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Review

Positioning Portugal in the Context of World Almond Production and Research

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Abstract: Almond production plays a very significant role in the Portuguese socio-economic context, especially with regard to dried fruit production. Indeed, Portugal is the third largest almond producer in Europe, producing 41,450 t of almonds in shells in 2021. This is due to its edaphoclimatic conditions that are favorable for its production. Traditionally, the north region of "Trás-os-Montes" has stood out as one of the most relevant for Portuguese almond production and bioeconomy. However, production in "Alentejo" and "Beira Interior" will surpass the northern region in a short time as a result of the installation of new orchards. Despite its importance, there is a need to uncover genetic traits underlying phenotypic desirable traits needed to improve yield and quality but also cope and mitigate the impacts of climate change on their production. To address this, it is important to characterize the genetic resources available and the germplasm collection since they are crucial players for conservation and breeding initiatives. In this review, we describe the main cultivars of almonds cultivated in Portugal and their productive challenges. We also provide an overview of the main genetic resources available, breeding goals, and accomplishments regarding their improvement towards biotic and abiotic constraints in both Portugal and the rest of the world.

Keywords: almond; bioeconomy; breeding; dry fruits; environmental constraints; genetic resources

Citation: Campos, C.R.; Sousa, B.; Silva, J.; Braga, M.; Araújo, S.d.S.; Sales, H.; Pontes, R.; Nunes, J. Positioning Portugal in the Context of World Almond Production and Research. *Agriculture* **2023**, *13*, 1716. https://doi.org/10.3390/agriculture13091716

Academic Editors: Elisabetta Nicolosi and Filippo Ferlito

Received: 30 June 2023
Revised: 18 August 2023
Accepted: 25 August 2023
Published: 30 August 2023

1. Introduction

Almond (*Prunus dulcis* (Mill.) D.A.Webb) is one of the most important tree nut crops in terms of production and belongs to the *Rosaceae* family, which comprises approximately 91 genera and 4828 species [1]. The almond tree was one of the first fruit trees to be domesticated by early farmers in Western and Central Asia and the Eastern Mediterranean zone, possibly during the third millennium Before Christ (BC) [2,3]. Its domestication process was probably the result of hybridizations among several species of indigenous almond trees, similar to the domesticated forms which are still widespread today in Southwest Asia, Central Asia and Southeast Europe [4,5]. In the Mediterranean region, almond appears to have been introduced by the early ocean trading Phoenicians and Greeks into Sicily and other cities of the Mediterranean basin prior to 300 BC [3,4,6,7]. Regarding its introduction into the Iberian Peninsula, it is generally accepted that the Phoenician or Greek traders passed through the coastal areas, where they established the first plantations [8]. Between 500 and 600 After Christ, the almond cultivation was spread to the interior of Portugal by the Arab colonizers, and the production expanded to all regions of the country in the following centuries [4,9].

According to the Flora Iberica, the almond tree is a deciduous tree 8–10 m tall when fully mature [10]. The shape of the trees is very variable, particularly in the branching angle and the intensity with which they branch at crown level. The trunk is about 30 cm wide and brownish with woody scales, and the young shoots are initially green, later turning purplish due to sun exposure [4]. The leaves have a dark green color, are placed as clusters on the tree and are lanceolate shaped, linear, dentate and sharp [11–13]. The almond tree flowers are similar to the rest of the *Prunus* genus, complete with five pinkish white petals, five reddish sepals and 30–33 stamens inside the petals. Depending on the cultivar, the flowers vary in size, shape and color of the petals [3,4,14]. Similarly, almond fruits (drupes) are diverse in size, shape, pubescence, retention of the pistil remnants and nature of the suture line depending on the cultivar [3]. Almond drupes exhibit an exocarp characterized by pubescent skin, a mesocarp constituted by a fleshy but thin hull and a distinct hardened shell, which constitutes the endocarp [3]. The mature endocarp, which protects the edible seed or kernel, can be hard to soft and papery depending on the genotype [3,15]. In horticultural terms, almonds are classified as a "nut" in which the edible kernel is the commercial product.

The purpose of this review is to provide a description of the main cultivars of almonds cultivated in Portugal and their productive challenges. Given the high consumption of this nut worldwide when compared to other nuts, the Portuguese bioeconomy is highly affected by this production. Portugal is the third largest producer in the European union, although their contribution output for the world is small. Therefore, a perspective of the importance to the Portuguese bioeconomy is given. In addition, this review provides a description of the most recent achievements and challenges underlying their improvement towards described abiotic and abiotic constraints.

2. Characterization of Edaphoclimatic Requirements

Although this species is characterized by its adaptation to the Mediterranean climate, almond trees can adapt to diverse conditions given their origin [2,3]. They can withstand high temperatures, extreme winter frosts, surviving prolonged periods of drought and adapting to very poor soils [16]. Trees can grow at temperatures below 15 °C or above 35 °C, but the range of temperatures considered optimal for photosynthetic activity is between 25 and 30 °C [17]. It requires accumulation of cold hours, ranging from 200 to 500 h of temperatures below 7.2 °C [4].

Regarding soil characteristics, almond trees can be grown on poor, chalky and stony soils; however, this crop prefers fertile, deep soils with organic matter (1.5–2%) and clay-like texture [18,19]. Generally, alkaline and neutral soils are required, but these trees can adapt to soils with a pH of 6.5 or even 5.5, upon acidity correction [18,19]. Soils with pH less than 5 and heavy clay soils are not considered suitable for almond production [18,19]. This species is considered salinity sensitive, being able to withstand up to 1 g/L of NaCl in the soil [18,19]. The nutrient contents of the soil, thus fertility, play another key aspect of almond production since it reflects on the nutritional status of the plant. Assessing the nutritional status of the plant together with soil analysis is relevant for defining the balance of nutrients between these two components and defining the fertilization plan for the almond orchards [4]. In general, the fertilization program covers nitrogen, phosphorus and potassium, which are the nutrients extracted in greater quantities by the crop, but also micronutrients such as boron, magnesium, among others, depending on the production of almonds [20,21]. Still, the fertilization recommendation should be adjusted for each almond tree, since they depend on soil fertility, availability of irrigation water, soil coating, age and vigor of the orchard, as well as the level of production obtained in the previous year and expected production [4].

Almond trees are considered drought tolerant, as they have a pivotal root system and a complex system of surface roots that exploit the soil at the surface and at depth [22]. The almond crop adapts well to rainfed cultivation, requiring between 300 and 600 mm of rainfall per year, although profitability is guaranteed for values above 600 mm [22].

The distribution of rainfall is also a factor to reflect on when considering implementing new orchards, as in Mediterranean climates, there may be periods of absence of rainfall in the months of greatest need (June, July and August) [22]. Thus, the productivity of this crop can be improved by the implementation of irrigation systems [22]. Until a few years ago, relative humidity was not an adverse factor for almond tree production, as they were confined to warmer and more arid lands [20]. However, the introduction of irrigation and intensive plantation systems has led to an increase in humidity within the plantations, which evidenced that this species does not tolerate waterlogging and soil humidity [20].

3. Almond Diseases and Pests

Similar to other woody crops, the almond tree is mainly affected by fungi, bacteria and insects, leading to sharp losses in production [4]. The main fungal diseases affecting almond trees are caused by *Diaporthe amygdali*, *Monilinia laxa*, *Polystigma amygdalinum*, *Colletotrichum acutatum*, *Wilsonomices carpophilus* and *Taphrina deformans*, among others [23,24]. The introduction of irrigation and intensive plantation systems led to an increase in humidity within the plantations, which favors the development of fungal diseases that previously were of no significance, such as anthracnose (*Colletotrichum acutatum*) [20]. In addition to fungal infections, bacterial infections such as *Xanthomonas arboricola* and *Xylella fastidiosa* also lead to marked losses in production [23,24]. These fungi and bacteria preferentially affect the leaves, flowers and fruits of the plant [4,23,24].

As far as pests are concerned, some have a biting-sucking action (such as the monostrix, aphids and tetranychid mites), and others have a chewing action (*Anarsia* and *Grafolita*) [23,24]. Among other pests with less expression in the Portuguese almond grove, we find the Mediterranean flat-headed root-borer (*Capnodis tenebrionis* L.), the wood leopard moth (*Zeuzera pyrina* L.) and the goat moth (*Cossus cossus* L.). The pests with greater expression are also described in Table 1 [4,23,24].

In Table 1, there is a description of the main fungal and bacterial diseases, as well as pests described for almond cultivars. The fight against these diseases and pests is done in several ways (see Table 1), with the most common being chemical control and the choice of cultivars resistant to these diseases and pests [4]. Regardless of the tool to combat these, the associated losses are usually large and associated with great economic loss [4].

Table 1. Main fungal and bacterial diseases as well as pests described for almond cultivars. Adapted from [4].

Diseases or Pests	Affected Organs	Symptoms	Means of Combat	Reference
Anthracnose *(Colletotrichum acutatum)*	All	Necroses; Leaves and fruit lesions	Elimination of the attacked organs; Aeration of the crown; Rational fertilization; Preventive treatments	[25]
Brown Rot Blossom Blight *(Monilinia laxa)*	Flowers	Necrosis of flower buds; Fruits mummify	Destruction of affected branches; Promote the aeration of the canopy; Nitrogen supplementation; Avoid prolonged irrigation	[26]
Ochre staining *(Polystigma amygdalinum)*	Leaves	Yellow spots of leaves; Reduced photosynthetic capacity	Destroy fallen leaves; Use fungicides	[27]
Xylella fastidiosa	All	Wilting and plant death; Leaf scorching; Decrease in productivity of orchards	There are no effective means of control	[28]
Tetranchid mites *(Tetranychus urticae* Koch *and Panonychus ulmi)*	Leaves	Pale yellow, whitish and silver spots	Reduce water stress; Nitrogen fertilization	[29]

Table 1. *Cont.*

Diseases or Pests	Affected Organs	Symptoms	Means of Combat	Reference
Aphids (*Myzus persicae* Sulzer, *Brachycaudus amygdalinus* and *Brachycaudus helichrysi* Kalt)	Branches and leaves	Curling and deformation of leaves and young twigs, shorter internodes; Reduction in production	Chemical control through the application of insecticides	[30]
Monosteira unicostata	Leaves and fruits	Leaves with yellow spots	No biological control methods known	[31]
Anarsia lineatella Zeller	Branches and leaves	Damages in young shoots and fruits	Treatment with *Bacillus thuringiensis* and kaolin; Sexual confusion method	[32]
Grapholita molesta	Shoots and fruits	Destruction of young shoots (malformations)	Application of insecticides; Technique of sexual confusion; Application of *Bacillus thuringiensis*	[33]

4. Almond Cultivars Grown in Portugal

Portugal is a traditional almond producing country, with a Mediterranean climate favorable to its cultivation. Despite the edaphoclimatic differences found in each Portuguese region, all of them are favorable to almond production, since they have hot and dry summers, low risk of frost in spring and precipitation during winter and spring [9]. Five distinct regions of almond production can be identified in Portugal, based on climate, soil and production practices. These regions are “Alentejo”, “Algarve”, Center and North (which includes “Trás-os-Montes and Alto Douro”) (Figure 1) [4,34,35].

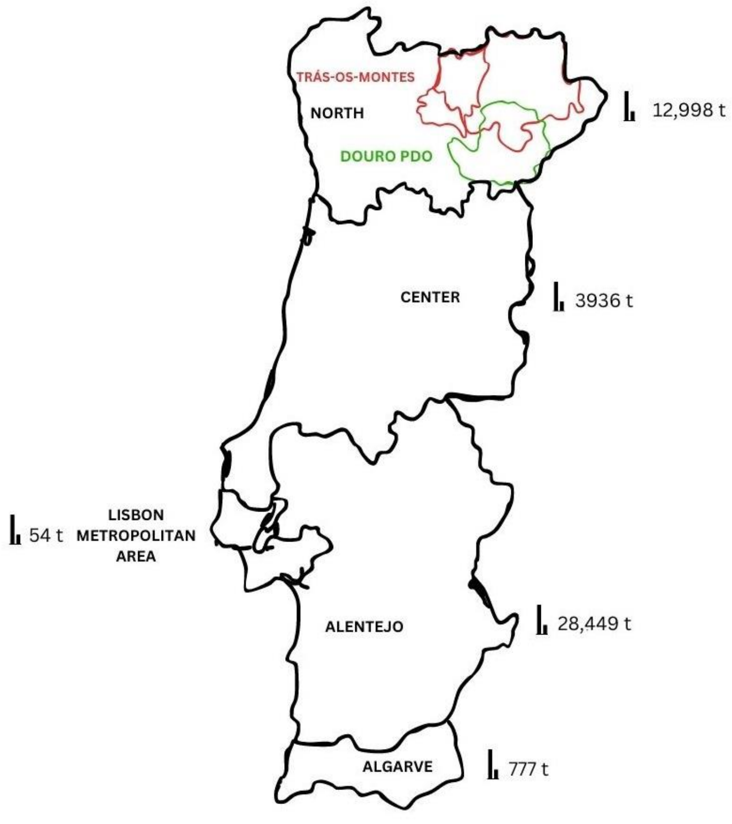

Figure 1. Geographical location of the main regions for almond production (NUTSII). Since no values exist for the “Madeira” and “Azores” islands, they were not included in the figure. The “Amêndoa do Douro” Protected Designation of Origin (PDO) is also evidenced. Numerical data included refer to the production (t) obtained in 2022, according to the information available at Instituto Nacional de Estatística [35].

There is a relatively high number of almond cultivars cropped worldwide and in Portugal. However, in the last few years, the largest producing countries have based their production on a relatively small set of cultivars [36–38], a tendency unfortunately observed in many other crops. The existence of all these options of almond cultivars allows farmers to choose those with the most suitable characteristics for the conditions of the farm and the production objectives [36,38–44]. A comprehensive description of the Portuguese and foreign cultivars currently grown in Portugal has been retrieved from the information available at the Centro National de Competências de Frutos Secos (see http://www.cncfs.pt, accessed on 24 July 2023), and their main characteristics are shown in Tables 2 and 3 [4,34].

Table 2. Characteristics of the main traditional Portuguese cultivars of almond trees, cultivated in the regions of "Trás-os-Montes" and "Algarve". Adapted from [4].

Cultivar	Region	Pollination	Flowering Season	Productivity
'Bonita'	Terra Quente	Cross	Early-mid	Medium
'Casanova'	Alto Douro	Cross	Early-mid	Medium
'Dona Virtude'	Alto Douro	Cross	Very early	Low
'Gama'	Alto Douro	Cross	Early-mid	Low
'Marcelina Grada'	Terra Quente	Cross	Early-mid	Medium-low
'Mourisca'	Alto Douro	Cross	Early-mid	Low
'Parada'	Alto Douro	Cross	Early-mid	Medium
'Romeira'	Alto Douro	Cross	Early-mid	Low
'Verdeal'	Alto Douro	Cross	Early-mid	Very High
'Boa Casta'	Algarve	Cross	Early-mid	Low
'Bonita de São Brás'	Algarve	Cross	Early-mid	Medium
'Duro Amarelo'	Algarve	Cross	Early-mid	Low
'José Dias'	Algarve	Cross	Early	Low

Table 3. Characteristics of some almond cultivars obtained in Spain, France and the USA, mostly used in Portugal. Adapted from [4].

Country	Cultivar	Plant Material	Pollination	Flowering Season	Productivity
Spain	'Belona'	'Blanquerna' × 'Belle d'Aurons'	Self	Late	High
	'Constantí'	'FGFD2' × 'open pollination'	Self	Late	High
	'Desmayo Largueta'	Tarragona	Cross	Early	High
	'Guara'	Clonal Selection (Zaragosa)	Self	Late	High
	'Marcona'	Alicante	Cross	Early-Mid	Very High
	'Marinada'	'Lauranne' × 'Glorieta'	Self	Late	Very High
	'Marta'	'Ferragnes' × 'Tuono'	Self	Late	High
	'Masbovera'	'Primorskyi' × 'Cristomorto'	Cross	Late	High
	'Penta'	'CEBAS S5133' × 'Lauranne'	Self	Very Late	High
	'Soleta'	'Blanquerna' × 'Belle d' Aurons'	Self	Late	High
	'Tardona'	'CEBAS S5133' × 'Grasselly R1000'	Self	Very Late	High
	'Tarraco'	'Ferralise' × 'Tuono' × 'Anxaneta'	Cross	Very Late	Very High
	'Vayro'	'Primorskij' × 'Cristomorto' × 'Lauranne'	Self	Late	Very High
France	'Ferraduel'	'Cristomorto' × 'Ai'	Cross	Late	Very High
	'Ferragnes'	'Cristomorto' × 'Ardéchoise'	Cross	Half late	Very High
	'Ferrastar'	'Cristomorto' × 'Ardéchoise'	Cross	Late	Very High
	'Lauranne'	'Farragnes' × 'Tuono'	Self	Late	Very High
USA	'Nonpareil'	California	Cross	Half late	Very High
	'Texas'	California	Cross	Half Late	High

Like many other woody crops, clonal almond propagation by grafting ensures that selected traits are maintained, ensuring not only varietal but also phytosanitary certification. Despite the effort made to breed cultivars with interesting productive characteristics (used as scion), a mounting body of research and breeding efforts have been devoted to deploying hybrids successfully used as rootstocks [4,38]. Rootstocks can be adapted to the different types of soil, management and irrigation systems but also to the characteristics and the effect on the phenological evolution of the cultivar to be used [41]. Importantly, the choice of the rootstock needs also to account, among other, for the compatibility with the cultivar chosen, the vigor it induces in the plant, adaptation to the cultivation system, resistance to pests and soil diseases, influence on productivity and fruit characteristics and speed of entry into production [4].

Three types of production systems for almond orchards are described in Portugal: low density dryland (<200 trees/ha), modern intensive (250–600 trees/ha) plantations and super-intensive plantations (>600 trees/ha) [9]. Besides this, there is a great variability in soil types in the Portuguese territory, which makes the correct choice of rootstock and cultivar extremely important, as the economic viability of the almond orchard depends on it [41]. Traditional plantations include almost all low-density dryland farms and rarely occur outside the North and "Algarve" regions. These almond groves are widely spaced, usually 6 m x 6 m, to obtain a greater amount of moisture stored in the soil per tree, and use almond tree rootstocks [4,9]. Until a few years ago, almond trees were destined for plots with poor soil, and the orchards were mainly cultivated in rainfed conditions [4,20]. In these conditions, the most used rootstock was the '*Francos de Amendoeira*', coming from bitter almond seeds and from the seeds of cultivars such as 'Marcona', 'Garrigés' and 'Ferrastar' [4,20]. These rootstocks were widely used because of their strong root system, capable of adapting to dry conditions and low soil fertility and, even so, inducing vigor in the grafted material and great longevity of the plantation [4,20]. The poor tolerance to root asphyxia and productive heterogeneity shown by these rootstocks led to the development of 'Fancos de Pessegueiro' [20]. These are more demanding in water but have a greater development in the first years and an earlier entry into production [20]. In Table 4, a summary of the rootstocks most used in Portugal and some of their advantages and disadvantages are described.

Intensive plantations tend to be more widely spaced, with a greater distance between rows, usually 7–8 m, than within the row to facilitate mechanization. For super-intensive plantations, a minimum of 4 m of distance is used between rows and 1 m between trees. These almond orchards tend to be irrigated using two-row pressurized drip irrigation systems with irrigation allocations ranging from 4500 to 8000 m^3/ha [5,9]. Since a lot of water is used, more vigorous rootstocks are used, such as 'GF677', 'GARNEM' and 'RootPac®-R' [4,9]. In super-intensive almond orchards, the trees are spaced with average distances of 3–4 m between rows and one meter in the row. These almond trees use nano rootstocks, which include 'Root-Pac®-20' and 'Root-Pac®-40.'

Table 4. Some examples of the most used almond rootstocks in Portugal. Their advantages and disadvantages are also described. Adapted from [4].

Rootstock	Origin	Advantages	Disadvantages
Almond 'Francos de amendoeira'	Sexual propagation through seeds of different almond cultivars (e.g., 'Verdeal' and 'José Dias')	Highly rustic rootstock; Resistant to water scarcity; Well adapted to arid, stony and calcareous soils	Difficulty in transplanting due to its pivotal root; Sensitive to soil diseases; Sensitive to hypoxia; Restricted compatibility with grafted cultivar; Development and behavior heterogeneity in the orchard; Low productivity and late entry into production
Peach 'Francos de Pessegueiro'	Sexual propagation through seeds of different peach cultivars	Highly rustic rootstock; Resistant to water scarcity; Fasciculate root system; High compatibility with several cultivars of almonds; Good adaptation to transplanting; Quick entry into production; Higher homogeneity of production	Low resistance to lime, which leads the cultivars to manifest iron chlorosis

Table 4. *Cont.*

Rootstock		Origin	Advantages	Disadvantages
	Clonal Plums	Plum clones	Resistant to root asphyxia, iron chlorosis and soil diseases	Drawbacks when used on almond trees, with localized and displaced incompatibilities at the physiological level
Interspecific Hybrids	Peach × Almond	e.g., GF 677, GF 557, Hansen, Adafuel, GxN-15	Deep rooting; Adaptation to the rainfeed and to calcareous soils	Sensitive to root waterlogging and soil diseases; Some of these (e.g., GF 677) are only propagated in vitro, dificulting its mass propagation
	Plum × Almond	e.g., Cadaman, Rootpac 20 (Densipac), Rootpac 40 (Nanopac), Rootpac 70 (Purplepac), Rootpac 90 (Greenpac), Rootpac R (Replantpac)	Depending on the rootstock has tolerance to root asphyxia and soil diseases; Good compatibility with most of the cultivars	Depending on the rootstock is sensitive to root asphyxia and soil diseases

5. Almond Value Chain: Socio-Economic Importance

According to the International Nuts & Dried Fruits Statistical Yearbook 2018/2019, almonds are the most consumed nut in high-income economies, accounting for 39%, followed by walnuts, cashews and hazelnuts, demonstrating a high importance in the field of dry fruit bioeconomy [42]. On a global scale, almond production is led by the United States, more specifically by the state of California, with around 79% of production. This is the reference country in terms of prices, product typification, promotion and communication [43,44]. In the 2019–2020 season, the average production rate in California was 2400 kg of almonds/ha due to the highly technological production focused on soft-shelled, non-self-fertile cultivars and ground harvesting. In second place is Australia, with a production of 104,437 t using a production model like the American one [45]. The European Union (EU) contributes only around 6% of world production. Other countries with some interesting production rates are Tunisia, Iran, Chile, Turkey and Morocco [46–48].

For the 2019–2020 campaign, the European Union contributed only 6% of the world output production, but production is clearly on an upward trend [45]. The main EU producing countries are Spain, Italy and Portugal, with Greece as a minor player [49]. In 2021, Spain led the European production with 365,210 t of almonds for a cultivated area of 744,470 ha [49]. Portugal is the third largest almond producer in Europe, with a total area of 58,400 ha and a production of 41,450 t of almond in shell in 2021 [49]. In the north of the country, the production of almonds is mainly based on rainfed systems (dryland) and is limited by climatic conditions. Therefore, productivity varies from year to year, with an average of 650 kg/ha of kernels in about 20,000 ha [9]. Traditionally cultivated in dryland in northern regions of the country, this crop has seen unprecedented progress in the last decade. Supported by a strong investment from foreign companies, mechanization in as well as the introduction of more adapted cultivars to local conditions has made Portugal surpass Italy in almond production in the 2021–2022 campaign [46,48,50]. The main Portuguese producing regions traditionally have been "Trás-os-Montes", Douro (North) and "Algarve" (South), but in recent years, the almond growing area has increased in the "Alentejo" and "Beira Interior" regions [9,50,51]. Since 1996, the "Trás-os-Montes" region holds one Protected Designation of Origin (PDO) designated as "Amêndoa do Douro" (see Figure 1). Despite the PDO certification, the introduction of this product in the market was unsuccessful despite the efforts made [52], highlighting that more efforts need to be undertaken to market and boost the competitiveness of this product with recognized quality.

Almond is cultivated worldwide for its kernels, and, among other factors, the commercial success of this crop is related to the nutritional and technological characteristics of the kernel [42]. Based on taste, almonds can be divided into two major varietal groups: bitter and sweet almonds [53,54]. The sweet almond is edible and used in the food industries or for human consumption without any pre-processing. The bitter type is non-edible or poisonous due to its cyanogenic glycosides and cannot be consumed without removal of toxic contents, even containing 4 to 9 mg of highly toxic hydrogen cyanide, and consumption in large amounts could lead to death [55]. However, the essential oil of bitter almonds is used in the pharmaceutical and cosmetic industries [56,57]. Sometimes during post-harvest processing, bitter and sweet almonds are unintentionally mixed, which gives an undesirable experience to consumers. This way is important to distinguish bitter and sweet almonds due to health risks of cyanide intake and likely economic losses from reduced value of kernel lots [58].

Increasing consumption of almonds and almond-derived ingredients in food applications is related to its desirable nutritional composition (45–50% lipids, 21–25% proteins, 17–21% carbohydrates and 10–12% fiber) and the desirable technological properties (such as solubility, emulsification, foaming and gelling properties) of the extracted protein [59,60]. Moreover, it is used as gluten-free alternative to wheat flour in cooking and baking [56]. Almonds are a very versatile food ingredient, consumed as non-processed dry fruits or included in nutritive snacks, bakery and confectionery ingredients, and as a feedstock to produce almond milk, flour and oil [61]. Almond-based drinks are widely used as an alternative to cow's milk by lactose-intolerant people or vegans due to their high levels of calcium, phosphorus and potassium [62,63]. Almond-based "milk" is a colloidal dispersion, containing only 2% of almonds (powdered or almond paste), produced from aqueous extraction of colloidal substances from almonds such as proteins and lipids [64]. To replace micronutrients lost during the production process, these beverages are also enriched with potassium and vitamins A and D [65]. Since it has a low sodium content and a balanced proportion of mono- and polyunsaturated fatty acids, it helps maintain healthy cholesterol levels and is high in antioxidant compounds, contributing to the prevention of heart disease [64].

Sweet almond oil, extracted from kernels of sweet cultivars, is used in the production of edible oil and the cosmetics industry because it has anti-inflammatory, immunity-boosting and anti-hepatotoxicity effects [56,66]. The essential oil of bitter almonds has potential application to produce biodiesel, and when it is refined, it can be used in the manufacture of flavorings [67].

6. Almond Genetic Resources, Genetic Diversity and Breeding Approaches

Plant genetic diversity is the foundation of crop improvement and a primary target of conservation efforts [68,69]. Living collections offer important research opportunities for the characterization of phenotypic and genetic variation and provide the germplasm needed to support plant breeding efforts targeting greater yields, environmental adaptation and pest and disease resistance [69].

6.1. Genetic Resources

Perennial woody plants, such as almonds, have unique conservation strategies based largely on living collections. Most woody perennial species are obligately crossbred, and, under cultivation, these heterozygous individuals are clonally propagated, resulting in the maintenance of genetically identical individuals over long periods of time and over wide geographical areas [70]. Currently, almond cultivation relies on a small number of highly productive cultivars. However, almond germplasm is composed of thousands of accessions that show great variability in terms of adaptation to different soil and climate conditions, resistance to biotic and abiotic stress and almond quality characteristics [71–78]. The self-incompatibility of most almond cultivars, coupled with the extensive use of seeds for propagation, has played an important role in differentiating the vast genetic diversity within the species [74,75]. Perennial woody plants, such as almonds, have unique conservation strategies, based largely on living collections. Despite the high genetic diversity described, only a limited number of almond accessions are currently maintained in the main germplasm collections worldwide [3]. In the Portuguese Germplasm Bank, there is presently described two main almond collection sites where accessions are kept [76]. One is in the "Trás-os-Montes" region, Mirandela municipality, at the Experimental Centre of "Terra Quente" with 122 accessions and managed by the Regional Direction of Agriculture and Fisheries North. The other one is in the "Algarve" region, Tavira municipality, at the Agriculture Experimental Centre of Tavira with 19 accessions and managed by the Regional Direction of Agriculture and Fisheries Algarve.

6.2. Genetic Diversity

As said before, self-incompatibility of most almond cultivars coupled with the extensive use of seeds for propagation plays an important role in the vast genetic diversity observed within this species [74,75]. Several research works have used simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) molecular markers to study the genetic diversity and relatedness of numerous accession and cultivars from Spain [77–79], Italy [80–82], Iran [83] Australia and the United States of America [84,85]. All these works evidence that the geographical diversity of the accessions of the studied collections is reflected on their genetic diversity. Moreover, markers developed could be used to discriminate among almond accessions and cultivars, constitute relevant tools and resources for analysis of genetic backgrounds and deploy new strategies to support new breeding approaches in this species.

Regarding Portuguese almond germplasm, the number of studies addressing their genetic variability is relatively small. One of the earlier studies was conducted in 2003 by Martins et al. [86]. These authors used randomly amplified polymorphic DNA (RAPD) and inter-simple sequence repeat (ISSR) markers to study the genetic diversity of Portuguese almond cultivars and their relationship to important foreign cultivars. Beside the high genetic diversity found, these authors described how northern and southern cultivars are in general mixed, indicating that no specific geographical distribution was found among the Portuguese cultivars studied [86]. This fact can be considered somewhat expected since it is known that the circulation of cultivars has occurred between these two regions in Portugal, which have the best edaphoclimatic conditions for their production. In another more recent study, Cabrita et al. [87] studied the genetic diversity and relationships among the almond germplasm accessions cultivated in "Algarve". Samples from trees from traditional "Algarve" orchards (123 accessions) and 53 accessions of the local field collection managed by the regional office of the Portuguese Ministry of Agriculture (DRAALG) were assessed using isozyme, inter-single sequence repeat (ISSR) and simple sequence repeat (SSR) or microsatellite approaches. Among others, the results evidenced a broad and unique genetic diversity of the "Algarve" almond germplasm, since the majority of the commercial cultivars studied assembled in a major cluster clearly differentiated from the local accessions [87]. Both studies herein described reinforced that the Portuguese almond germplasm presents a high level of genetic diversity, as well as a high variability in traits of interest for the supply chain that deserves to be exploited in future breeding programs.

6.3. Breeding Approaches

Almonds, either in cultivated orchards or as feral or wild seedlings, have been an important source of food for thousands of years. Within each region, the best wild seedlings were routinely selected for propagation by local farmers, while natural selection continued its unrelenting pressures toward greater adaptation to local environments, including regionally important disease and insect pests [3]. The self-sterile nature of the almond has ensured an exchange and mixing over the centuries between cultivated and wild germplasm, including, in many cases, related species [88]. In the early 1900s, formal plant breeding programs were established in most major production areas (USA, Australia, China and Mediterranean countries) to accelerate this selective process through controlled crosses and related genetic improvement. While many goals such as total yield and production efficiency were similar among programs, regional breeding goals often varied due to different environments, disease and pest problems [3].

In the USA and Australia, the predominant cultivar is 'Nonpareil', which represents 40% and 50%, respectively. The 'Nonpareil' cultivar is highly adapted to environmental, cultural and commercial conditions of these countries. The release of the moderately saturated Australian almond genetic map, which is highly syntenic and collinear with the *Prunus* reference map and peach genome V1.0, opens new possibilities to deploy improvement strategies supported by molecular markers [85]. Several quantitative trait loci (QTL) for shell hardness were detected on three linkage groups: LG2, LG5 and LG8, evaluated for an N ('Nonpareil') × L ('Lauranne') progeny. The results showed that Nonpareil-like marker genotypes were associated with softer shells at all these QTLs. Thus, depending on whether the (soft) paper-shell characteristic of 'Nonpareil' is considered favorable or unfavorable, selection could be imposed for or against based on the screening of associated markers [85].

In Mediterranean and Near Eastern countries, many local cultivars adapted to each area, along with new cultivars that were later obtained in breeding programs, mainly from France and Spain, and are cultivated nowadays. The most important breeding European programs have been conducted by the Institut National de la Recherche Agronomique (INRA) in France (with cultivars like 'Ferragnes', 'Ferraduel', 'Lauranne' and 'Mandaline'), the Spanish Institute of Agrifood Research and Technology (IRTA) Constantí ('Francolí', 'Masbovera', 'Glorieta', 'Vayro', 'Constantí', 'Marinada' and 'Tarraco'), the Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA) Zaragoza ('Ayles', 'Guara', 'Moncayo', 'Blanquerna', 'Cambra', 'Felisia', 'Soleta', 'Belona', 'Mardía' and 'Vialfás') and the Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC) ('Antoñeta', 'Marta', 'Penta' and 'Tardona') [86]. We must emphasize the great diffusion of French cultivars 'Ferragnes' and 'Ferraduel' in several European countries, and of 'Guara' specifically in Spain [88]. Disease resistance to red leaf blotch (RLB) of almonds, caused by biotrophic ascomycete *Polystigma amygdalinum*, has been a particular trait of interest in Spain, where the incidence of this disease has increased in Spain particularly in newly planted orchards, as a result of the use of susceptible cultivars such as 'Guara' and 'Tuono' [89].

These new cultivars are gradually displacing traditional cultivars, having as traits of interest self-compatibility and late flowering time, which is a great advantage in colder areas. Such a tendency has been widely adopted in Portuguese orchards, in which traditional cultivars have been substituted by the installation of new orchards cultivars that are more productive. Cultivars such as 'Soleta', 'Belona', 'Marinada', 'Constantí', 'Vairo', Mardía', 'Penta', 'Tardona' and 'Vialfas' have a later blooming, which allows them to avoid, or at least mitigate, the effects of spring frosts, the major cause of productivity losses in Portuguese almond orchards [20]. Research efforts that would support the valorization and improvement of local and traditional cultivars are of extreme importance. This strategy will tackle an important need of the almond sector, since Portuguese almonds have unique organoleptic quality, while contributing to the preservation of diversity.

6.4. Prospects for the Portuguese Almond Research and Production

The planted area and production of almonds in Portugal has varied over the last 35 years, and overall, there has been a 5% growth in the planted area, while production has declined since the peak of production in the 1990s [9,35]. According to the data available at the Portuguese Institute of Statistics (Instituto Nacional de Estatística—INE) production and area of production have been increased for all the NUTSII regions ("Norte", "Centro", "Área Metropolitana de Lisboa" and "Alentejo") for the period of 2010–2022, with the exception of "Algarve", in which a decrease was observed [35]. Currently, the almond area is growing at about 15–20% per year and is expected to double by 2025, due to rising almond prices and the perceived improvement in crop yields, particularly in the

"Alentejo" and "Centro-Beira Interior" regions with greater water availability and moderate risks associated with rain and frost. Indeed, kernel production in "Alentejo" has already overcome the "Norte" region with the results of the new almond orchards installed in that region [35].

The main challenges for the sector lie in climatic conditions and the need to tackle the global agricultural challenges: the risk of frost, which is present in all planting regions, and the amount and frequency of precipitation events in spring and autumn. These can trigger the appearance of diseases and weeds in the almond groves and diseases in the post-harvest period, delaying the harvest period and causing production losses [48]. Disease and weed management are further hampered by the steady reduction in EU-approved pesticide classes, which promotes reliance on fewer but more expensive chemicals, which increases the likelihood of resistance until better methods or technologies are researched, developed, and used. The existing labor force and infrastructures in Portugal are also limiting. It is not easy to find human resources willing to work in almond fields and specialized equipment, which is usually imported, and the processing capacity is currently restricted and insufficient to cope with the increase in planted areas [9].

In the Mediterranean basin, major breeding objectives have generally aimed to obtain self-compatible and late flowering cultivars to increase the fruit set and to avoid the spring frost damages and by this way increase crop productivity in terms of net income per hectare. Fruit quality and ease of management of the trees have also been important traits to consider [88]. Nevertheless, it is generally accepted that the market will demand in the mid-term cultivars of almonds with different chemical composition, organoleptic properties and technological characteristics for industrial use, as observed for many other dry fruits.

New opportunities for almond tree improvement involve traits, such as early maturation: in warmer areas, this allows for harvesting of the crop before the high summer temperatures, facilitating the preparation of the tree for the adequate development for the following year, and in cold areas, it prevents excessive delay in ripening [90]. Furthermore, improvement in pest and diseases control has many advantages for producers and consumers, as it reduces the production costs by eliminating or reducing phytosanitary applications, with a continuous and perpetual effect [3]. The cultivation of resistant cultivars is more environmentally friendly, and it generates healthier almonds for consumers [3]. Other objectives for almond tree improvement can be the identification of good sources of resistance within the species, requiring the breeder to use wild related species, conducting more complex and lengthier breeding processes [3].

The cultivation system for rainfed or irrigated conditions and their large differences bring the need for the creation of cultivars for each type of culture. In the case of rootstocks, traits like vigor compatibility with a wide spectrum of cultivars from different species, good tolerance to root hypoxia, water use efficiency, aptitude to extract or exclude certain soil nutrients and tolerance to soil or water salinity will be the focus of research in the coming years [91].

7. Conclusions

Portugal is a traditional almond-producing country, where a Mediterranean climate favors needed conditions. Excluding the "Algarve" region, the almond production area is expected to double in the short term due to rising almond prices and the perceived improvement in crop yields, particularly in "Alentejo" and "Centro-Beira Interior". "Alentejo" kernel production (28,449 t) has already surpassed the production observed for the North region (12,998 t) as a result of the (super)-intensive young culture almond orchards recently planted. The relevant increase in Portuguese production seen in the last decade was accomplished either by a strong investment from foreign companies and mechanization in as well as the introduction of more productive foreign cultivars adapted to local conditions. These new foreign cultivars are gradually substituting traditional cultivars, having as traits of interest self-compatibility and late flowering time, which is a great advantage in areas with spring frost episodes. This choice has led to the traditional cultivars being lost and this contributes largely to the loss of diversity. Numerous genetic resources, as well as new molecular tools, are being deployed not only for conservation purposes but also for breeding objectives. Self-compatibility and delayed flowering have been preferred traits for breeding programs worldwide, with direct impact on production. Considerable success has been described for the development of compatible rootstocks with improved resistance to biotic and abiotic constraints. Still, extensive efforts need to be made to target other important traits such as shell hardness and disease resistance. Coordinated research efforts are needed to overcome the lack of genomic and genetic resources still observed in this species. One relevant example is the lack of a fully sequenced and annotated reference genome. The increase of the knowledge of almond genetics and its correlation with phenotypic traits is expected to enable selection and improvement of desired traits. Such approaches will enhance our capacity to respond to almond production challenges and are expected to bring innovation and competitiveness to the almond sector.

Author Contributions: Conceptualization, J.N.; writing—original draft preparation, C.R.C., B.S., J.S. and M.B.; writing—review and editing, C.R.C., B.S., J.S., M.B., S.d.S.A., H.S., R.P. and J.N.; supervision, S.d.S.A., H.S., R.P. and J.N.; funding acquisition, J.N. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the I-CERES project, NORTE-01-0145-FEDER-000082—Norte Portugal Regional Operational Program (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF); RHAQ NORTE, NORTE-06-3559-FSE-000103—Norte Portugal Regional Operational Program (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Social Fund (ESF) and RHAQ CENTRO, CENTRO-04-3559-FSE-000146—Centro Portugal Regional Operational Program (CENTRO 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Social Fund (ESF); the Centre Bio R&D Unit (UIDB/05083/2020) through Fundação para a Ciência e Tecnologia and the Interface Mission RE-C05-i02 under the Portuguese Recovery and Resilience Plan through the European Union NextGenerationEU Fund.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Christenhusz, M.J.M.; Byng, J.W. The Number of Known Plants Species in the World and Its Annual Increase. *Phytotaxa* **2016**, *261*, 201–207. [CrossRef]
2. Martí, A.V.F.I.; Forcada, C.F.I.; Kamali, K.; Cabetas, M.J.R.; Wirthensohn, M. Molecular Analyses of Evolution and Population Structure in a Worldwide Almond [*Prunus Dulcis* (Mill.) D.A. Webb Syn. P. *Amygdalus Batsch*] Pool Assessed by Microsatellite Markers. *Genet. Resour. Crop Evol.* **2014**, *62*, 205–219. [CrossRef]
3. Gradziel, T.M.; Martínez-Gómez, P. Almond Breeding. In *Plant Breeding Reviews*; Janick, J., Ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2013; pp. 207–258. [CrossRef]
4. Rodrigues, Â.M. *Manual Técnico Amendoeira: Estado Da Produção: Frutos Secos: Da Produção à Comercialização*; Centro Nacional de Competências dos Frutos Secos: Bragança, Portugal, 2017; pp. 1–499.
5. Homet-Gutiérrez, P.; Schupp, E.W.; Gómez, J.M. Naturalization of Almond Trees (*Prunus Dulcis*) in Semi-Arid Regions of the Western Mediterranean. *J. Arid Environ.* **2015**, *113*, 108–113. [CrossRef]
6. Zeinalabedini, M.; Khayam-Nekoui, M.; Grigorian, V.; Gradziel, T.M.; Martínez-Gómez, P. The Origin and Dissemination of the Cultivated Almond as Determined by Nuclear and Chloroplast SSR Marker Analysis. *Sci. Hortic.* **2010**, *125*, 593–601. [CrossRef]
7. Sana, S.; Akhter, N.; Amjum, F.; Khan, S.G.; Akram, M. Genetic Diversity in Almond (*Prunus Dulcis*). In *Prunus—Recent Advances*; Küden, A.B., Küden, A., Eds.; IntechOpen: London, UK, 2021. [CrossRef]
8. Company, R.S.I.; Gradziel, T.M. *Almonds: Botany, Production and Uses*; CABI: Oxfordshire, UK, 2017; pp. 1–494.
9. Doll, D.A.; Freire De Andrade, J.; Serrano, P. *Produção de Amêndoa Em Portugal: Tendências de Plantação e Desafios de Produção Num Setor Em Desenvolvimento*; AGRO.GES: Cascais, Portugal, 2021.
10. Blanca, G.; Díaz de la Guarda, C. *Prunus* L. In *Flora Iberica*; Garmendia, F.M., Navarro, C.C., Eds.; Real Jardín Botánico, CSIC: Madrid, Spain, 1998; pp. 444–466.
11. Chin, S.W.; Shaw, J.; Haberle, R.C.; Wen, J.; Potter, D. Diversification of Almonds, Peaches, Plums and Cherries—Molecular Systematics and Biogeographic History of Prunus (*Rosaceae*). *Mol. Phylogenet. Evol.* **2014**, *76*, 34–48. [CrossRef]

12. Verma, M.K.; Awasthi, O.P.; Giri, R. Prospectus of Temperate Fruit Production in Subtropical Climate. In Proceedings of the National Seminar on "Precision Farming in Horticulture", Jhalawar, India, 28–29 December 2010.
13. Brittain, C.; Kremen, C.; Garber, A.K.; Klein, A.M. Pollination and Plant Resources Change the Nutritional Quality of Almonds for Human Health. *PLoS ONE* **2014**, *9*, e90082. [CrossRef] [PubMed]
14. Gradziel, T.M. Almond (*Prunus Dulcis*) Breeding. In *Breeding Plantation Tree Crops: Temperate Species*; Priyadarshan, P.M., Mohan Jain, S., Eds.; Springer Science + Bussiness Media: New York, NY, USA, 2009; pp. 1–31. [CrossRef]
15. Salas-Salvadó, J.; Casas-Agustench, P.; Salas-Huetos, A. Cultural and Historical Aspects of Mediterranean Nuts with Emphasis on Their Attributed Healthy and Nutritional Properties. *Nutr. Metab. Cardiovasc. Dis.* **2011**, *21*, S1–S6. [CrossRef]
16. Méndez, J.; Vicedo, P.V.; Martín, R.G.; Sánchez, J.N. Comportamiento de Nuevas Variedades de Almendro En El Campo de Cartagena. 2021. Available online: https://www.carm.es/web/descarga?IDCONTENIDO=20865&ALIAS=PUBT&RASTRO=c2889$m58245,58256,58865&IDADIC=15713&ARCHIVO=Texto+Completo+1+Comportamiento+de+nuevas++variedades+de+almendro+en+el++campo+de+Cartagena.pdf (accessed on 27 July 2023).
17. Arquero, O. *Manual Del Almendro*; Junta de Andalucía, Consejería de Agricultura, Pesca y Desarrollo Rural: Sevilla, Spain, 2013; pp. 1–80.
18. Malagón, J. *Cultivo del Almendro*; Conselleria d'Agricultura: Valencia, Spain, 2020; pp. 1–4.
19. Hernández, D.; Moreno, P. *El Cultivo Del Almendro, Cultivos Leñosos: Frutales de Zonas Áridas*; Antonio Madrid Vicente: Madrid, Spain, 2019.
20. Queirós, F. *Manual de Boas Práticas de Fruticultura*, 213th ed.; Frutas, Legumes e Flores, em parceria com INIAV, I.P. (Estação Nacional de Fruticultura Vieira Natividade) e COTR: Oeiras, Portugal, 2020.
21. Grasselly, C.; Duval, H. *L'Amandier*; Maisonneuve et Larose: Paris, France, 1980; pp. 1–445.
22. AJAP: Associação dos Jovens Agricultores de Portugal. *Manual das boas Práticas para Culturas Emergentes: A Cultura da Amêndoa*; AJAP: Lisboa, Portugal, 2017.
23. Torguet, L.; Maldonado, M.; Miarnau, X. Importancia y Control de las Enfermedades en el Cultivo del Almendro. Available online: https://archivo.revistaagricultura.com/almendro/cultivos/importancia-y-control-de-las-enfermedades-en-el-cultivo-del-almendro_10697_38_13324_0_1_in.html (accessed on 27 July 2023).
24. Gort, J.A.; Sánches, J. Controlo de plagas y enfermedades en el cultivo del Almendro. *Vida Rural* **2011**, *332*, 68–74.
25. McKay, S.; Shtienberg, D.; Sedgley, M.; Scott, E.S. Anthracnose on Almond in Australia: Disease Progress and Inoculum Sources of Colletotrichum Acutatum. *Eur. J. Plant Pathol.* **2014**, *139*, 773–783. [CrossRef]
26. Rungjindamai, N.; Jeffries, P.; Xu, X. Epidemiology and Management of Brown Rot on Stone Fruit Caused by *Monilinia laxa*. *Eur. J. Plant Pathl.* **2014**, *140*, 1–17. [CrossRef]
27. Pons-Solé, G.; Miarnau, X.; Torguet, L.; Lázaro, E.; Civera, A.V.; Luque, J. Airborne Inoculum Dynamics of *Polystigma Amygdalinum* and Progression of Almond Red Leaf Blotch Disease in Catalonia, NE Spain. *Ann. Appl. Biol.* **2023**, *183*, 33–42. [CrossRef]
28. Almeida, R.P.P.; Purcell, A.H. Biological Traits of *Xylella Fastidiosa* Strains from Grapes And Almonds. *Appl. Environ. Microbiol.* **2003**, *69*, 7447–7452. [CrossRef] [PubMed]
29. Barnes, M.M.; Andrews, K. Effects of Spider Mites on Almond Tree Growth and Productivity. *J. Econ. Entomol.* **1978**, *71*, 555–558. [CrossRef]
30. Mdellel, L.; Adouani, R.; Kamel, M.B.H. Aphid on Almond and Peach in Tunisia: Species, Bioecology, Natural Enemies and Control Methods. In *Fruit Industry*; Kahramanoğlu, İ., Wan, C., Eds.; IntechOpen: London, UK, 2022. [CrossRef]
31. Marcotegui, A.; Sánchez-Ramos, I.; Pascual, S.; Fernández, C.E.; Cobos, G.; Armendáriz, I.E.; Cobo, A.; González-Núñez, M. Kaolin and Potassium Soap with Thyme Essential Oil to Control *Monosteira unicostata* and Other Phytophagous Arthropods of Almond Trees in Organic Orchards. *J. Pest Sci.* **2015**, *88*, 753–765. [CrossRef]
32. Hamby, K.A.; Nicola, N.; Niederholzer, F.; Zalom, F.G. Timing Spring Insecticide Applications to Target Both *Amyelois Transitella* (Lepidoptera: Pyralidae) and *Anarsia Lineatella* (Lepidoptera: Gelechiidae) in Almond Orchards. *J. Econ. Entomol.* **2015**, *108*, 683–693. [CrossRef] [PubMed]
33. Jha, P.K.; Zhang, N.; Rijal, J.P.; Parker, L.E.; Ostoja, S.; Pathak, T.B. Climate Change Impacts on Insect Pests for High Value Specialty Crops in California. *SSRN* **2023**. [CrossRef]
34. Centro Nacional de Competências dos Frutos Secos (CNCFS). Available online: http://www.wp.cncfs.pt/ (accessed on 27 July 2023).
35. Instituto Nacional de Estatística, I.P. (INE). Estatíscas da Produção Vegetal. Available online: https://www.ine.pt (accessed on 7 August 2023).
36. Vargas, F.J.; Romero, M.A.; Clavé, J.; Vergés, J.; Santos, J.; Batlle, I. 'Vayro', 'Marinada', 'Constantí', and 'Tarraco' Almonds. *Hortscience* **2008**, *43*, 535–537. [CrossRef]
37. Calvo, Á.; Gómara, E. *Almendro. Resultado de 12 Años de Experimentación Con Variedades*; Navarra agraria: Navarra, Spain, 2011; pp. 1–5.
38. Arquero, O.; Casado, B.; Salguero, A.; Viñas, M. Sistemas de Formación y Poda. In *Manual del Cultivo del Almendro*; Arquero, O., Ed.; Junta de Andalucía, Consejería de Agricultura, Pesca y Desarrollo Rural: Sevilla, Spain, 2013; pp. 39–46.
39. Monteiro, A.; Cordeiro, V.; Laranjo, J. *A Amendoeira: Com Especial Referência a Trás-Os-Montes e Alto Douro*; João Azevedo Editor, D.L.: Mirandela, Portugal, 2003; pp. 1–186.

40. Miarnau, X.; Alegre, S.; Vargas, F. Productive potential of six almond cultivars under regulated deficit irrigation. In *XIV GREMPA Meeting on Pistachios and Almonds*; Zakynthinos, G., Ed.; CIHEAM/FAO/AUA/TEI Kalamatas/NAGREF Zaragoza: Athens, Greece, 2010; pp. 267–271.
41. Hernández, D.M.S.; López-Cortés, I. *La Producción Integrada Em El Almendro*; UPV: Valência, Espanha, 2009; pp. 1–226.
42. International Nut and Dried Fruit Council Foundation. *Nuts Dried Fruits Statistical Yearbook*; International Nut and Dried Fruit Council Foundation: Reus, Spain, 2019.
43. Waycott, R.; Saa, S. Principales Características Del Sector de La Almendra En California: Los Inicios, La Consolidación, Las Perspectivas. *Dialnet* **2020**, *36*, 12–19.
44. Iglesias, I. El Almendro en España: Situación, Innovación Tecnológica, Costes y Retos Para una Producción Sostenible. Available online: https://www.interempresas.net/Horticola/Articulos/316394-almendro-Espana-situacion-innovacion-tecnologica-costes-retos-produccion-sostenible.html (accessed on 8 August 2023).
45. Almond Board of California. Almond Almanac. 2019. Available online: https://www.almonds.com/sites/default/files/2020-04/2019_Almanac.pdf (accessed on 24 May 2023).
46. Almond Board of California. Almond Almanac. 2022. Available online: https://www.almonds.com/sites/default/files/2023-04/2022_Almanac.pdf (accessed on 29 May 2023).
47. Pathak, T.B.; Maskey, M.L.; Rijal, J. Impact of Climate Change on Navel Orangeworm, a Major Pest of Tree Nuts in California. *Sci. Total Environ.* **2021**, *755*, 142657. [CrossRef]
48. Lamichhane, J.R.; Dachbrodt-Saaydeh, S.; Kudsk, P.; Messéan, A. Toward a Reduced Reliance on Conventional Pesticides in European Agriculture. *Plant Dis.* **2016**, *100*, 10–24. [CrossRef]
49. Food and Agriculture Organization of the United Nations (FAO). FAOSTAT. Available online: https://www.fao.org/faostat/en/#home (accessed on 8 August 2023).
50. Oliveira, I.; Meyer, A.S.; Afonso, S.; Aires, A.; Goufo, P.; Trindade, H.; Gonçalves, B. Phenolic and Fatty Acid Profiles, A-tocopherol and Sucrose Contents, and Antioxidant Capacities of Understudied Portuguese Almond Cultivars. *J. Food Biochem.* **2019**, *43*, e12887. [CrossRef]
51. Rodrigues, I.; Bento, A.; Reis, C.; Pereira, J.A. *Monitorização das principais pragas da amendoeira em pomares da região de Trás-os-Montes*; 4º Simpósio Nacional de Fruticultura: Faro, Portugal, 2020; pp. 450–455.
52. Cabo, P.; Matos, A. *Amendoeira: Estado da Comercialização: Frutos Secos: Da Produção à Comercialização*; Centro Nacional de Competências dos Frutos Secos: Bragança, Portugal, 2017; pp. 1–107. Available online: http://www.wp.cncfs.pt/2017/04/02/amendoeira-estado-da-comercializacao (accessed on 16 May 2023).
53. Borràs, E.; Amigo, J.M.; Van Den Berg, F.; Boqué, R.; Busto, O. Fast and Robust Discrimination of Almonds (*Prunus amygdalus*) with Respect to Their Bitterness by Using near Infrared and Partial Least Squares-Discriminant Analysis. *Food Chem.* **2014**, *153*, 15–19. [CrossRef] [PubMed]
54. Karatay, H.; Sahin, A.; Yilmaz, O.; Aslan, A. Major Fatty Acids Composition of 32 Almond (*Prunus dulcis* (Mill.) D. A. Webb.) Genotypes Distributed in East and Southeast of Anatolia. *Turk. Biyokim. Derg.* **2014**, *39*, 307–316. [CrossRef]
55. Volpi, G. Demonstrating the Presence of Cyanide in Bitter Seeds While Helping Students Visualize Metal–Cyanide Reduction and Formation in a Copper Complex Reaction. *J. Chem. Educ.* **2016**, *93*, 891–897. [CrossRef]
56. Javaid, T.; Mahmood, S.; Saeed, W.; Alam, M.Q. A Critical Review on Cultivars and Benefits of Almond (*Prunus Dulcis*). *Act. Sci. Nutr. Health* **2019**, *3*, 70–72. [CrossRef]
57. Loghavi, M.; Souri, S.; Khorsandi, F. Physical and Mechanical Properties of Almond (Prunus Dulcis l. Cv. 7Shahrood). In Proceedings of the American Society of Agricultural and Biological Engineers Annual International Meeting, Louisville, Kentucky, 7–10 August 2011. [CrossRef]
58. Toomey, M.B.S.V.; Nickum, B.S.E.A.; Flurer, C.L. Cyanide and Amygdalin as Indicators of the Presence of Bitter Almonds in Imported Raw Almonds. *J. Forensic Sci.* **2012**, *57*, 1313–1317. [CrossRef]
59. Amirshaghaghi, Z.; Rezaei, K.; Rezaei, M.H. Characterization and Functional Properties of Protein Isolates from Wild Almond. *J. Food Meas. Charact.* **2017**, *11*, 1725–1733. [CrossRef]
60. Grundy, M.M.L.; Lapsley, K.; Ellis, P.R. A Review of the Impact of Processing on Nutrient Bioaccessibility and Digestion of Almonds. *Int. J.Food Sci. Technol.* **2016**, *51*, 1937–1946. [CrossRef]
61. Martinez, M.L.; Penci, M.C.; Marin, M.A.; Ribotta, P.D.; Maestri, D.M. Screw Press Extraction of Almond (*Prunus Dulcis* (Miller) D.A. Webb): Oil Recovery and Oxidative Stability. *J. Food Eng.* **2013**, *119*, 40–45. [CrossRef]
62. Bernat, N.; Cháfer, M.; Rodriguez-Garcia, J.; Chiralt, A.; González-Martínez, C. Effect of High Pressure Homogenisation and Heat Treatment on Physical Properties and Stability of Almond and Hazelnut Milks. *LWT- Food Sci. Technol.* **2015**, *62*, 488–496. [CrossRef]
63. Chaouali, N.; Gana, I.; Amira, D.; Khelifi, F.; Nouioui, A.; Masri, W.; Belwaer, I.; Ghorbel, H.; Hedhili, A. Potential Toxic Levels of Cyanide in Almonds (*Prunus Amygdalus*), Apricot Kernels (*Prunus Armeniaca*), and Almond Syrup. *Int. Sch. Res. Notices.* **2013**, *2013*, 1–6. [CrossRef] [PubMed]
64. Dhakal, S.; Giusti, M.M.; Balasubramaniam, V.M. Effect of High Pressure Processing on Dispersive and Aggregative Properties of Almond Milk. *J. Sci. Food Agric.* **2016**, *96*, 3821–3830. [CrossRef] [PubMed]
65. Silva, A.R.A.; Silva, M.M.N.; Ribeiro, B.D. Health Issues and Technological Aspects of Plant-Based Alternative Milk. *Food Res. Int.* **2020**, *131*, 108972. [CrossRef] [PubMed]

66. Ahmad, Z. The Uses and Properties of Almond Oil. *Complement. Ther. Clin. Pract.* **2010**, *16*, 10–12. [CrossRef]
67. Čolić, S.; Zec, G.; Natić, M.; Fotiric-Aksic, M. Almond (*Prunus Dulcis*) Oil. In *Fruit Oils: Chemistry and Functionality*; Ramadan, M.F., Ed.; Springer: Cham, Switzerland, 2019; pp. 149–180. [CrossRef]
68. Harlan, J.R.; De Wet, J.M.J. Toward A Rational Classification of Cultivated Plants. *Taxon* **1971**, *20*, 509–517. [CrossRef]
69. Migicovsky, Z.; Warschefsky, E.; Klein, L.L.; Miller, A.J. Using Living Germplasm Collections to Characterize, Improve, and Conserve Woody Perennials. *Crop Sci.* **2019**, *59*, 2365–2380. [CrossRef]
70. Miller, A.J.; Matasci, N.; Schwaninger, H.; Aradhya, M.K.; Prins, B.; Zhong, G.Y.; Simon, C.; Buckler, E.S.; Myles, S. Vitis Phylogenomics: Hybridization Intensities from a SNP Array Outperform Genotype Calls. *PLoS ONE* **2013**, *8*, e78680. [CrossRef]
71. Klein, A.M.; Brittain, C.; Hendrix, S.D.; Thorp, R.; Williams, N.; Kremen, C. Wild Pollination Services to California Almond Rely on Semi-Natural Habitat. *J. Appl. Ecol.* **2012**, *49*, 723–732. [CrossRef]
72. Kodad, O.; Estopañan, G.; Juan, T.; Alonso, J.M.; Espiau, M.T.; Company, R.S.I. Oil Content, Fatty Acid Composition and Tocopherol Concentration in the Spanish Almond Genebank Collection. *Sci. Hortic.* **2014**, *177*, 99–107. [CrossRef]
73. Currò, S.; La Malfa, S.; Distefano, G.; Long, G.; Sottile, F.; Gentile, A. Analysis of S-Allele Genetic Diversity in Sicilian Almond Germplasm Comparing Different Molecular Methods. *Plant Breed.* **2015**, *134*, 713–718. [CrossRef]
74. Tamura, M.; Ushijima, K.; Sassa, H.; Hirano, H.; Tao, R.; Gradziel, T.M.; Dandekar, A.M. Identification of Self-Incompatibility Genotypes of Almond by Allele-Specific PCR Analysis. *Theor. Appl. Genet.* **2000**, *101*, 344–349. [CrossRef]
75. Channuntapipat, C.; Wirthensohn, M.; Ramesh, S.A.; Batlle, I.; Arús, P.; Sedgley, M.; Collins, G. Identification of Incompatibility Genotypes in Almond (*Prunus Dulcis Mill.*) Using Specific Primers Based on the Introns of the S-Alleles. *Plant Breed.* **2003**, *122*, 164–168. [CrossRef]
76. Ministério da Agricultura e do Mar. *Plano Nacional para os Recursos Genéticos Vegetais*; Instituto Nacional de Investigação Agrária e Veternaria, I.P. (INIAV): Oeiras, Portugal, 2015.
77. Martí, A.F.I.; Alonso, J.M.; Espiau, M.T.; Cabetas, M.J.R.; Company, R.S.I. Genetic Diversity in Spanish and Foreign Almond Germplasm Assessed by Molecular Characterization with Simple Sequence Repeats. *J. Am. Soc. Hortic. Sci.* **2009**, *134*, 535–542. [CrossRef]
78. Padilla, G.; Company, R.S.I.; Ordás, A. Molecular Characterization of Almond Accessions from the Island of La Palma (Canary Islands, Spain) Using SSR Markers. *Plant Genet. Resour.* **2014**, *12*, 323–329. [CrossRef]
79. Martínez-Gómez, P.; Romero, A.; Batlle, I.; Dicenta, F. Molecular characterization of Spanish autochthonous almond breeding collections using SSRs. In *XVI GREMPA Meeting on Almonds and Pistachios*; Kodad, O., López-Francos, A., Rovira, M., Rafael Socias i Company, Eds.; CIHEAM Zaragoza: Meknes, Morrocco, 2016; pp. 111–114. Available online: http://om.ciheam.org/article.php?IDPDF=00007374 (accessed on 9 August 2023).
80. Savoia, M.A.; Del Faro, L.; Venerito, P.; Gaeta, L.; Palasciano, M.; Montemurro, C.; Sabetta, W. The Relevance of Discovering and Recovering the Biodiversity of Apulian Almond Germplasm by Means of Molecular and Phenotypic Markers. *Plants* **2022**, *11*, 574. [CrossRef] [PubMed]
81. Rigoldi, M.P.; Rapposelli, E.; De Giorgio, D.; Resta, P.; Porceddu, A. Genetic Diversity in Two Italian Almond Collections. *Electron. J. Biotechnol.* **2015**, *18*, 40–45. [CrossRef]
82. Pavan, S.; Delvento, C.; Mazzeo, R.; Ricciardi, F.; Losciale, P.; Gaeta, L.; D'Agostino, N.; Taranto, F.; Sánchez-Pérez, R.; Ricciardi, L.M.; et al. Almond Diversity and Homozygosity Define Structure, Kinship, Inbreeding, and Linkage Disequilibrium in Cultivated Germplasm, and Reveal Genomic Associations with Nut and Seed Weight. *Hortic. Res.* **2021**, *8*, 1–12. [CrossRef]
83. Rahimi-Dvin, S.; Gharaghani, A.; Pourkhaloee, A. Genetic Diversity, Population Structure, and Relationships among Wild and Domesticated Almond (*Prunus* Spp.) Germplasms Revealed by ISSR Markers. *Adv. Hort. Sci.* **2020**, *34*, 287–300. [CrossRef]
84. Goonetilleke, S.N.; March, T.J.; Wirthensohn, M.G.; Arús, P.; Walker, A.R.; Mather, D.E. Genotyping by Sequencing in Almond: SNP Discovery, Linkage Mapping, and Marker Design. *G3: Genes Genon. Genet.* **2018**, *8*, 161–172. [CrossRef]
85. Tavassolian, I.; Rabiei, G.; Gregory, D.; Mnejja, M.; Wirthensohn, M.G.; Hunt, P.W.; Gibson, J.P.; Ford, C.M.; Sedgley, M.; Wu, S.B. Construction of an Almond Linkage Map in an Australian Population Nonpareil × Lauranne. *BMC Genom.* **2010**, *11*, 1–10. [CrossRef]
86. Martins, M.; Tenreiro, R.; Oliveira, M.M. Genetic Relatedness of Portuguese Almond Cultivars Assessed by RAPD and ISSR Markers. *Plant Cell Rep.* **2003**, *22*, 71–78. [CrossRef] [PubMed]
87. Cabrita, L.; Apostolova, E.; Neves, A.; Marreiros, A.; Leitão, J. Genetic Diversity Assessment of the Almond (*Prunus Dulcis* (Mill.) D.A. Webb) Traditional Germplasm of Algarve, Portugal, Using Molecular Markers. *Plant Genent. Resour.* **2014**, *12* (Suppl. S1), S164–S167. [CrossRef]
88. Dicenta, F.; Egea, J.; Ortega, E.; Martínez-Gómez, P.; Sánchez-Pérez, R.; Rubio, M.; Martínez-García, P.J.; Gómez, E.M.; del Cueto, J.; Sánchez-Prudencio, A.; et al. Almond Breeding: Important issues and challenges for research. In *XVI GREMPA Meeting on Almonds and Pistachios*; Kodad, O., López-Francos, A., Rovira, M., Socias i Company, R., Eds.; CIHEAM Zaragoza: Morocco, 2016; pp. 23–28. Available online: http://om.ciheam.org/om/pdf/a119/00007357.pdf (accessed on 18 August 2023).
89. Miarnau, X.; Zazurca, L.; Torguet, L.; Zúñiga, E.; Batlle, I.; Alegre, S.; Luque, J. Cultivar Susceptibility and Environmental Parameters Affecting Symptom Expression of Red Leaf Blotch of Almond in Spain. *Plant Dis.* **2021**, *105*, 940–947. [CrossRef]

90. Dicenta, F.; Martínez-Gómez, P.; Martínez-Pato, E.; Gradziel, T.M. Screening for *Aspergillus flavus* Resistance in Almond. *Hortscience* **2003**, *38*, 266–268. [CrossRef]
91. Gainza, F.; Opazo, I.; Guajardo, V.; Meza, P.; Ortiz, M.; Pinochet, J.; Muñoz, C. Rootstock Breeding in Prunus Species: Ongoing Efforts and New Challenges. *Chil. J. Agric. Res.* **2015**, *75*, 6–16. [CrossRef]