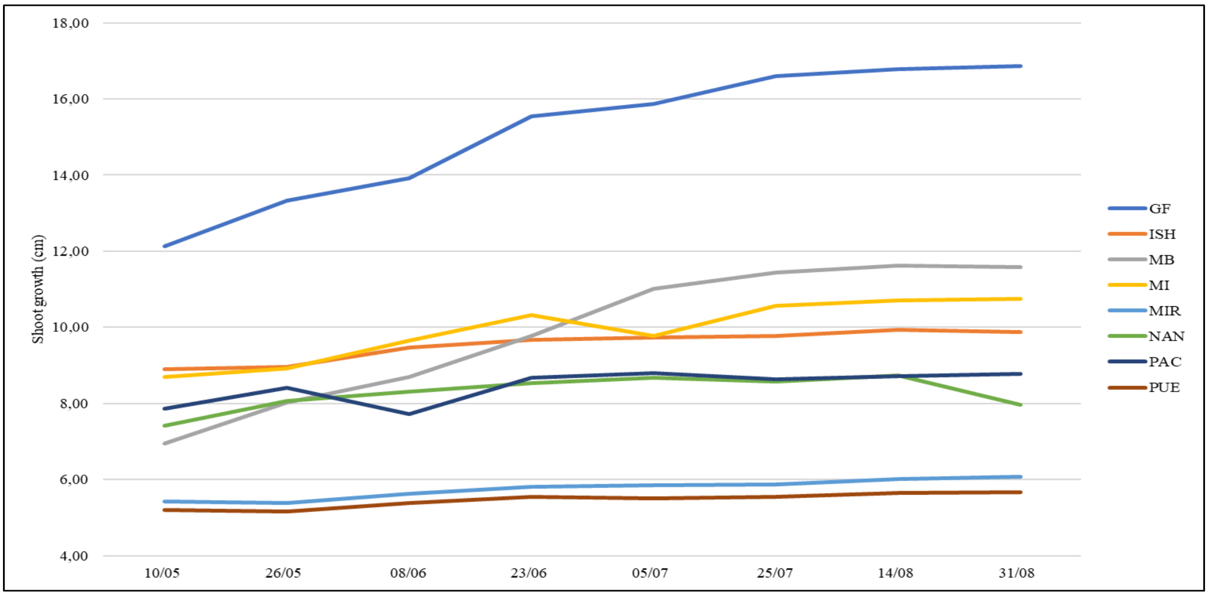

Figure 10. Shoot growth of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 10. Shoot growth (cm) values (means ± standard errors) with different letters were significantly different (P<0.05). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	10/05	**26/05**	**08/06**	**23/06**	**05/07**	**25/07**	**14/08**	**31/08**
GF	12,13 ± 2,08b	13,33 ± 2,76b	13,93 ± 3,03b	15,54 ± 3,44b	15,88 ± 3,70b	16,61 ± 3,99b	16,79 ± 3,99b	16,86 ± 4,00b
ISH	8,89 ± 1,53ab	8,95 ± 1,62ab	9,46 ± 2,03ab	9,67 ± 2,03ab	9,73 ± 2,09ab	9,77 ± 2,09ab	9,93 ± 2,14ab	9,88 ± 2,08ab
MB	6,94 ± 0,95a	8,03 ± 1,66ab	8,70 ± 2,27ab	9,78 ± 2,54ab	11,01 ± 2,79ab	11,44 ± 2,99ab	11,61 ± 3,02ab	11,59 ± 3,03ab
MI	8,69 ± 1,38ab	8,92 ± 1,71ab	9,65 ± 2,17ab	10,33 ± 2,45ab	9,77 ± 2,58ab	10,56 ± 2,61ab	10,71 ± 2,60ab	10,75 ± 2,54ab
MIR	5,42 ± 0,66a	5,39 ± 0,66a	5,63 ± 0,79a	5,81 ± 0,91a	5,86 ± 0,94a	5,88 ± 0,94a	6,02 ± 0,96a	6,08 ± 0,94a
NAN	7,42 ± 1,85a	8,06 ± 2,22ab	8,30 ± 2,37ab	8,54 ± 2,47ab	8,68 ± 2,57ab	8,57 ± 2,56a	8,73 ± 2,58a	7,97 ± 2,39a
PAC	7,87 ± 1,30ab	8,42 ± 1,48ab	7,72 ± 1,57ab	8,67 ± 1,54ab	8,80 ± 1,51ab	8,64 ± 1,54a	8,71 ± 1,48a	8,77 ± 1,52a
PUE	5,21 ± 0,56a	5,17 ± 0,60a	5,39 ± 0,62a	5,56 ± 0,63a	5,51 ± 0,61a	5,55 ± 0,62a	5,64 ± 0,63a	5,66 ± 0,63a

3.4. Stem water potential

Stem water potential had a decrease tendency for all rootstocks along the grow cycle. Gomes-Laranjo *et al.* (2005) confirmed that the decrease tendency of stem water potential exists even in watered trees. This fact can be explained by the increase of temperature and higher evaporative demands [61].

Excluding the 1st and 3rd measurement, there were significant differences in the stem water potential (Ψstem) among rootstocks (Table 11). This measurement highly depends on climacteric conditions, especially temperature [44].

The stem water potential values ranged between -2.1 MPa and -0.5 MPa. Trees grafted on the less vigorous rootstock 'ROOTPAC-R' had unfavourable water status resulting in the lowest average Ψstem observed. The highest average Ψstem was recorded in the rootstock 'ROOTPAC-40'.

In the 3rd measurement, made on 8th of June, there was an increase of the Ψstem values (Figure 11). It can be justified by analysing the climacteric data. When the 3rd measurement was made there was a drop on the temperature values. Consequently, the stem water potential values started to go up. On the 5th and 7th measurement it's also visible the effect of the temperature variation on the stem water potential values.

The results confirmed the influence of rootstocks on the water status of the tree as reported by Jiménez *et al.* (2013) [31]. It has been demonstrated that trees grafted on invigorating rootstocks have consistently presented higher Ψstem than trees grafted on dwarfing rootstocks as reported for cherry, peach and apple [62]–[64]. This phenomenon is likely to be related to the lower water absorption capability of the root system of dwarfing rootstocks to fulfil the transpiration demand of the canopy [60].

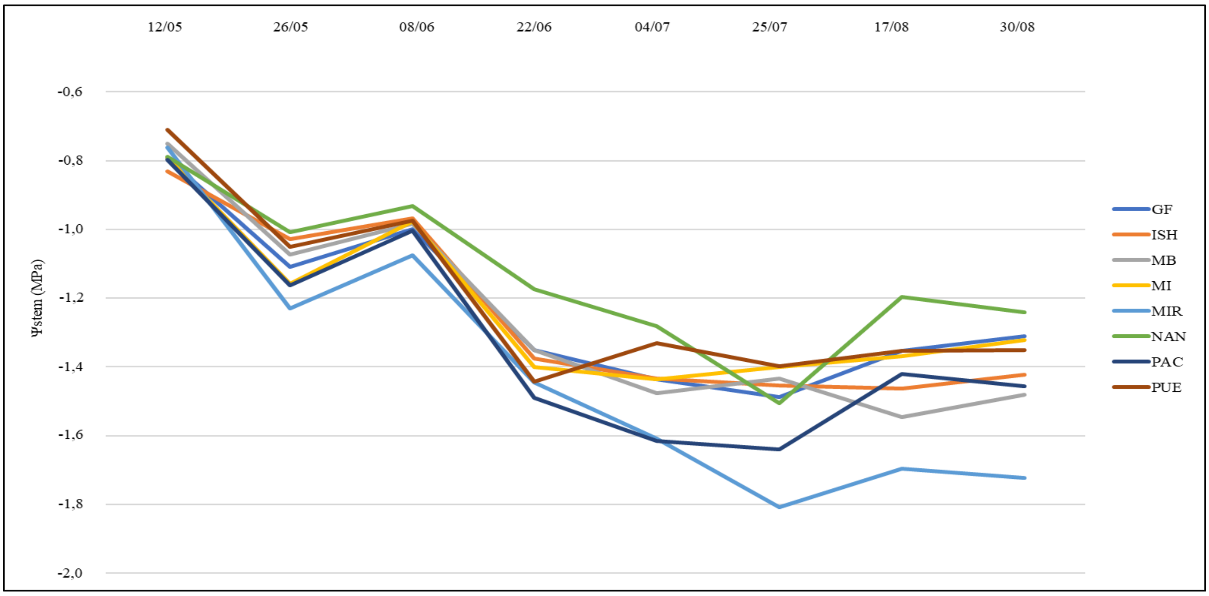

Figure 11. Ψstem of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 11. Ψstem (MPa) values (means ± standard errors) with different letters were significantly different (P<0.05). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**	**04/07**	**25/07**	**17/08**	**30/08**
GF	-7,93 ± 0,67a	-11,08 ± 0,47ab	-10,00 ± 0,30a	-13,51 ± 0,45b	-14,36 ± 0,62ab	-14,87 ± 0,69ab	-13,53 ± 0,61ab	-13,09 ± 0,49ª
ISH	-8,30 ± 0,44a	-10,28 ± 0,39a	-9,67 ± 0,49a	-13,76 ± 0.50b	-14,35 ± 0,46ab	-14,54 ± 0,40ab	-14,64 ± 0,61b	-14,23 ± 0,91ª
MB	-7,51 ± 0,51a	-10,73 ± 0,75ab	-9,83 ± 0,53a	-13,51 ± 0,46b	-14,76 ± 0,47ab	-14,33 ± 1,05ab	-15,46 ± 0,60bc	-14,80 ± 0,86ª
MI	-7,90 ± 0,47a	-11,57 ± 0,46ab	-9,76 ± 0,60a	-14,00 ± 0,54b	-14,35 ± 0,72ab	-13,99 ± 0,78a	-13,70 ± 0,96ab	-13,21 ± 0,56ª
MIR	-7,61 ± 0,40a	-12,29 ± 0,42b	-10,75 ± 0,40a	-14,46 ± 0,76b	-16,08 ± 0,86b	-18,08 ± 0,69c	-16,95 ± 0,79c	-17,23 ± 0,43b
NAN	-7,88 ± 0,55a	-10,08 ± 0,59a	-9,32 ± 0,38a	-11,73 ± 0,59a	-12,82 ± 0,67a	-15,06 ± 0,47ab	-11,95 ± 0,72a	-12,42 ± 0,63ª
PAC	-7,98 ± 0,56a	-11,62 ± 0,59ab	-10,04 ± 0,53a	-14,91 ± 0,40b	-16,16 ± 0,59b	-16,40 ± 0,53bc	-14,20 ± 0,60b	-14,56 ± 0,79ª
PUE	-7,11 ± 0,42a	-10,51 ± 0,63a	-9,73 ± 0,44a	-14,44 ± 0,73b	-13,31 ± 0,53a	-13,97 ± 0,54a	-13,52 ± 0,61ab	-13,51 ± 0,99ª

3.5. Stomatal conductance

Greater stomatal conductance has been associated with cooler canopy temperatures [45]. Canopy temperatures are highly dependent on climacteric factors. This can explain why the conductance values took an abrupt rise in the 8th of June (3rd measurement) for all rootstocks (Figure 12). A decrease in temperature, as observed in the climacteric data, lead to the opening of the stomata in all rootstocks increasing stomatal conductance. Plus, winds were reported on that day, a fact that could help turning the canopy temperatures even cooler and consequently rising stomatal conductance [45]. In the 6th measurement the stomatal conductance started to raise due to a drop in the temperature.

There were significant differences among rootstocks in the stomatal conductance, except in the 1st and 3rd measurement (Table 12). The rootstock with the highest average leaf conductance was ‘IRTA 1’ followed by ‘ROOTPAC-40’. In the other hand, the rootstock with the lowest average leaf conductance was ‘ROOTPAC-R’.

Clearly, the most stressed trees are the ones grafted on ‘ROOTPAC-R’ and that’s why they show the lowest stomatal conductance values. This fact can be supported by the stem water potential values, or else the tree water status values, where the ‘ROOTPAC-R’ is also the rootstock that present the lowest values.

Gomes-Laranjo *et al.* (2006) obtained values in the same range with trees grafted in ‘GF-677’ and reported the influence of temperature on gas exchange parameters.

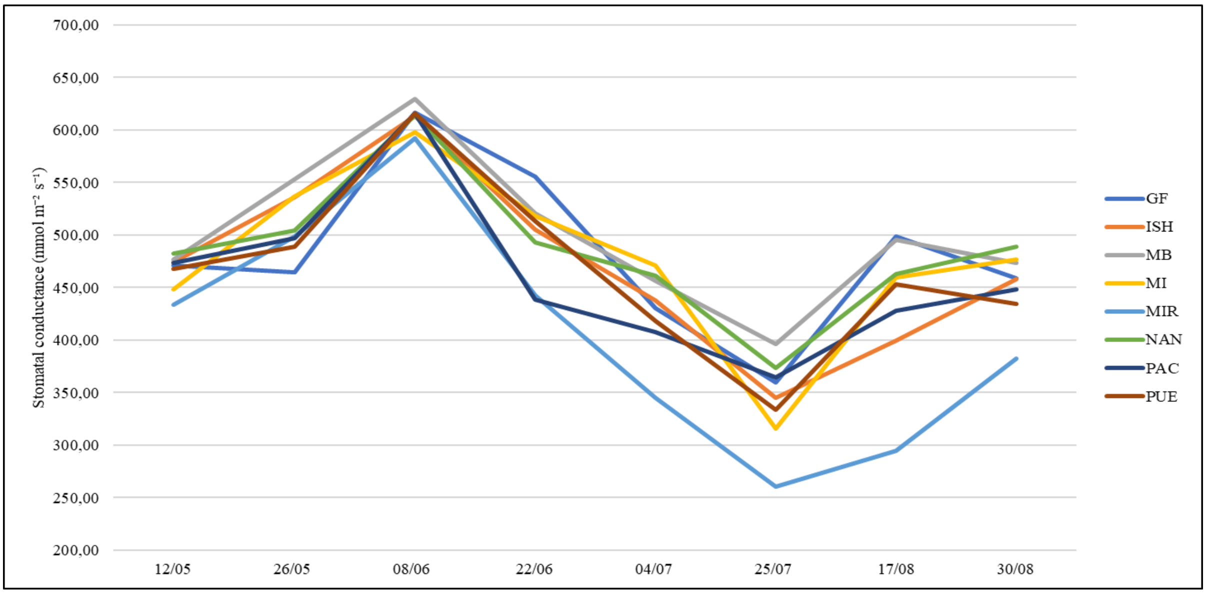

Figure 12. Stomatal conductance of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 12. Stomatal conductance (mmol m^{-2} s^{-1}) values (means ± standard errors) with different letters were significantly different (P<0.05). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**	**04/07**	**25/07**	**17/08**	**30/08**
GF	471,46 ± 12,39a	464,78 ± 26,52a	616,92 ± 21,62a	555,69 ± 13,59c	430,11 ± 14,67b	359,77 ± 18,18bc	498,58 ± 11,94d	459,15 ± 13,59b
ISH	474,73 ± 26,19a	536,01 ± 20,21ab	613,77 ± 17,30a	504,93 ± 22,97bc	438,05 ± 27,61b	345,04 ± 21,36bc	399,51 ± 13,52b	458,53 ± 13,78b
MB	476,51 ± 26,12a	553,01 ± 34,73b	629,53 ± 10,89a	520,74 ± 22,30bc	456,70 ± 19,83b	396,61 ± 14,84c	495,54 ± 13,14d	473,29 ± 19,01b
MI	448,45 ± 18,66a	537,32 ± 19,97ab	598,13 ± 19,19a	518,01 ± 9,46bc	470,73 ± 26,86b	316,21 ± 19,09ab	459,69 ± 18,82cd	476,75 ± 18,74b
MIR	433,83 ± 18,43a	499,04 ± 25,85ab	592,65 ± 12,26a	442,81 ± 18,34a	345,13 ± 18,62a	260,87 ± 9,87a	294,65 ± 26,67a	382,18 ± 11,43[a]
NAN	482,38 ± 16,96a	504,39 ± 27,83ab	614,08 ± 16,44a	493,37 ± 18,46ab	460,98 ± 27,46b	373,82 ± 17,49bc	463,29 ± 21,07cd	489,13 ± 23,46b
PAC	473,88 ± 20,61a	497,13 ± 27,84ab	615,67 ± 12,81a	438,56 ± 21,84a	407,58 ± 23,57ab	364,33 ± 38,00bc	428,23 ± 14,08bc	448,63 ± 23,02b
PUE	468,13 ± 20,36a	488,91 ± 21,23ab	615,86 ± 14,74a	513,66 ± 20,83bc	418,58 ± 29,91b	333,83 ± 17,65bc	452,93 ± 20,61cd	434,28 ± 19,52b

3.6. Canopy volume

As expected, the canopy volume was significantly affected by the rootstocks. With this measurement results it's possible to see which rootstock is vigorous and which is dwarfing type.

The rootstock with the biggest average canopy volume was 'GF-677'. 'ROOTPAC-R' was the most dwarfing rootstock (Figure 13).

'GF-677'. 'ROOTPAC-40' and 'IRTA 1' were the rootstocks with the biggest average canopy volume (Table 13). Expected results since they resulted from almond-peach crosses. The most dwarfing rootstocks were 'ROOTPAC-R' and 'ROOTPAC-20'. 'IRTA 1' and 'IRTA 2' presented similar canopy volume. 'ISHTARA' and 'Puebla de Soto' had medium canopy volume values.

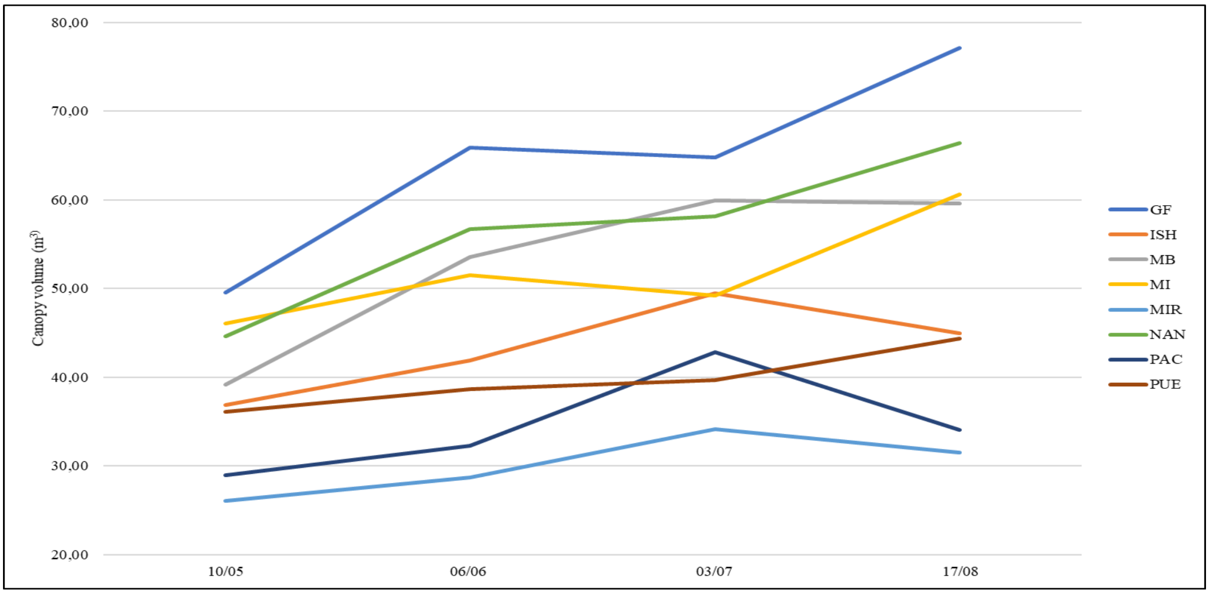

Figure 13. Canopy volume (m^3) of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 13. Canopy volume (m^3) values (means ± standard errors) with different letters were significantly different ($P<0.005$). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	10/05	**06/06**	**03/07**	**17/08**
GF	49,55 ± 1,10d	65,92 ± 3,04e	64,76 ± 6,43c	77,10 ± 4,79d
ISH	36,88 ± 2,33b	41,88 ± 3,07c	49,49 ± 5,02abc	44,98 ± 3,16b
MB	39,20 ± 1,05bc	53,55 ± 2,10d	59,91 ± 3,23c	59,64 ± 5,33c
MI	46,06 ± 1,52d	51,48 ± 2,80d	49,24 ± 6,86abc	60,62 ± 2,13c
MIR	26,05 ± 1,42a	28,73 ± 1,23a	34,12 ± 2,08a	31,54 ± 1,56a
NAN	44,59 ± 1,26cd	56,70 ± 3,82d	58,17 ± 6,77bc	66,41 ± 3,49c
PAC	28,98 ± 3,22a	32,31 ± 3,64ab	42,79 ± 4,40ab	34,06 ± 4,09ab
PUE	36,08 ± 2,42b	38,67 ± 3,57bc	39,64 ± 2,83a	44,36 ± 4,21b

3.7. Photosynthetically active radiation

Apart from the 2^{nd} measurement, the photosynthetically active radiation was significantly affected by the rootstocks (Table 14). During the measurement period, the PAR values had a growing tendency (Figure 14).

The PAR values ranged from 753,57 to 1725,57. ‘GF-677’ was the rootstock with the highest average PAR values and the ‘ROOTPAC-20’ with the lowest average PAR values.

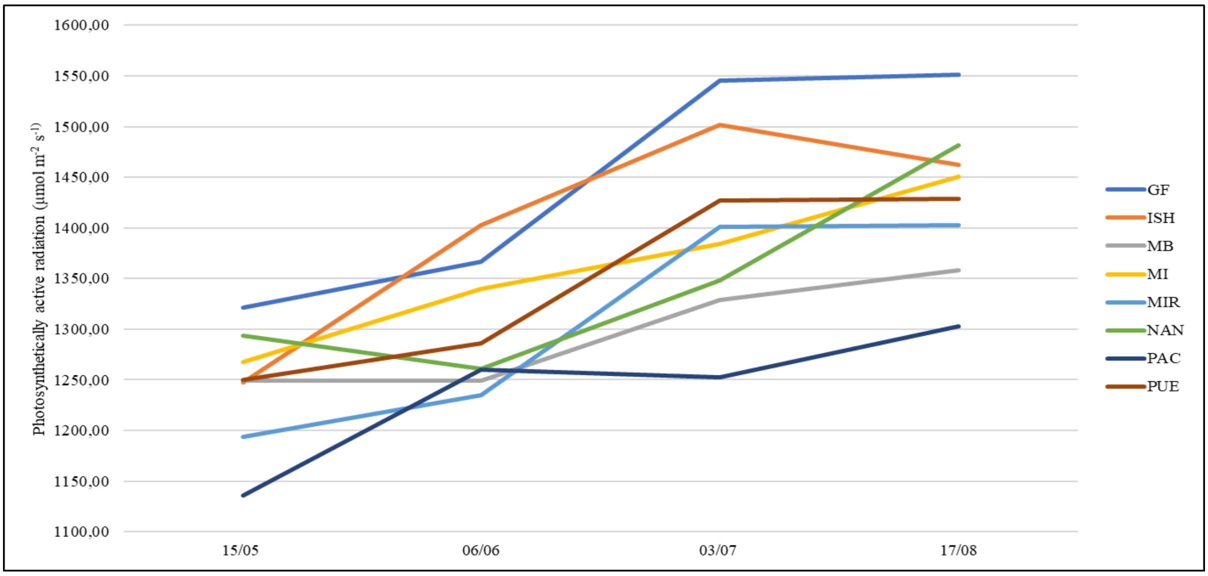

Figure 14. Photosynthetically active radiation of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 14. Photosynthetically active radiation values (means ± standard errors) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	15/05	**06/06**	**03/07**	**17/08**
GF	1320,93 ± 14,33c	1366,38 ± 37,62a	1545,47 ± 58,75b	1551,55 ± 19,94d
ISH	1247,33 ± 30,39bc	1403,01 ± 27,07a	1501,53 ± 71,79b	1462,32 ± 29,22bcd
MB	1249,17 ± 44,26bc	1248,97 ± 59,64a	1329,06 ± 84,97ab	1358,56 ± 51,92ab
MI	1267,44 ± 23,14bc	1340,13 ± 59,77a	1384,00 ± 78,10ab	1450,18 ± 31,07bcd
MIR	1193,96 ± 42,53ab	1235,25 ± 61,38a	1400,67 ± 69,01ab	1402,43 ± 44,60abc
NAN	1293,65 ± 18,33c	1260,60 ± 56,92a	1347,75 ± 85,62ab	1481,77 ± 34,93cd
PAC	1136,24 ± 27,82a	1260,31 ± 57,30a	1252,18 ± 44,05a	1302,50 ± 50,87a
PUE	1249,88 ± 27,01bc	1286,14 ± 43,22a	1427,09 ± 63,67ab	1428,40 ± 29,54bc

3.8. Fruit and kernel volume

The fruit volume was measured as it was collected from the tree, inside the hull. The fruit volume was significantly affected by the rootstocks (Table 15).

The rootstock that in average produced bigger fruits was the ‘GF-677’ followed by the ‘ROOTPAC-40’. In contrast, the rootstock that in average produced smaller fruits was the ‘ROOTPAC-20’ (Figure 15).

The fruit volume measurements stopped in the 4th measurement because in general the volumes started to drop. The fruits started to lose volume mainly because the hull started to dry.

The kernel volume measurements also stopped in the 4th measurement. The kernel had reached the maximal volume and from that point on it was only gaining weight. The kernel volume dropped due to the loss of water in the kernel. In the 4th measurement, there were no significant differences between the rootstocks (Table 16).

The rootstock that in average produced bigger kernels was the ‘GF-677’ followed by ‘Puebla de Soto’. The rootstock that in average produced smaller kernels was the ‘ROOTPAC-20’ (Figure 15). ‘ROOTPAC-20’ was simultaneously the rootstock with the average smaller fruits and kernels. ‘ROOTPAC-40’ and ‘Puebla de Soto’ switched places when compared to fruit volume meaning that both rootstocks produce very similar fruits and kernels in size.

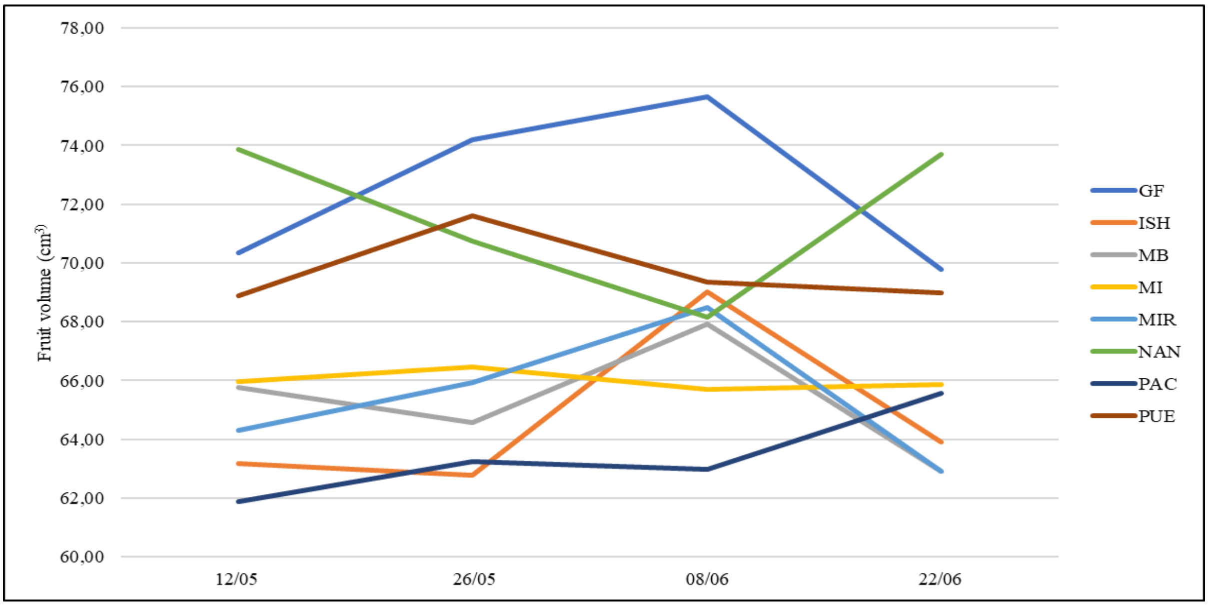

Figure 15. Fruit volume (cm3) of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 15. Fruit volume (cm3) values (means ± standard errors) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**
GF	70,36 ± 2,70bc	74,19 ± 2,19c	75,65 ± 3,67b	69,77 ± 3,13ab
ISH	63,17 ± 1,09ab	62,78 ± 1,01a	69,01 ± 2,18ab	63,89 ± 3,02ab
MB	65,76 ± 1,69abc	64,57 ± 1,25a	67,93 ± 1,72ab	62,90 ± 2,10a
MI	65,97 ± 0,86abc	66,47 ± 1,94ab	65,71 ± 1,41a	65,85 ± 2,56ab
MIR	64,31 ± 1,32ab	65,93 ± 1,44ab	68,48 ± 2,86ab	62,92 ± 1,67a
NAN	73,87 ± 5,37c	70,74 ± 2,89bc	68,16 ± 2,71ab	73,71 ± 6,07b
PAC	61,87 ± 2,00a	63,24 ± 1,56a	62,97 ± 2,27a	65,55 ± 3,50ab
PUE	68,88 ± 2,17abc	71,60 ± 2,30bc	69,36 ± 3,39ab	68,99 ± 1,08ab

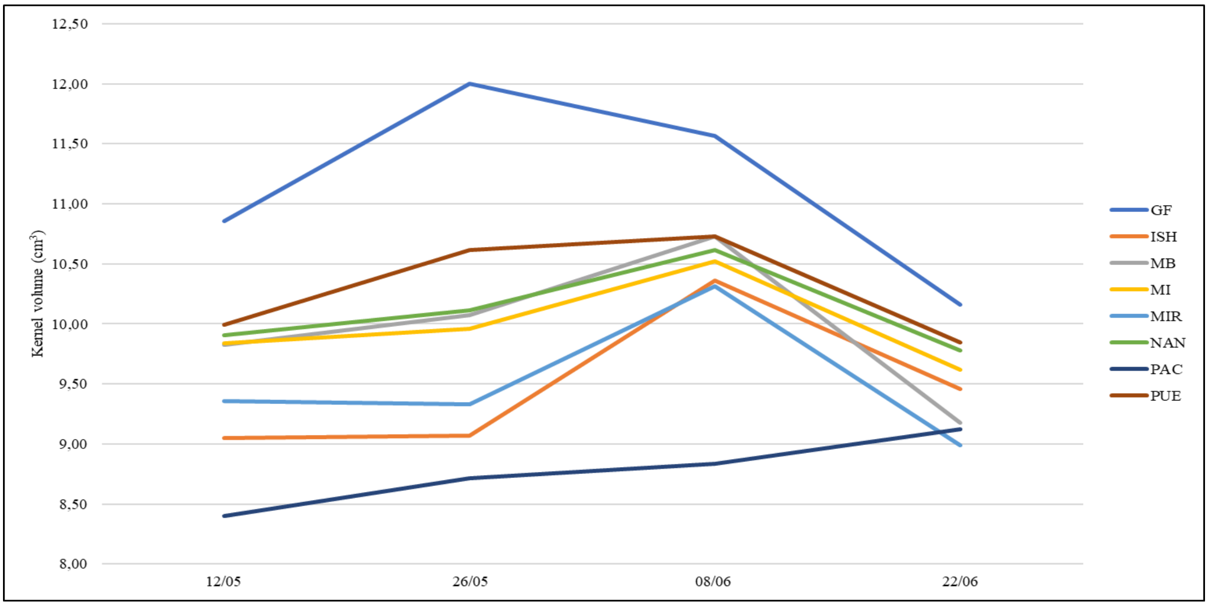

Figure 16. Kernel volume (cm^3) of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 16. Kernel volume (cm3) values (means ± standard errors) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**
GF	10,86 ± 0,17c	12,00 ± 0,20e	11,57 ± 0,53b	10,16 ± 0,66a
ISH	9,05 ± 0,36ab	9,07 ± 0,31ab	10,36 ± 0,23b	9,46 ± 0,49a
MB	9,83 ± 0,37bc	10,08 ± 0,30cd	10,73 ± 0,60b	9,17 ± 0,36a
MI	9,84 ± 0,44bc	9,96 ± 0,43bcd	10,52 ± 0,48b	9,62 ± 0,53a
MIR	9,35 ± 0,40ab	9,33 ± 0,13abc	10,32 ± 0,44b	8,99 ± 0,30a
NAN	9,90 ± 0,65bc	10,11 ± 0,44cd	10,62 ± 0,26b	9,78 ± 0,72a
PAC	8,40 ± 0,33a	8,72 ± 0,19a	8,83 ± 0,63a	9,12 ± 0,40a
PUE	9,99 ± 0,28bc	10,61 ± 0,25d	10,73 ± 0,50b	9,85 ± 0,52a

3.9. Fruit and kernel weight

The fruits were weighed as they were collected from the trees, within the hull. The rootstocks had significantly affected the fruit weight (Table 17). In the last measurement, a generally decrease on the fruit weight in all rootstocks was reported. Fact justified because at the time of the measurement almost all hulls were already dry (Figure 17).

GF-677' was the rootstock with the highest fruit weight average and 'ROOTPAC-20' the rootstock with the lowest fruit weight average.

The kernel weight was significantly affected by the rootstocks (Table 18). All the rootstocks had a growing tendency reaching maximum values near the harvest date, as it was pretended and expected.

The rootstock with the highest kernel weight average was the 'GF-677' and had the heaviest kernel measured with a weight of 1,55g. 'ROOTPAC-20' was the rootstock with the lowest kernel weight average (Figure 17).

'ROOTPAC-20' was the rootstock that produced smallest fruits, kernels and with smallest weight.

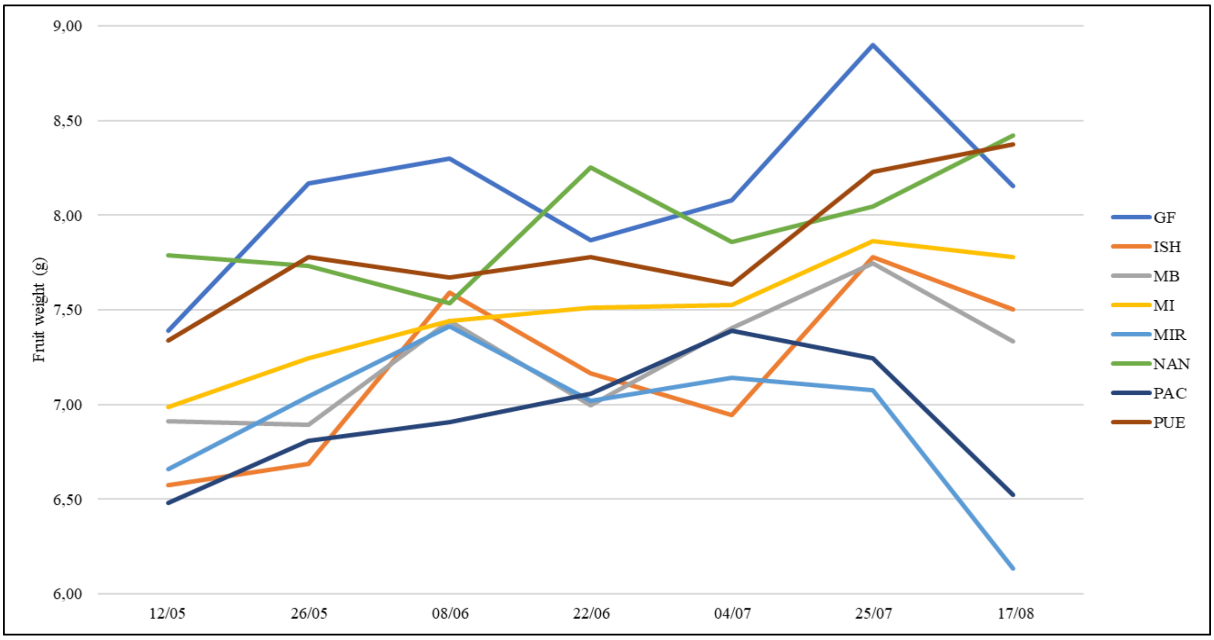

Figure 17. Fruit weight (g) of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 17. Fruit weight (g) values (means ± standard errors) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**	**04/07**	**25/07**	**17/08**
GF	7,39 ± 0,29ab	8,17 ± 0,26c	8,30 ± 0,44b	7,87 ± 0,38ab	8,08 ± 0,16c	8,90 ± 0,32d	8,16 ± 0,39c
ISH	6,57 ± 0,14a	6,69 ± 0,11a	7,59 ± 0,26ab	7,17 ± 0,32ab	6,94 ± 0,22a	7,78 ± 0,30abc	7,50 ± 0,24bc
MB	6,91 ± 0,18ab	6,89 ± 0,14a	7,44 ± 0,23ab	7,00 ± 0,27a	7,40 ± 0,05abc	7,75 ± 0,31abc	7,33 ± 0,12bc
MI	6,99 ± 0,09ab	7,24 ± 0,23ab	7,44 ± 0,16ab	7,51 ± 0,30ab	7,53 ± 0,17abc	7,86 ± 0,33abc	7,78 ± 0,35c
MIR	6,66 ± 0,10a	7,04 ± 0,15ab	7,41 ± 0,31ab	7,02 ± 0,22a	7,14 ± 0,17ab	7,08 ± 0,14a	6,13 ± 0,39a
NAN	7,79 ± 0,63b	7,73 ± 0,35bc	7,53 ± 0,31ab	8,25 ± 0,72b	7,86 ± 0,43bc	8,04 ± 0,22bc	8,42 ± 0,37c
PAC	6,48 ± 0,23a	6,81 ± 0,20a	6,91 ± 0,31a	7,06 ± 0,15a	7,39 ± 0,35abc	7,25 ± 0,21ab	6,52 ± 0,54ab
PUE	7,34 ± 0,23ab	7,78 ± 0,32bc	7,67 ± 0,40ab	7,78 ± 0,17ab	7,63 ± 0,28abc	8,23 ± 0,27cd	8,37 ± 0,21c

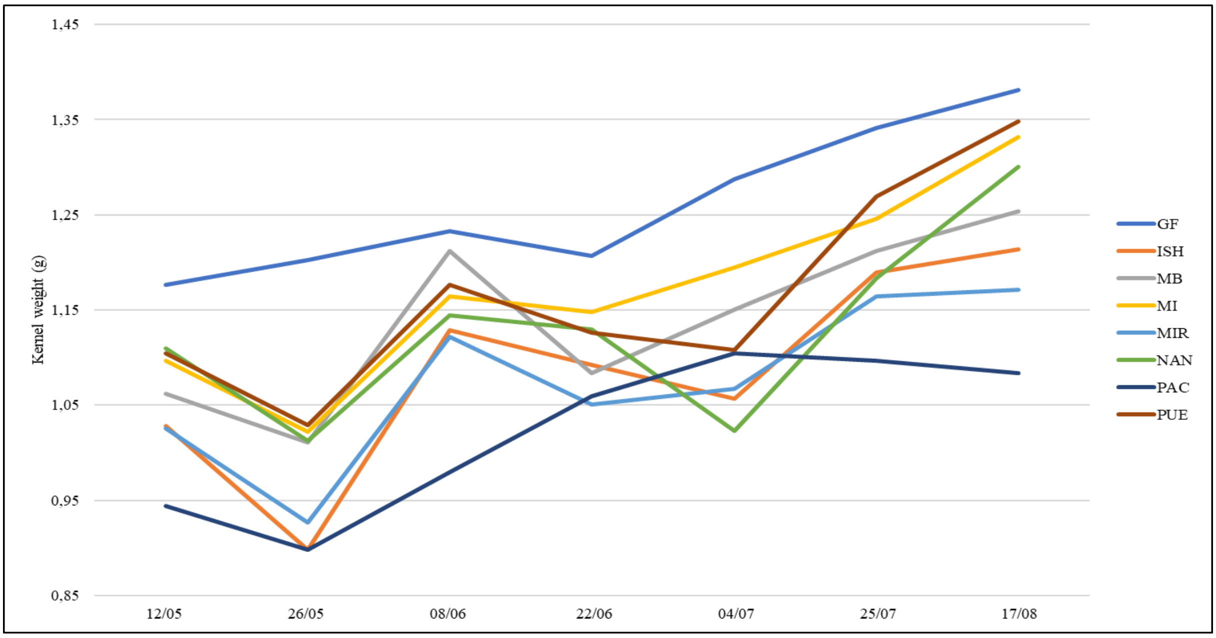

Figure 18. Kernel weight (g) of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 18. Kernel weight (g) values (means ± standard errors) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	12/05	**26/05**	**08/06**	**22/06**	**04/07**	**25/07**	**17/08**
GF	1,18 ± 0,05b	1,20 ± 0,02c	1,23 ± 0,05b	1,21 ± 0,05b	1,29 ± 0,02d	1,34 ± 0,03d	1,38 ± 0,04d
ISH	1,03 ± 0,07ab	0,90 ± 0,04a	1,13 ± 0,02ab	1,09 ± 0,04ab	1,06 ± 0,06ab	1,19 ± 0,01bc	1,21 ± 0,03bc
MB	1,06 ± 0,06ab	1,01 ± 0,03b	1,21 ± 0,05b	1,08 ± 0,02ab	1,15 ± 0,03bc	1,21 ± 0,03bc	1,25 ± 0,03bcd
MI	1,10 ± 0,06ab	1,02 ± 0,05b	1,16 ± 0,05b	1,15 ± 0,04ab	1,19 ± 0,02cd	1,25 ± 0,04bc	1,33 ± 0,04cd
MIR	1,03 ± 0,05ab	0,93 ± 0,02ab	1,12 ± 0,04ab	1,05 ± 0,04a	1,07 ± 0,04ab	1,16 ± 0,03ab	1,17 ± 0,05ab
NAN	1,11 ± 0,06ab	1,01 ± 0,04b	1,14 ± 0,03b	1,13 ± 0,08ab	1,02 ± 0,02a	1,18 ± 0,01bc	1,30 ± 0,04cd
PAC	0,94 ± 0,05a	0,90 ± 0,03a	0,98 ± 0,07a	1,06 ± 0,04ab	1,10 ± 0,05abc	1,10 ± 0,02a	1,08 ± 0,06a
PUE	1,10 ± 0,04ab	1,03 ± 0,02b	1,18 ± 0,05b	1,13 ± 0,05ab	1,11 ± 0,05abc	1,27 ± 0,04cd	1,35 ± 0,03d

3.10. Yield

The yield values were registed in the harvest day and correspond to the average weight obtained per tree. Significant differences in yield were observed between rootstocks (Table 19).

'GF-677' was the rootstock with the highest yield average and with the highest yield value recorded, maximum value of 55,10 kg in one tree. On the opposite site, 'ROOTPAC-20' was the rootstock with the lowest yield average and also with the lowest yield value recorded, minimum value of 12,47 kg in one tree (Figure 19).

'IRTA 1' and 'IRTA 2' presented very similar results with no significant differences between them. Same case with the rootstocks 'ISHTARA' and 'Puebla de Soto', with very similar results and no significant differences between them. 'ROOTPAC-40' presented the second highest yield average value, 'ROOTPAC-R' and 'ROOTPAC-20' were the lowest.

The relation between yield (kg/tree) and canopy volume (m^3) was made in order to obtain the production in kg/m^3. The values used were the yield per tree and the last measurment of canopy volume.

The values ranged between 0,48 $kg/m^3$and 0,64 kg/m^3. 'GF-677' was the rootstock with the highest value and 'ROOTPAC-20' with the lowest (Figure 20). Although the behaviour of these two rootstocks is the same when compared to the yield values, big changes occurred in the other rootstocks. Indeed 'ROOTPAC-R', the rootstock that presented the second lowest yield value, turned to second highest with 0,61 kg/m^3. 'ISHTARA' and 'Puebla de Soto' registered the same value of 0,55 kg/m^3 and were followed by 'IRTA 1' and 'ROOTPAC-40' also with the same value of 0,54 kg/m^3. 'IRTA 2' had 0,51 kg/m^3.

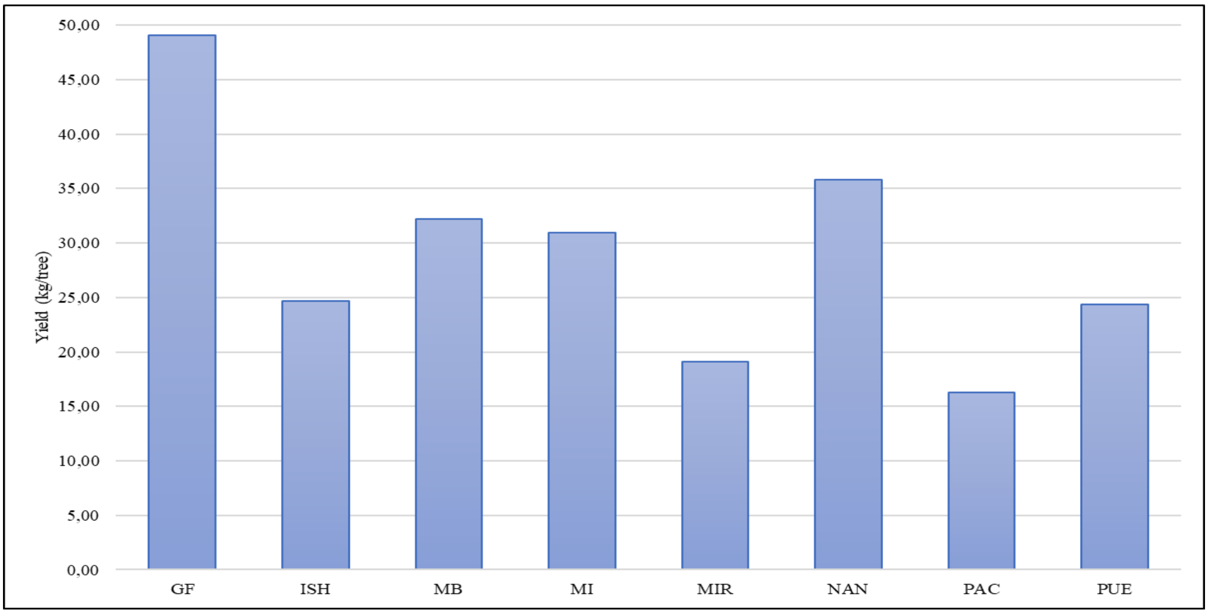

Figure 19. Average yield (kg/tree) of almond cultivar ‘Vairo’ on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

Table 19 Yield (kg/tree) values (mean ± standard error) with different letters were significantly different (P<0.005). GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

	Yield (kg/tree)
GF	49,04 ± 2,01a
ISH	24,70 ± 1,55cd
MB	32,19 ± 3,93bc
MI	30,98 ± 1,88bc
MIR	19,13 ± 0,86d
NAN	35,78 ± 3,24b
PAC	16,28 ± 1,00d
PUE	24,37 ± 1,82cd

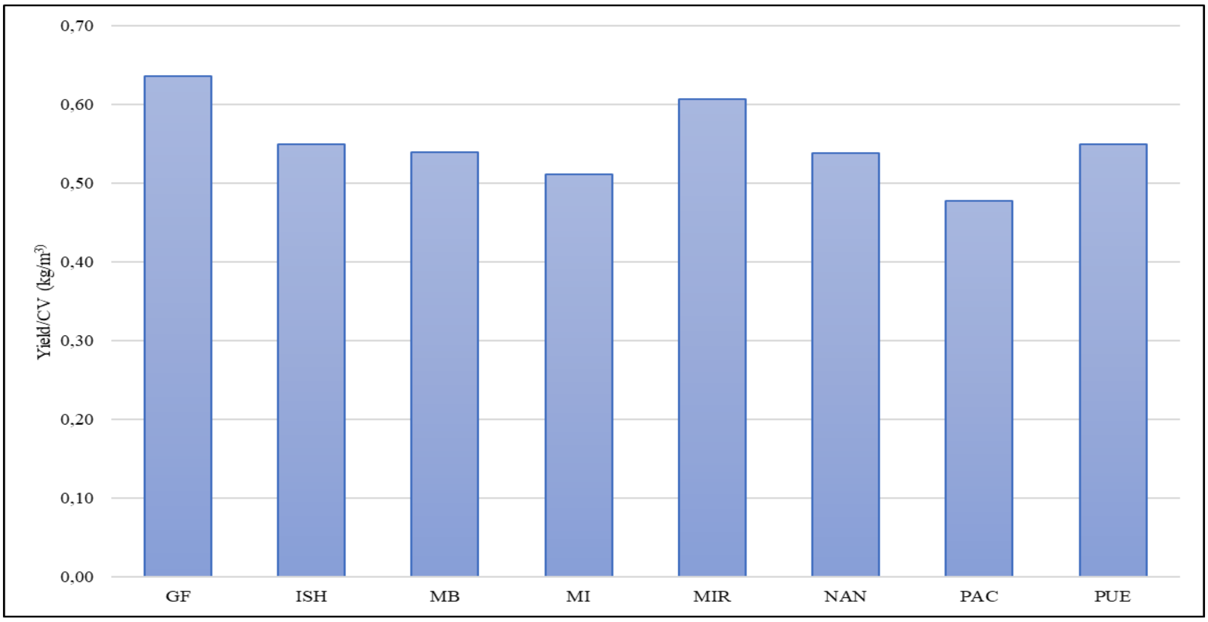

Figure 20. Production per m^3 of canopy volume of almond cultivar 'Vairo' on eight different rootstocks. GF: 'GF-677'; ISH: 'ISHTARA'; MB: 'IRTA 1'; MI: 'IRTA 2'; MIR: 'ROOTPAC-R'; NAN: 'ROOTPAC-40'; PAC: 'ROOTPAC-20'; PUE: 'Puebla de Soto'.

4. Conclusion

The aim of this study was to understand the influence of different *Prunus* rootstocks on the behaviour of the ‘Vairo’ cultivar, compare them with each other, and conclude which are the most appropriate on these soil and weather conditions. All the rootstocks were managed equally, with the same growing conditions, pruning type, fertilization and water incomes.

As it was previously showed, the rootstock has a big influence on the proper function of the tree, as it can influence parameters like leaf chlorophyll content, photosynthesis, tree water status, shoot growth, canopy volume, fruit size and weight, stomatal conductance, photosynthetically active radiation and yield. The results obtained also revealed how well the rootstocks could adapt to the soil and climate conditions experienced on the study site and their influence on almond cultivar ‘Vairo’.

Regarding compatibility, all the rootstocks seemed to be compatible with the almond cultivar ‘Vairo’ since none of them showed symptoms of compatibility problems.

The trees grafted on ‘ROOTPAC-R’ rootstock were the ones showing biggest stress symptoms, as they presented the lowest stem water potential and stomatal conductance values. This high stress is likely to be related with a poor adaptability of the rootstock ‘ROOTPAC-R’ to the soil and climate conditions of the study site, however when the production per m^3 of canopy volume was calculated, showed a very interesting value that needs to be better studied, namely more years of observations.

‘ROOTPAC-20’ was the rootstock that seemed to be less suited to the ‘Vairo’ cultivar, as it simultaneously presented the smallest fruits, smallest kernels, lowest fruits weights, lowest kernels weights and lowest yield.

The most well suited and adapted rootstock to the ‘Vairo’ cultivar and to the conditions of the experimental site seemed to be ‘GF-677’. It was the rootstock that had the highest yield, highest production per m^3 of canopy volume and produced bigger and heavier almonds. Also, the healthier trees, with bigger leaf chlorophyll content and photosynthesis values. It was by far the most vigourous rootstock. However, his size can be a problem regarding the new orchard managements techniques. ‘Puebla de Soto’ can be a good alternative if restraining the tree size is an important trait.

The trees crafted into ‘ROOTPAC-40’ rootstock were the ones less stressed regarding water status, presenting the highest stem water potential values and the second highest values of stomatal conductance.

‘IRTA 1’and ‘IRTA 2’ presented overall medium values and can be presented as viable choices.

‘ISHTARA’, followed by ‘ROOTPAC-R’, presented the lowest SPAD values. ‘ISHTARA’ may have problems with iron chlorosis since it was considered the most susceptible of all rootstocks. However, no symptom was reported during the measurements. The low SPAD values can also indicate a bad adaptation of the rootstock to the growing conditions.

These results had confirmed findings by Jiménez *et al.* (2013), Yahmed *et al.* (2016) and Gomes-Laranjo *et al.* (2005) in some of the parameters measured. Also, are supported by Mestre *et al.* (2015), which concluded that the good adaptation of the rootstock to the growing conditions may be associated with the SPAD values.

The rootstock choice is one of the most important decisions to make to have a successfully orchard. However, choosing a rootstock only by his main characteristics and discarding his adaptability to the soil and climate experienced on the designated orchard site may not be the best decision.

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