OPTIONS méditerranéennes

Plant Material for the Future of Nut Production in the Mediterranean Region

Edited by:
M. J. Rubio-Cabetas and A. López-Francos








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Président / President: Frida KRIFCA
Secretariat General / General Secretariat: Teodoro MIANO

11, rue Newton, 75116 Paris, France
Tél.: +33 (0) 1 53 23 91 00 - Fax: +33 (0) 1 53 23 91 01 / 02
secretariat@ciheam.org
www.ciheam.org

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3191, Route de Mende
34093 Montpellier Cedex 5, France
Tel.: (+33) (0)4 67 04 60 00 - Fax: (+33) (0)4 67 54 25 27
pascal.bergeret@iamm.fr et/and sciuto@iamm.fr
www.iamm.fr

IAM-Zaragoza
Dir.: Raúl COMPÉS
Avda. Montañana, 1005
50059 Zaragoza, Spain
Tel.: (+34) 976 716000 - Fax: (+34) 976 716001
iamz@iamz.ciheam.org
www.iamz.ciheam.org

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Plant Material for the Future of Nut Production in the Mediterranean Region

Editors: M. J. Rubio-Cabetas and A. López-Francos

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Zaragoza, Spain, 25-26 September 2024

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Foreword

Global consumption of nuts is growing steadily due to their nutritional value, health benefits, as well as their versatility for incorporating them into the diet, both consumed directly and through traditional and innovative recipes and products. According to the International Nut and Dried Fruit Council, the global shelled nut market exceeded 5 million tonnes and was valued at 36 billion dollars in 2023.

The most traditional nuts in the Mediterranean region are almonds, hazelnuts, chestnuts, walnuts, pistachios and stone pine nuts, while pecan is emerging as a promising crop. Nut trees form part of traditional farming systems in all Mediterranean countries, and nuts are a fundamental staple of the Mediterranean diet. FAOStat (2024) estimates that the global cultivation area for these species (excluding pecan) exceeds 6.6 million hectares, of which around 50 per cent is located in Mediterranean countries. Despite this, the region contributes only about 26% of global production (3.3 million tonnes out of 12.9 million tonnes of in-shell nuts), reflecting relatively low productivity. For some of these species Mediterranean countries are among the leading producers of the world. Türkiye stands out for hazelnuts, walnuts and pistachios, but so too does Spain and Türkiye for almonds and chestnuts (and, more recently, pistachios), Italy for hazelnuts, France for walnut and Portugal for Mediterranean pine nuts.

This outlook confirms that the Mediterranean region, with its favourable climate, is ideal for growing nuts. However, there remains considerable potential for improving production and productivity through varietal improvement and advances in cultivation and post-harvest management techniques. For example, in the US, where intensive cultivation has been practised for many years, yields from almond, hazelnut, walnut and pistachio average 3.5, 2.2, 3.9 and 2.7 t/ha respectively. In contrast, Mediterranean countries maintain large areas of extensive cultivation, and national averages are much lower: around 0.5 t/ha for almond, 1 t/ha for hazelnut, 2 t/ha for walnut and 0.6 t/ha for pistachio. This yield gap is being bridged in some cases through the intensification of cultivation, with new plantations at closer spacing, often under irrigation, aimed at high yields. More extensive and traditional farming systems, however, deserve due attention, not only to improve their yields but also for their contributions to other services such as generating income for the rural population, maintaining the landscape, combating erosion and land degradation, and for the quality and specificity of their products.

Nut cultivation relies heavily on the quality of plant material and genetic resources. Future challenges require advances in plant breeding and genetic improvement. The development of new, resilient varieties is crucial to withstand climate change, pests, and diseases and to match the growing and changing demands of these fruits. Ongoing research focuses on identifying and conserving valuable genetic material to enhance breeding programmes. Access to diverse genetic resources allows breeders to select traits for improved yield, drought resistance, and pest tolerance. Moreover, biotechnology and genomic tools can play a significant role in accelerating the selection process, enabling the creation of superior cultivars. Ensuring the sustainability of nut cultivation in the Mediterranean region depends on these efforts in genetic improvement and resource conservation, and the continuous adaptation of plant material to meet environmental and market demands.

CIHEAM Zaragoza has long pursued cooperation and scientific knowledge exchange activities around Mediterranean nut crops. For over 30 years, the FAO CIHEAM Network on Nuts and the GREMPA (Mediterranean Research Group for Almonds and Pistachios) organised international seminars, colloques and conferences and published research results on the main traditional species in countries around the Mediterranean basin.

In 2024, CIHEAM Zaragoza reinforced its commitment by relaunching scientific networking around nut crops with an International Seminar entitled 'Plant material for the future of nut production in the Mediterranean region'. This event brought together 45 experts on the seven aforementioned species from nine countries: Algeria, France, Italy, Hungary, Morocco, Portugal, Spain, Tunisia and Turkey. The objectives were as follows:

- Assessing the current situation of plant material (varieties, ecotypes and rootstocks, both commercially available and in collections), as well as existing collections and breeding programmes.
- Sharing and proposing the main strategies and lines that should guide the identification, conservation, genetic improvement and selection of these plant materials to meet the future needs of Mediterranean nut production.
- Identifying the main needs for research, innovation and knowledge exchange to support the development and the use of more suitable plant materials.

The Seminar was organised by CIHEAM Zaragoza in collaboration with the Agri-Food Research and Technology Centre of Aragon (CITA). The programme included working sessions, beginning with a keynote address on the nut industry's needs in terms of plant material to satisfy consumer demand. This was followed by presentations and discussions focusing on each of the seven species. The second day consisted of a field trip to Caspe in the Zaragoza province, where participants observed plantations, nurseries, and varietal and agronomic tests in situ. We would like to express our sincere gratitude to the 'El Vivero de Abel' nursery, AFRUCCAS (the Association of Fruit Growers of Caspe) and the farmers whose plots were visited for their support during the field visit and for generously opening their fields and facilities to the visitors.

This volume contains the seven species reports elaborated by the Seminar invited participants, each one providing an overview of the situation and needs of plant materials and their conservation and improvement in the main Mediterranean producing countries. The chapters are structured around several sections and attempt to answer common questions, despite the fact that the seven species covered in this volume differ greatly in terms of biology, crop management, economic development and technological advancement.

We thank all the authors for their valuable contributions and hope that this volume will be of interest to genetic resources researchers, collection curators, plant breeders, nursery owners, farmers and policymakers responsible for plant resources and crop production in Mediterranean countries and beyond.

Raúl Compés (CIHEAM Zaragoza Director)

Maria José Rubio (CITA Aragón, Seminar Scientific Coordinator)

Plant Material for the Future of Nut Production in the Mediterranean Region: Almond Case Study

Gaetano Distefano[1], Ilaria Inzirillo[1], María José Rubio Cabetas[2,3]

[1] University of Catania
Dipartimento di Agricoltura, Alimentazione e Ambiente (Di3A)
Via Santa Sofia 100, 95123 Catania (Italy)
[2] Departamento de Ciencia Vegetal. Centro de Investigación y Tecnología Agroalimentaria de Aragón (CITA)
Avda. Montañana 930, 50059, Zaragoza (Spain)
[3] Instituto Agroalimentario de Aragón – IA2 (CITA-Universidad de Zaragoza), Zaragoza (Spain)

Abstract. Almonds, scientifically known as *Prunus dulcis*, originated in Central Asia and spread to Persia, Mesopotamia, and the Mediterranean, which is a major area of diversity. Almond cultivation has grown from a secondary crop into a major global crop through improvements in orchard management, irrigation, and nut processing. The global importance of almonds comes from their nutritional value, versatility in food preparation, and the species hardiness. Almonds thrive in warm, temperate climates as they have low chilling and moderate heat requirements. In 2022, global almond production reached 3,630,427 tonnes across 2,357,075 hectares, with the USA as the largest producer. The first *ex situ* collection of almonds was described in Yalta, Russia, in 1935. Since then, collections have been established in California, France, Spain, Italy, Portugal, and Greece. There are over 1500 almond cultivars maintained in germplasm collections globally, with 80% of the diversity held in Asian and European banks. The study of almond genetic diversity has progressed from using microsatellites (SSRs) and amplified fragment length polymorphism (AFLPs) to single nucleotide polymorphism (SNP) markers and the publication of the almond genome sequence in 2020. Breeding programs have focused on characteristics like late blooming, self-compatibility, tree architecture, and disease resistance. Rootstock breeding aims to resist biotic and abiotic stresses by using interspecific hybrids of almond, peach, and other *Prunus* species.

Keywords. Almond – Germplasm – Mediterranean area – Inventory – Breeding challenges.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne: étude de cas sur l' amandier

Résumé. Les amandiers, scientifiquement connues sous le nom *de Prunus dulcis*, sont originaires d'Asie centrale et se sont répandues en Perse, en Mésopotamie et en Méditerranée, qui est une zone de diversité majeure. La culture de l'amande est passée du statut de culture secondaire à celui de culture mondiale majeure grâce à l'amélioration de la gestion des vergers, de l'irrigation et de la transformation des fruits. L'importance mondiale des amandes provient de leur valeur nutritionnelle, de leur polyvalence dans l'alimentation et de leur rusticité. Les amandes prospèrent dans les climats chauds et tempérés car ils ont de besoins de froid faibles et de besoins de chaleur modérées. En 2022, la production mondiale d'amandes a atteint 3 630 427 tonnes sur 2 357 075 hectares, les États-Unis étant le plus grand producteur. La première *collection ex situ* d'amandes a été décrite à Yalta, en Russie, en 1935. Depuis lors, des collections ont été établies en Californie, en France, en Espagne, en Italie, au Portugal et en Grèce. Il existe plus de 1500 cultivars d'amandiers conservés dans les collections de matériel génétique dans le monde, dont 80% sont détenus dans des banques asiatiques et européennes. L'étude de la diversité génétique de l'amande est passée de l'utilisation de microsatellites (SSR) et de polymorphisme de longueur de fragment amplifié (AFLP) à des marqueurs de polymorphisme nucléotidique unique (SNP) et à la publication de la séquence du génome de l'amande en 2020. Les programmes de sélection se sont concentrés sur des caractéristiques telles que la floraison tardive, l'auto-compatibilité, l'architecture des arbres et la résistance aux maladies. La sélection des porte-greffes vise à résister aux stress biotiques et abiotiques en utilisant des hybrides interspécifiques d'amandiers, de pêchers et d'autres espèces de *Prunus*.

Mots-clés. *Amandier – Germoplasme – Méditerranée – Inventaire – Defis – Amélioration génétique.*

I – Introduction

Almonds (*Prunus dulcis*) [*Prunus amygdalus* (L.) Batsch, syn *P. dulcis* (Mill.)] are of great cultural, economic and nutritional importance throughout the world, particularly in the Mediterranean and other major producing areas. The place of origin of the almond tree is not yet well defined: the presence of ancestral species in different locations (central and western Asia, from the Himalayas to the eastern Mediterranean), together with high interspecific variability, has made it difficult to identify not only the centre of origin but also the progenitors from which the cultivated species derives. The prevailing theory is that the almond originated from crosses between various wild relatives, including species such as *P. fenzliana*, *P. orientalis*, *P. bucharica*, *P. kuramica*, and *P. webbii* (Grasselly, 1976; Browicz and Zohary, 1996; Ladizinsky, 1999). Molecular studies (Zeinalabedini *et al*., 2010) suggesting that *P. fenzliana* is the most likely ancestor based on nuclear and chloroplast SSR data; instead, broader analysis later identified *P. kuramica* as the closest wild relative of the cultivated almond (Delplancke *et al*., 2016).

The first evidence of cultivated almonds dates to the Early Holocene (10,000–9,000 BC) in Northern Syria (Willcox *et al*., 2008). The origin and spread of almond cultivation in the Mediterranean area is due to the trade between the Phoenicians and the Greek peoples with the Italic Magna Graecia, especially in Sicily (Pérez-Jordà *et al*., 2021). The Greeks and Phoenicians played a key role in this spread, introducing almonds to their colonies throughout the Mediterranean. Today, almond cultivation flourishes along the coasts of Mediterranean countries. The cultivation of almonds in temperate warm climates with mild winters and low rainfall is facilitated by their low chilling requirements (150-400 hours below 7°C during dormancy) and moderate heat requirements (5000-8000 Growing Degree Hours – GDH – after dormancy). In 2022, a world production of 3,630,427 tonnes was recorded on an area of 2,357,075 hectares; the world's largest producer is the USA (1,872,500 tonnes), followed by Australia (360,328 tonnes), Spain (245,990 tonnes) and Turkey (190,000 tonnes). If we compare the volume of production with the area cultivated (Table 1, Figure 1), we can see that there is no real correlation between the two data; e.g. the USA, with an area of 546,332 ha, produces significantly more than Spain, with an area of 761,660 ha (FAOSTAT, 2022).

Table 1. Area harvested (ha) and production of almond in shell in the world

Country	Area harvested (ha)	Country	Production (t)
Spain	761,660	USA	1,858,010
USA	546,332	Australia	360,328
Morocco	226,213	Spain	245,990
Tunisia	194,785	Turkey	190,000
Iran	73,857	Morocco	175,763
Syrian Arab Republic	70,881	China	104,000
Portugal	63,880	Iran	88,561
Türkiye	63,266	Italy	74,590
Libya	61,882	Tunisia	70,000
Australia	57,872	Afghanistan	64,000
Italy	53,890	Algeria	62,988



Fig. 1. Percentages of almond tree areas and production in the world.

Among the various almond products (in-shell and shelled almonds, oil, vegetable drinks, bakery products, etc.), the trade in in-shell and shelled almonds accounts for the largest turnover (with significant differences between the two, as shown in Figure 2). To date, the value of the United States as an exporting country for shelled almonds is so high that it has no significant competitors; whereas, the value of imports is universally distributed with some differences between countries, with Germany and Spain dominating. Spain, for example, continues to import almonds from other countries, despite its considerable domestic production, a sign of the great use and value of the almond product (Fig. 3).

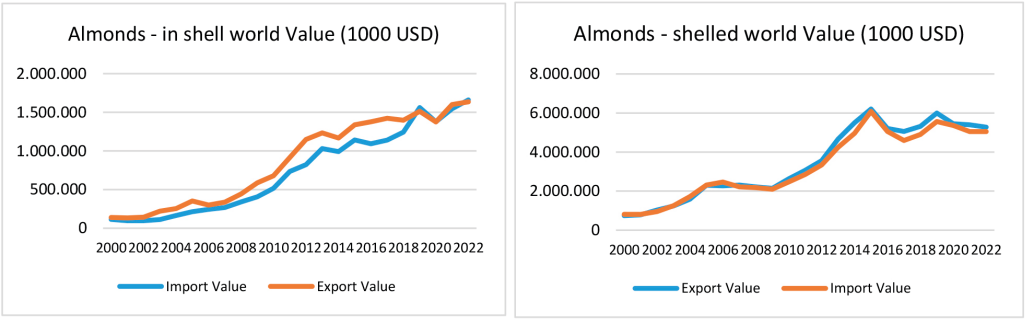


Fig. 2. Import-export value trends for in-shell and shelled almonds.

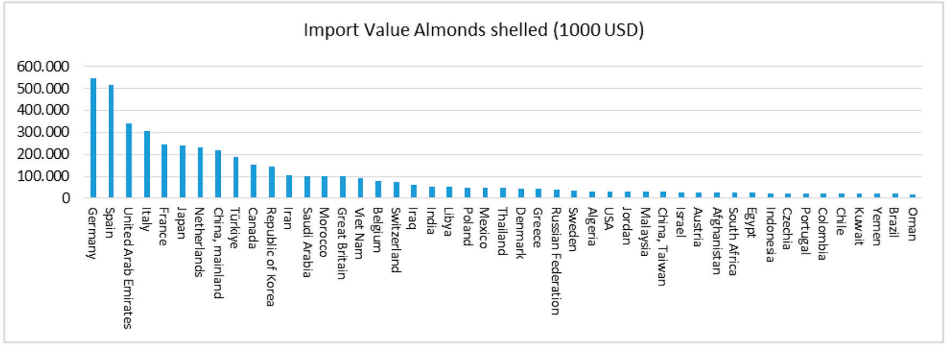


Fig. 3. Main importers and exporters of shelled almonds in the world.



Fig. 3. (cont). Main exporters of shelled almonds in the world.

II – Plant material catalogue

1. Germplasm repositories & Reference collections − Modern cultivar collections

In **France**, the INRAE collection started in 1951 and by 1974 had already brought together some 600 introductions representing 400 cultivars of all origins.

In **Spain**, collections were started in several centres. At the Mas de Bover centre of IRTA (Institute Recherche Technologic Alimentaria in Reus, the first work on almond trees carried out dates back to 1965. In Zaragoza, in 1966, INIA (National Institute of Agricultural Research) began to build up a collection which was continued by CITA (Agri-Food Research and Technology Centre of Aragon), has brought together some 160 commercial cultivars from among the most important in the main producing countries. This collection was the base to initiate the first breeding program on almonds in 1974. In Murcia, the CEBAS (Centro de Edafología y Biología Aplicada del Segura), belonging to the CSIC (Spanish National Research Council), began in 1971 with the prospecting of plant material cultivated in the Murcia region (Felipe *et al.*, 2022).

In **Italy**, The University of Catania has guaranteed the conservation of Sicilian biodiversity through the replication, in its experimental fields, of Sicilian accessions preserved in the 'Museo vivente del mandorlo Francesco Monastra' in Agrigento, Sicily. To date, the germplasm collection consists of 123 Sicilian accessions (selected for centuries for their agronomic characteristics of interest, such as quality, resistance to stresses, shell hardness, etc.), 9 international varieties (from Russia, Ukraine, Spain, France and USA) and 8 nationals (Apulian). All collection-related parameters such as origin, seed weight and size, shell texture, percentage of double seeds and others are described in the work of Di Guardo *et al.*, (2021).

Other countries like Greece, Portugal, Tunisia, Morocco, etc., also have more or less extensive collections depending on their needs and interests.

Based on the knowledge acquired in each centre by observing the behaviour of the cultivars present in these varietal collections, selection and improvement programmes have been developed, the objectives of which vary according to the situations and climates as well as the agronomic and commercial needs of the countries and regions concerned. The entry into the market of new cultivars with desirable characteristics is leading to the abandonment of old local varieties, which are giving way to new ones. It is therefore of interest to keep the best local varieties, which may be of genetic interest, in germplasm banks for possible future use.

For centuries, almond production has been based on local cultivars and landraces adapted to the specific geographical and ecological conditions of each growing region. However, in the last century, the newly released late-blooming, self-compatible, high fruit quality commercial cultivars, rapidly replaced this rich diversity in basically all the growing regions, which resulted in a drastic genetic erosion in the cultivated almond diversity worldwide, specially emphasized by the fact that most modern almond breeding cultivars share a very narrow genetic base (Pérez de los Cobos *et al*., 2021). Many germplasm collections which had previously been created, thanks to

Table 2. Almond germplasm collection maintained by the main research institutions

Acronym	Oficial name	Institution	Institution Address	Collection address	Total number of accessions	Unique material per collection	Available cultivars in nuerseries
CITA	ESP110	Centro de Investigación y Tecnología Agroalimentaria de Aragón	Avda Montañana 930 50059 Zaragoza	Avda Montañana 930 50059 Zaragoza	198	129	8
IRTA-Mas Bové	ESP014	Institut de Recerca i Tecnologia agroalimentàries	Torre Marimon. 08140 Caldes de Montbui (Spain)	Mas Bové. 43120 Constantí (Spain)	99	39	6
CEBAS	ESP207	Centro de Edafología del Segura	C. Campus Universitario, 3A, 30100 Murcia	Santomera 3014 Murcia	97	43	5
IRFAP	ESP200	Institut de Recerca i Formació Agroalimentaria i Pesquera de les Illes Balears	Eusebio Estada, 145, 07009, Palma, Baleares, España	Diseminado Son Real, 158, 07459 Santa Margalida, Illes Balears	68	58	0
				TOTAL SPAIN	**462**	**269**	
INRAE	FRA011	Inst. nat. de recherche pour l'agriculture, l'alimentation et l'environnement	84140 Avignon, France	2100 Rte de Sorgues, 84230 Châteauneuf-du-Pape, France	100		1
U CATANIA	ITA331	University of Catania	Via Valdisavoia 5 951323 Catania	Via Valdisavoia 5 951323 Catania	140		
IO-INRAT-CRRA	TUN001	L'Institut de l'Olivier/ Institut National de Recherche Agronomique de Tunisie / Centre Régional de Recherche Agronomique de Sidi Bouzid	Rue Hédi Karray, CP 1004 Menzah 1 Tunisie	Central Tunisia (Sfax region)/ Northern Tunisia (Mornag region)/ Central Tunisia (Sidi Bouzid region)	49		
ENAM	MAR059	École Nationale d'Agriculture de Meknès	Meknes, Morocco	Meknès, BP S/40, Morocco	24		
				TOTAL MED	**313**		
					775	**269**	**20**

the awareness of the scientific community on the extreme genetic erosion taking place worldwide, benefitted from the initiative of FAO for the formation of a world network of genetic resource preservation. The first almond germplasm collection in the world was created at the end of the nineteenth century at the Nikitski Botanical Garden in Yalta (Russia) (Rikhter, 1972). Afterward, France, in the 1950s (Grasselly and Crossa-Raynaud, 1980), Italy and Spain in the 1960s (de Giorgio and Polnigano 2001; Espiau *et al*., 2002), followed the steps of Russia in Europe. Currently, the European collection reports 978 almond accessions, preserved in 16 different countries. Italy and Spain hold 92% of the total European germplasm (EURISKO, 2022). In the African continent, the collection at INRA (Institut National de la Recherche Agronomique) in Rabat (Morocco) holds 120 cultivars, while Tunisia preserves 77 accessions at the INRAT (Institut National de la Recherche Agronomique). In Asia, where domestication appears to have primarily taken place (Kester *et al*., 1991), many orchards are still from seedlings and therefore a wider in situ diversity remains. Furthermore, there are four main ex situ collections held at the National Plant Gene Bank in Karaj (Iran), the Centre for Studies of Arid Zones (Syria), the Ege University (Turkey) and the Newe Ya'ar Research Center (Israel). Among the four of them, 260 accessions are held in the Asian continent (FAO, 2022).

2. Breeding goals and modern cultivars and rootstocks

Self-compatibility and late blooming are the main objectives of the majority of almond breeding programs (Fig. 4).

Traditionally cultivated almond cultivars are self-incompatible (meaning that plants from the same cultivar cannot fertilize each other). To overcome this, orchards growing traditional cultivars must

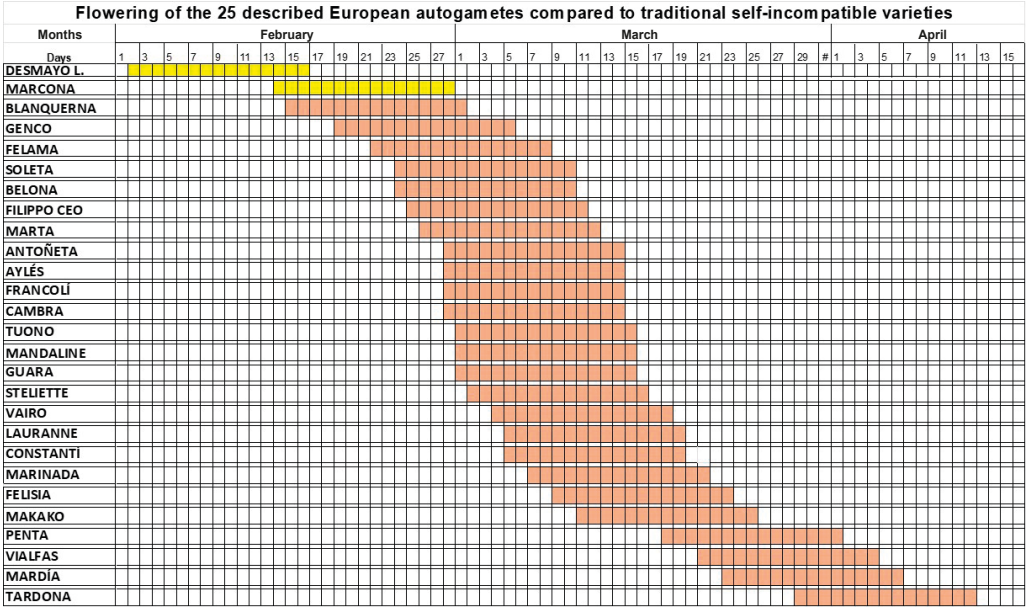


Fig.4. Mean flowering time in twenty-five European self-compatible almond cultivars (in orange) in comparison with 2 non-compatible cultivars (in yellow) available for the Mediterranean almond plant market. (Felipe *et al*., 2022).

include inter-compatible cultivars that coincide in their flowering periods and ensure the existence and activity of pollinating insects. The majority of the newly released cultivars are self-compatible which don't need pollinating neighbor cultivars. However, the presence of pollinating insects is still necessary in this case to achieve maximum yields. Once fertilization occurs and the development of the ovary is visible, the fruit is considered set and fruit, and seed growth begins.

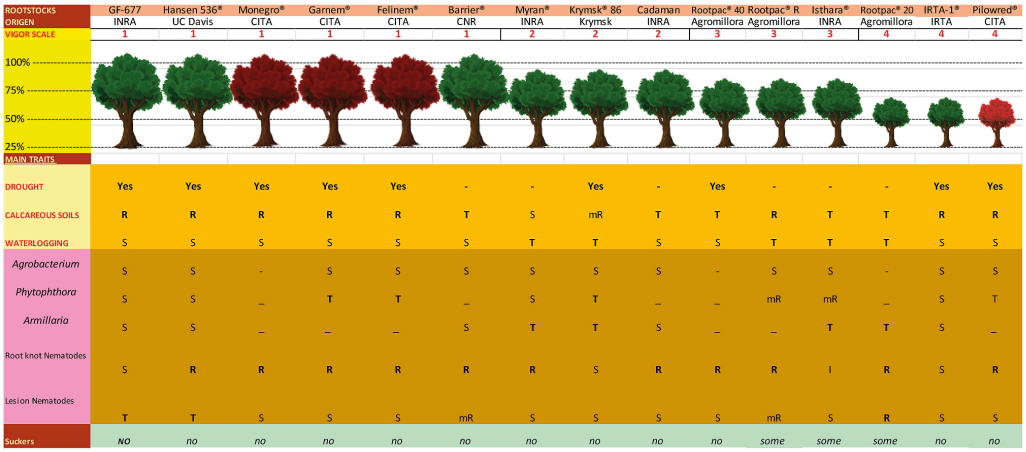
Self-compatible naturally occurring almond cultivars were found in the Italian region of Puglia, which have been widely used as sources of this trait in many breeding programs, particularly the cultivar 'Tuono' (Socias i Company, 2002). Out of the *Prunus dulcis* species, other sources of self-compatibility used for almond breeding are peach, *P. mira*, *P. davidiana*, and Yugoslavian *P. webbii* accessions (Gradziel, 2009).

Late blooming is also an important objective in Europe but has been associated with lower productivity in high-input California plantings. The main sources for the late blooming trait have been natural late-blooming almond cultivars from Puglia, and from Russian almond cultivars. Another source of the late blooming trait is the genotypes derived from the 'Tardy Nonpareil' mutant (Socias i Company *et al*., 1999). Tolerance to frost also seems transmitted from 'Tuono' to progeny (Felipe, 1988).

Resistance to various diseases has become an important objective in many breeding programs, especially since some cultivars frequently used as parentals, like 'Tuono', have high susceptibility to fungal leaf diseases. 'Ardèchoise' has been often used as a source of resistance in these cases (Grasselly, 1972).

The use of rootstocks in modern orchards is normally linked to the planting system used. Different types or systems of almond tree cultivation can be considered: traditional, intensive and super-intensive.

(i) Traditional. This has been practised with almond trees throughout history. Plantations are in areas where some of their environmental requirements appear as a limiting factor (water, type and depth of soil, nutrients, etc.), for example, on dry land, on mountain slopes and on limestone soils that are often shallow. This type of cultivation is characterised by low, alternating harvests. This was the system that was used in most Asian and Mediterranean areas.



ROOTSTOCKS	GF-677	Hansen 536®	Monegro®	Garnem®	Felinem®	Barrier®	Myran®	Krymsk® 86	Cadaman	Rootpac® 40	Rootpac® R	Isthara®	Rootpac® 20	IRTA-1®	Pilowred®
ORIGEN	INRA	UC Davis	CITA	CITA	CITA	CNR	INRA	Krymsk	INRA	Agromillora	Agromillora	INRA	Agromillora	IRTA	CITA
VIGOR SCALE	1	1	1	1	1	1	2	2	2	3	3	3	4	4	4
MAIN TRAITS															
DROUGHT	Yes	Yes	Yes	Yes	Yes	-	-	Yes	-	Yes	-	-	-	Yes	Yes
CALCAREOUS SOILS	R	R	R	R	R	T	S	mR	T	T	R	T	T	R	R
WATERLOGGING	S	S	S	S	S	S	T	T	S	S	T	T	T	S	S
Agrobacterium	S	S	-	S	S	S	S	S	S	-	S	S	-	S	S
Phytophthora	S	S	_	T	T	_	S	T	_	_	mR	mR	_	S	T
Armillaria	S	S	_	_	_	S	T	T	S	_	_	T	T	S	_
Root knot Nematodes	S	R	R	R	R	R	R	S	R	R	R	I	R	S	R
Lesion Nematodes	T	T	S	S	S	mR	S	S	S	S	mR	S	R	S	S
Suckers	NO	no	no	no	no	no	no	no	no	no	some	some	some	no	no

Fig.5. Vigor rate, biotic and abiotic traits of some commercial rootstock available in commercial nurseries (Rubio-Cabetas *et al*., 2026).

(ii) Intensive. In this system, cultivation practices aimed at maximising production are introduced, trying to eliminate all limiting factors. The soils in which the plantations are located are rich and the necessary irrigation and fertilisation as well as the appropriate phytopathological treatments are provided. The production per hectare is much higher, but so are the costs. This system is mainly practised in California and Australia. It is also used in modern plantations in the Mediterranean countries.

(iii) Super-intensive. Super-intensive or high-density plantations, which have recently been implemented in Spain using new plant material and are spreading to other producing countries, should also be considered today.

III – Research capabilities, programmes and activities on breeding

A paradigm change in almond cultivation systems has been possible by the cultivar and rootstock innovation achieved by the different almond breeding programs developed since the 20th century. The most important almond breeding programs are located in producer countries such as Spain (CITA, IRTA and CSIC-Murcia), USA (University of California and USDA), Israel (ARO), and Australia (The University of Adelaide), among others. From the beginning, the main objectives have been the increase of crop yield, the improvement of fruit quality and the reduction of production costs. These three major objectives have been worked on from different breeding approaches (Socias i Company, 1998). To reach these objectives, almond breeders focused on traits such as self-compatibility, late flowering, kernel quality, yield, biotic resistance and abiotic adaptation and tree architecture.

In the past, achievements in almond breeding programs were extended for long time, requiring more than a decade to obtain a new cultivar. Over time, the development of new molecular techniques related to genetic screening of the desirable traits, marker-assisted selection (MAS), have allowed to significantly reduce the timelines. These techniques varied from the use of quantitative trait loci (QTLs) to association mapping studies (Rubio-Cabetas *et al*., 2017; Vahdati *et al*., 2021). Recently, the advances in the molecular techniques as well as the reduction on sequencing prices have permitted new approaches in almond breeding including *de novo* sequencing of genomes. After that, it was the turn of the almond genome, sequencing the 'Lauranne' cultivar (Sánchez-Pérez *et al*., 2019) and the 'Texas' cultivar (Alioto *et al*., 2020) almost at the same time which facilitated the performance of genome wide association studies (GWAS) in almond populations (di Guardo *et al*., 2021; Pavan *et al*., 2021).

Molecular markers have been used in almond for diversity studies. The microsatellite markers (SSRs) have been obtained covering almost the whole genome of *Prunus*, and the first set of almond SSRs was published in 2004 (Testolin *et al*., 2004). More recently, single nucleotide polymorphism (SNP) markers have also been specifically applied for almond identification (Wu *et al*., 2008; Duval *et al*., 2023). Therefore, a candidate gene/QTL approach is necessary to associate major genes and QTLs involved in expression of traits of interest to structural genes in almond. The recent publication of the almond genome sequence (Alioto *et al*., 2020) has now made it possible to leverage the novel diversity found in almond.

IV – Demands and needs of producers and the industry

The strengths of Mediterranean varieties include attributes such as self-fertility, late flowering, relatively hard skin, higher fat content, and higher oleic acid content. The taste of Mediterranean almonds is considered to be superior, though this is not always a determining factor. In order to maintain these strengths, and compete with American varieties, the Spanish almond industry is looking to develop varieties that have other qualities valued by the almond processing industry, such as light skin color and a white color when peeled, as well as a good balance between protein and fatty acids. To understand how this is affecting the processing level, more research is necessary as well as to work closely with the processing industry.

Sustainability is another broad concept that is valued. Sustainability, including less water consumption, less use of chemical treatments, and proximity to the point of consumption.

At the agronomic level, the almond industry needs varieties that are productive without excessive vegetation, with low chilling hours, and resistant to fungal diseases like anthracnose, monilia, and fussicocum, especially given the limitations on active ingredients in the EU. Regional trials will be desirable before the release of a variety and the collaboration with an Almond Board will be desirable.

At the processing level, the almond sector needs varieties that are mechanically resistant, do not generate halves/chunks in the shelling and do not generate halves/pieces in the blanching. Varieties with thin skin to minimize peeling waste and light skin color to make them more attractive to consumers when consumed raw, are also needed.

The almond industry requires an additional hulling step to remove the green hull; however, this process can cause damage to the almonds during shelling and blanching. Therefore, the processing industry should be adapted to the specific requirements of certain cultivars.

In summary, qualities that the almond processing industry values include:

- Light skin color.
- White color of the peeled almond.
- Good balance between protein and fatty acids.
- A cracking or crunch when biting.
- Varieties that are mechanically resistant and do not generate halves/chunks in the shelling and do not generate halves/pieces in the blanching.

New varieties of almonds have a problematic industrial behavior, with a high percentage of halves and pieces generated, making it impossible to use them to produce certain products. The manufacturing industry needs varieties that can compete with American varieties without renouncing the attributes of Mediterranean varieties.

Table 3 summarises the main constraints, demands, needs and challenges that may drive the almond breeding programs.

Table 3. Main constraints, demands, needs and challenges for almond plant materials and breeding

Constraint	Demands/needs for almond cultivars (plants and nuts)	Challenges
Climate Change *Increasing temperature* *Water scarcity* *Agronomical behavior*	• Low-chill cultivars / rootstocks • Early harvesting • Performance in the different valleys	• Appropriate estimation methods • Avoid episode of rain in harvesting • Regional trials
Pest & Diseases *Fungal diseases* *Bacterial diseases* *Nematodes diseases*	• Identification of sources of resistant genes • Tolerant cultivars • Tolerant rootstocks	• Active ingredients in EU • Microbiome and biostimulants interactions
Industrial Aptitudes	• Avoid halves /pieces in shelling • Avoid halves /pieces in the blanching • Think and light skin • High quality kernel	• More mechanically resistant • Genetic dependence • Appropriate horticultural practices for harvesting and processing

V – Conclusions and perspectives

Currently, we have two sequenced almond genomes, in addition to the peach genome, which serve as key references. These resources facilitate the identification, characterization, and cloning of important genes of Rosaceae species. This wealth of information is already applied in scion breeding programs and has contributed to notable improvements in agronomic traits.

Nevertheless, there is a lack of studies dedicated to understanding root physiology, and the lack of standardized phenotyping remains a major hurdle in advancing genetic research in almond rootstock breeding.

A comprehensive search for candidate genes at the whole-genome level, taking advantage of the increasing transcriptome data, promises to yield fruitful results in the near future. Further efforts are necessary to refine screening methodologies timing, duration, intensity, to improve our understanding of disease resistance, tolerance to environmental factors and abiotic stresses.

Accelerating the integration of adaptive traits is hampered by the lack of advances in screening methodologies for the complex traits, compounded by limited knowledge of genetic systems. Similar challenges exist for most major agronomic traits and root adaptations to soil conditions, including drought and salinity, where progress trails behind that of annual crops. Observed differences in fruit crop performance are not only due to scion selection but also to unidentified soil limiting factors.

The almond industry needs to adapt to remain competitive. This involves addressing the industrial processing challenges of new varieties, improving harvesting practices to minimize damage, and breeding almonds that meet evolving consumer preferences, particularly regarding appearance, texture, and nutritional content. Emphasis on sustainability could also provide a competitive advantage.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Chestnut case Study

José Gomes Laranjo[1], Burak Akyüz[2], Gabriele Beccaro[3], Santiago Pereira-Lorenzo[4]

[1] CITAB|Inov4Agro, UTAD, Vila Real (Portugal)
jlaranjo@utad.pt
[2] Ondokuz Mayıs University, Samsun (Türkiye)
burak.akyuz@omu.edu.tr
[3] University of Torino, Chestnut R&D Center (Italy)
gabriele.beccaro@unito.it
[4] Universidade de Santiago de Compostela, Campus Terra, Lugo (Spain)
santiago.pereira.lorenzo@usc.es

Abstract. The CIHEAM (International Centre for Advanced Mediterranean Agronomic Studies) member countries (Albania, Algeria, Egypt, Spain, France, Greece, Italy, Lebanon, Malta, Morocco, Portugal, Tunisia and Turkey) account for 12.5 % of the world's production of chestnuts (*Castanea* sp.). Nine of the 13 CIHEAM countries are producers of this fruit. Europe is one of the most representative producing regions worldwide. Chestnut tree grows in the Mediterranean region under three types of ecosystem management: forestry (for wood), agroforestry (for wood and fruit) and agriculture (for fruit). Fruit production is supported by a great genetic biodiversity. References to 594 genotypes were found. Climate change is affecting tree growth, but research already carried out indicates that this species has good intrinsic plasticity that needs to be exploited. Many *in situ* and *ex situ* conservation programmes for genetic resources of different species, progenies, cultivars, hybrids and rootstocks are also in place in CIHEAM producer countries. Many programmes on genetic resources and chestnut improvement are active in Europe, led by research centres located in the main producing countries. Plant quality, including clonal rootstocks and new cultivars, nursery certification, improved crop management techniques, chestnut characteristics and tolerance to biotic and abiotic stresses are priorities for the future of a sector that is professionally organised in the Eurocastanea association.

Key words. *Castanea sativa* – Germplasm - Breeding – Plasticity – Interspecific hybrids – Clonal rootstocks – Cultivation systems – Biotic and abiotic stress.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne: étude de cas sur le chataignier

Résumé. *Les pays membres du CIHEAM (Centre International de Hautes Études Agronomiques Méditerranéennes, à savoir : Albanie, Algérie, Égypte, Espagne, France, Grèce, Italie, Liban, Malte, Maroc, Portugal, Tunisie et Turquie) représentent 12,5 % de la production mondiale de châtaignes (*Castanea *sp.). Neuf des treize pays du CIHEAM sont producteurs de ce fruit. L'Europe figure parmi les régions productrices les plus représentatives au niveau mondial. Le châtaignier se développe dans la région méditerranéenne selon trois types de gestion des écosystèmes: forestière (pour le bois), agroforestière (pour le bois et le fruit) et agricole (pour le fruit). La production fruitière repose sur une grande biodiversité génétique : 594 génotypes ont été recensés. Le changement climatique affecte la croissance des arbres, mais les recherches déjà menées indiquent que cette espèce possède une bonne plasticité intrinsèque qui doit être exploitée. De nombreux programmes de conservation in situ et ex situ des ressources génétiques — concernant différentes espèces, descendances, cultivars, hybrides et porte-greffes — sont également en place dans les pays producteurs membres du CIHEAM. En Europe, plusieurs programmes dédiés aux ressources génétiques et à l'amélioration du châtaignier sont actifs, sous la conduite de centres de recherche situés dans les principaux pays producteurs. La qualité des plants, y compris les porte-greffes clonaux et les nouveaux cultivars, la certification des pépinières, l'amélioration des techniques culturales, les caractéristiques des châtaignes ainsi que la tolérance aux stress biotiques et abiotiques constituent des priorités pour l'avenir d'un secteur professionnellement structuré au sein de l'association Eurocastanea.*

Mots clés. Castanea sativa – *Matériel génétique – Sélection – Plasticité – Hybrides interspécifiques – Porte-greffes clonaux – Systèmes de culture – Stress biotiques et abiotiques.*

I – Introduction

1. Main grown species and ecology

The genus *Castanea* is divided into three sections: *Eucastanon* (5 species), *Balanocastanon* (7 species), and *Hypocastanon* (1 species). The first section includes the most representative species and those of greatest economic interest (Mellano *et al*., 2012; Pereira-Lorenzo *et al*., 2012). The species grouped in section *Eucastanon*, whose burr contains three chestnuts, are (from most to least vigorous): *C. dentata* (Marsh.) Brokh. (North America), *C. sativa* Mill. (Europe), *C. crenata* Sieb. (Japan), *C. mollissima* BL.(China), and *C. seguinii* Dode (China), each with varying economic importance in their respective regions and influenced by human colonization.

Despite the Mediterranean region encompass countries from Europe, Asia, and Africa, *C. sativa* is almost exclusively the cultivated species in chestnut stands. However, the introduction of *C. crenata* and *C. mollissima* in Europe during the first half of the 20th century, as part of breeding programs aimed at developing genotypes resistant to *Phytophthora* spp., has led to the cultivation of hybrid genotypes with significant expression. These hybrids are grown both as direct fruit/timber producers and as rootstocks.

According to Mattioni *et al*., (2017), there are two main genetic pools in Europe: the West and the East (subdivided into East and Central sub-pools). The West pool was influenced by both natural and anthropogenic dispersion (notably by the Roman Empire) from Italy to the Iberian Peninsula, resulting in significant genetic similarities (Pereira-Lorenzo *et al*., 2019).

Castanea is a Mediterranean genus (Fig 1.), thriving in regions with Humid and Pré-Atlantic bioclimates, corresponding to the environmental zones of Anatolian, Lusitanian Mediterranean Mountains, and Mediterranean North (Metzger *et al*., 2005). This range of ecological sites demonstrates the species' considerable plasticity, which is advantageous for breeding programs aimed at improving adaptation in the context of climate change.

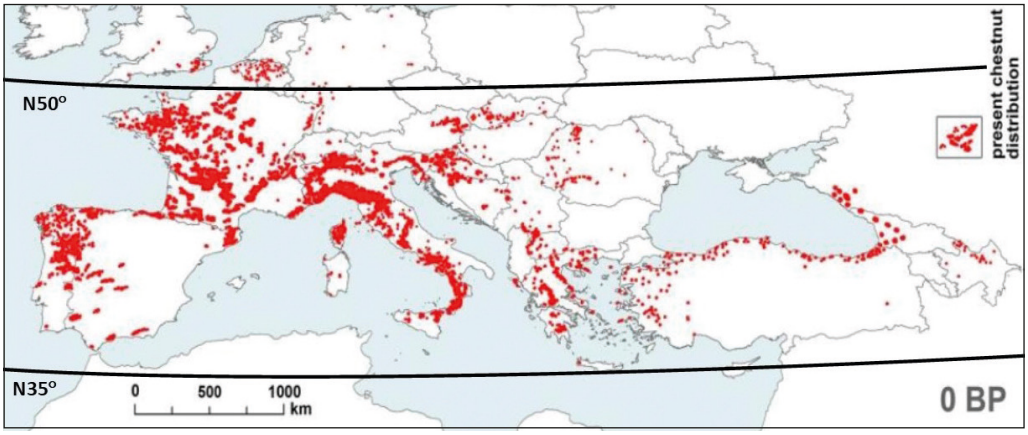


Fig. 1. Distribution of *Castanea sativa* in Europe. Source: Adapted from Pereira Lorenzo *et al*., 2012.

2. Main producing countries

World production is estimated at 2.1 million tonnes per year, with 99% of this production occurring in the Northern Hemisphere. Asia is the largest producer globally, accounting for 85% of the total, while Europe contributes 14.3% (298,000 tonnes per year) of the world's production (Gomes-Laranjo *et al*., 2024). This output is insufficient to meet the demand for fresh consumption and the 70,000 tonnes required annually by the European industry (Bellat and Dasque, 2019). The CIHEAM countries (Albania, Algeria, Egypt, Spain, France, Greece, Italy, Lebanon, Malta, Morocco, Portugal, Tunisia and Turkey) represent 12.5% of global production. Besides China, which is the largest producer worldwide (1.7 million tonnes per year), Turkey is the leading producer in Europe and among the CIHEAM countries (Table 1). Within CIHEAM, European countries account for more than 99% of chestnut production. There is also some chestnut production in other Mediterranean countries such as Croatia, Bosnia and Herzegovina, North Macedonia or Slvenia.

Table 1. Annual production (average 2017-2022) per CIHEAM[1] country. No reports were found for CIHEAM countries not appearing in the table. Source: FAOstat, 2022

Nº.	Country	2017-2022 (t)	(%)
1	Türkiye	72,586	27.8
2	Spain	62,946	24.1
3	Italy	40,070	15.4
4	Greece	35,094	13.5
5	Portugal	34,546	13.2
6	France	9,138	3.5
7	Albania	5,893	2.26
8	Lebanon	470	0.18
9	Morocco	100	0.04
	Total	**260,842**	**100.0**

[1] CIHEAM member countries: Albania, Algeria, Egypt, Spain, France, Greece, Italy, Lebanon, Malta, Morocco, Portugal, Tunisia and Turkey.

3. Representative cultivation systems

Chestnut is primarily cultivated under three different ecosystem types: forest, agroforest, and agro (Fig. 1). The forest system is the most prevalent in Europe, covering approximately 2 million ha, while the agroforest and agro systems together occupy around 300,000 ha. The forest system is more common in central Europe, Atlantic France and Britain; agroforest and agro systems are most frequent in the Mediterranean areas of distribution f chestnut.

Forest system

This system is primarily aimed at timber production, with secondary outputs including edible fungi and honey. Additionally, this ecosystem plays a crucial role in slope protection against natural hazards in hilly areas and supports wildlife habitats, particularly through the provision of small fruits. Landscape and recreational benefits are also significant externalities of this ecosystem. Forest stands dominated by chestnut trees are typically managed as high coppice forests, with

tree felling occurring every 40-50 years, or as coppice forests, with tree felling every 6-10 years, maintaining high tree densities (more than 1,000 trees per ha).

Agroforest system

This traditional system, used since the Roman Empire, is designed to produce both fruit and timber, while also promoting the production of edible fungi and honey. It is characterized by an irregular and low-density distribution of trees (less than 100 trees per ha). The trees are typically large and centuries-old, often exceeding 20 meters in height, with trunks measuring between 2 and 3 meters in circumference. Most of these trees are grafted with the oldest varieties, such as 'Longal' in the Iberian Peninsula. This system requires minimal human intervention and mechanization is infrequent. Consequently, it yields low to medium fruit production levels, typically less than 2 t per ha.

Agro system

This system is exclusively aimed at fruit production. It includes modern orchards with a regular and high-density distribution, typically exceeding 120 trees per ha. The trees are relatively young, generally less than a century old. They are usually grafted, predominantly using hybrid rootstocks instead of *C. sativa* ones. While the varieties are mainly from *C. sativa*, precocious hybrid varieties are increasingly being used in the main producing countries. This system is characterized by continuous human agricultural intervention, facilitating the introduction of mechanization. High yields are achieved, depending on the variety and edaphoclimatic conditions, ranging from 2 to 8 t per ha.



Fig. 1. The three chestnut ecosystems managed by humans: Forest (left), agroforest (centre) and agro (right).

II – Plant Material Catalogue

1. Germplasm repositories & Reference collections − Modern cultivar collections

In **Europe**, 27 countries produce chestnuts. The countries with the highest production are Türkiye, Spain, Italy, Greece, Portugal, Germany, and France (FAOSTAT, 2022). In these countries, the European chestnut (*Castanea sativa*) is naturally grown. However, due to the adverse effects of pests and diseases, other species (*C. crenata* and *C. mollissima*) and their hybrids have been introduced to Europe.

There are 594 registered cultivars and rootstocks in Europe. Of these, 527 are registered as cultivars, 62 as rootstocks, and 5 as both cultivars and rootstocks (Table 2).

Table 2. Registered cultivars and rootstocks according to the country of origin

Country of Origin	Species	Cultivars	Rootstock
Italy	*C. sativa*	231	-
	C. sativa x C. crenata	1	-
	C. crenata x C. sativa	1	-
Spain	*C. sativa*	174	22
	C. sativa x C. crenata	-	11
Portugal	*C. sativa*	40	7
	C. crenata	-	1
	C. sativa x C. crenata	1	1*
France	*C. sativa*	26	1
	C. crenata	2	-
	C. mollissima	-	3
	C. sativa x C. crenata	5	9*
	C. crenata x C. sativa	6	10**
Türkiye	*C. sativa*	21	1
	C. sativa x C. crenata	1	-
	C. crenata x C. sativa	1	1*
	C. mollissima x *C. seguine* X *C. crenata* x *C. sativa* x *C. dentata*	3	1*
Romania	*C. sativa*	7	-
Greece	*C. sativa*	5	-
Australia	*C. sativa*	4	-
Switzerland	*C. sativa*	3	-
Total	**532**	**67**	

* 1 of the was counted as both cultivar and rootstock.
** 2 of the was counted as both cultivar and rootstock.

Italy is the leading country in terms of registered cultivars, with 233. Nearly all the cultivars belong to the *C. sativa* species, including “Chestnut type” and “Marrone type” cultivars, the latest being most valued for high-quality traits such as easy peeling and excellent texture. Some important cultivars in Italy are ‘Madonna’, ‘Precoce di Brignola’, ‘Pelosa’, ‘Gabbiana’, ‘Garrone Rosso’, ‘Bracalla’, and ‘Marrone di Chiusa Pesio’.

In **Spain**, 174 cultivars have been described, with 27 registered in the national register of commercial varieties. Most cultivars are “Marrone type” and belong to the *C. sativa* species. The Protected Geographical Indication (PGI) ‘Castaña de Galicia’ includes all Galician cultivars (over 80).

Portugal has 41 characterized cultivars, including 22 registered in the National Catalogue of Cultivars and 4 with Protected Designation of Origin (PDO). The main cultivars produced in Portugal are ‘Longal’, ‘Judia’, ‘Martainha’, and ‘Baria’.

Türkiye has 26 registered cultivars in the National Catalogue of Cultivars, most of which belong to the European chestnut (*C. sativa*). In the 1990s, the breeding program focused on cultivars

suitable for fresh consumption and the chestnut candy industry. However, in recent years, most cultivars have been registered for their resistance to pests and diseases. To this end, Türkiye has focused on obtaining hybrid cultivars, some of which were imported from different European countries, while others were developed through controlled breeding programs.

France is divided into two regions, the Southwest and the PDO Ardèche regions. In France, there are 39 cultivars belonging to different species. In the Southwest region, hybrid cultivars are predominantly preferred. France is a pioneer in hybrid chestnut breeding programs, which have produced *C. crenata* x *C. sativa* and *C. sativa* x *C. crenata* hybrids. The popular cultivars from this program include 'Marigoule', 'Bouche de Bétizac', and 'Marsol'. These hybrids are very popular and widespread throughout Europe.

Other European countries also have registered local *C. sativa* cultivars: Romania has 7, Greece has 5 ('Volos' and 'Cretan' among them), Austria has 4, and Switzerland has 3.

Countries in other regions of the world maintain important number of cultivars of different species of *Castanea* (*mollissima, henry, crenata, sativa*) or hybrids: Japan, China, USA, South Korea and Australia in order of importance. But of these countries, only Australia (4) and the USA (3) have *C. sativa* cultivars.

Rootstock breeding studies are rare in nut crops due to the limitations of clonal production. In chestnuts, adventitious rooting capacity is particularly low. While clonal propagation methods can be used for chestnuts, they are highly dependent on the genotype or cultivar. In **Europe**, 67 cultivars are registered as rootstocks; however, only 22 of these can be clonally propagated, and they are generally local and not widespread. The 'Marsol' cultivar is the only one recognized as a worldwide rootstock. Breeders focus on traits such as tolerance to ink disease, reduced vigor, climate adaptation, ease of propagation, and graft compatibility with *C. sativa* cultivars.

There are 32 germplasm collection orchards in **Europe**: 8 in Portugal, 5 in Spain, 5 in Italy, 4 in Türkiye, 3 in France, 2 in Greece, and 1 each in Slovakia, Romania, Hungary, Switzerland, and Georgia. These orchards contain *C. sativa*, *C. crenata*, *C. mollissima* cultivars, and their hybrids, maintained for breeding purposes and future studies.

The propagation capacity of a cultivar or rootstock is crucial for commercialization. Some cultivars exhibit high graft incompatibility with rootstocks, making them less preferred by producers. As previously mentioned, there is a strong demand for clonal chestnut rootstocks, but many bottlenecks exist in the clonal propagation of chestnut plants. These issues limit commercialization capacity, resulting in local cultivars being more common. Each country has its own commercialized cultivars, with only French *C. sativa* x *C. crenata* hybrid cultivars like 'Marsol', 'Marigoule', and 'Bouche de Bétizac' being widely available across Europe. 'Bouche de Bétizac' is popular for its resistance to the Asian chestnut gall wasp, while 'Marsol' is valued for its tolerance to ink disease and good graft compatibility with *C. sativa*.

III – Research capabilities, programmes and activities

1. Genetic resources and breeding

In Europe, a total of 519 and 55 rootstocks are being conserved *in situ* and/or *ex situ* (Table 3), which have been selected or bred over the last 100 years.

Table 3. Species, hybrids, cultivars and rootstocks conserved in Europe

Country	No. of Cultivars	No. of Rootstocks	Species and hybrids
France	26		*C. sativa*
France	11	19	Hybrid
France	2		*C. crenata*
France		3	*C. mollissima*
Greece	5		*C. sativa*
Italy	231		*C. sativa*
Italy	2		Hybrid
Portugal	41		*C. sativa*
Portugal	1	1	Hybrid
Romania	7		*C. sativa*
Spain	175		*C. sativa*
Spain		31	Hybrid
Switzerland	3		*C. sativa*
Türkiye	20		*C. sativa*
Türkiye	5	1	Hybrid
Total	**519**	**55**	

A total of 14 European countries (Table 4) have programs on chestnut genetic resources and breeding, involving up to 23 research institutions, universities, and public administrations. Research activities include:

- The *in situ* and *ex situ* conservation of genetic resources of different species, progenies, cultivars, hybrids, and rootstocks.
- Phenotypic characterization.
- Molecular evaluation. Most genetic tools are utilized. Some genetic maps have already been published.
- Breeding activities aimed at obtaining new rootstocks and cultivars, such as developing crosses for disease resistance and tolerance to high temperatures. Genetic transformation is already utilized as a breeding tool.

Table 4. Countries and institutions conserving genetic resources of chestnut in the Mediterranean area

Country	Organism	Website/Reference	Type of material	Type of conservation/ characterisation
France	**1.** INRAE Chestnut Germplasm Collection in Villenave d'Ornon, Bordeaux, France **2.** INRAE Cestas **3.** INRAE Bourran (INRAE : National Research Institute for Agriculture, Food and Environment)	**1.** doi.org/10.1007/s13595-021-01104-w **1, 2 and 3.** www.inrae.fr	**1.** Two experimental plots of 29 and 215 chestnut trees from three species: the European chestnut (*Castanea sativa*), the Japanese chestnut (*Castanea crenata*), and the Chinese chestnut (*Castanea mollissima*), as well as their hybrids **2.** Two interspecific crosses, maintained as rootstocks **3.** Di-allel trial involving *C.sativa*, *C. crenata* and *C. mollissima* parents	*Ex situ*. Phenotypic characterisation, SSRs, SNPs
Georgia	Scientific - research Centre of Agriculture of Georgia	https://srca.gov.ge/en/	Anaseuli (Naruja). Collection of cultivars	
Greece	Aristotle University of Thessaloniki	https://doi.org/10.17660/ActaHortic.2010.866.24	Taxiarchis and Arnea: Combined provenance-progeny test consisting of six range-wide European provenances and 143 open pollinated families of *Castanea sativa*	*Ex situ*. Phenotypic and genotypic characterisation
Hungary	Institute of Plant Protection University of Debrecen	https://mek.unideb.hu/en/institute-plant-protection	Kadarkut. Cultivar collection of chestnut species.	*Ex situ.*
Italy	**1.** Chestnut R&D National Center; Univ. Torino, Chiusa Pesio, Cuneo Province **2.** Institute of Agro Environmental and Forest Biology - National Research Council (CNR-IBAF). **3.** ARSAC Calabria Sersale (CZ) **4.** Granaglione Univ. Bologna (BO)	**1.** www.centrocastanicoltura.org DOI 10.1007/s10722-012-9794-x **4.** https://centrobiodiversita-castagnetogranaglione.it/	**1.** Chestnut R&D National Center in Chiusa Pesio: seedlings, hybrids, cultivars. More than 350 Castanea spp. grafted trees. Several European ecotypes and cultivars from Italy, Portugal, Spain (including the Canary Islands), France and Switzerland, and accessions from the USA, China, and Japan. The collection also includes 5 Castanea species (C. sativa, C. mollissima, C. dentata, C. crenata, C. pumila), 17 Euro-Japanese hybrids (C. sativa × C. crenata) obtained from different countries. Interspecific progeny 'Bouche de Bétizac' (*C.sativa* x *C. crenata*) x 'Madonna' (*C. sativa*), **2.** Porano. F1 intraspecific *C. sativa* mapping progeny	*Ex situ*. Phenotypic characterisation, genotypic characterisation. Basic materials conservation in screenhouse according to EU nursery certification process
Portugal	**1.** University of Trás-os-Montes and Alto Douro (UTAD). **2.** Polytechnic Institute of Bragança **3.** Colónia Agrícola Martim Rei. Sabugal Municipality **4.** Ministry of Agriculture **5.** Instituto Nacional de Investigação Agrária e Veterinária (INIA-V) **6.** Trancoso Municipality	1 www.utad.pt 2.portal3.ipb.pt	**1.** Quinta de Prados, Vila Real. 26 cultivars and 20 genotypes of rootstock Colutad F2. **1.** Torgueda, Vila Real. 10 genotypes of Judia cultivar and hybrid rootstocks. **2.** Bragança. Progenies obtained from controlled crosses between *C. sativa* x *C. crenata* and *C. sativa* x *C. mollissima*. **3.** Martim Rei. Collection of 10 Portuguese varieties, 9 French varieties. **4.** Viseu. Collection of 15 Portuguese varieties. **4.** Felgueiras. Collection of Portuguese varieties **5.** F1 progenies obtained from controlled crosses between *C. sativa* x *C. crenata* and *C. sativa* x *C. mollissima.* **6.** Martainha variety grafted on different Hybrid rootstocks. *150 accessions*	*Ex situ*. Phenotypic characterisation, genotypic characterisation

Table 4. (cont.) Countries and institutions conserving genetic resources of chestnut in the Mediterranean area

Country	Organism	Website/Reference	Type of material	Type of conservation/ characterisation
Romania	University of Craiova	www.ucv.ro https://biozoojournals.ro/swjhbe/v4n2/02_swjhbe_v4n2_Manthos.pdf	Vâlcea. Collection of cultivars From Epirus and Oltenia areas, 48 genotypes were selected to be introduced into germplasm collections.	Phenotypic and phenological evaluation of the trees, and biochemical characterization of fruits.
Slovakia	Institute of Forest Ecology, Slovak Academy of Sciences	https://onlinelibrary.wiley.com/doi/10.1111/efp.12439	Chestnut Orchard Príbelce. Collection of grafts and seedlings derived from *C. sativa* and *C. sativa* x *C. crenata* of home origin and seedlings of *C. crenata* of foreign origin.	Screening to blight resistance
Spain	**1.** Centro de Investigacións Forestal Lourizán (CIFL). **2.** Universidad de Córdoba **3.** Universidade de Santiago de Compostela **4.** Universidad de Extremadura. **5.** IRTA Torre Marimon. **6.** TRAGSA	**1.** Lourizan.xunta.gal/es **2.** www.uco.es **3.**www.usc.es **4.** www.uex.es **5.**https://www.irta.cat/ca/centre/irta-torre-marimon/ **6.**www.tragsa.es/es/actividad/innovacion-i-d-i/vivero-de-maceda/Paginas/default.aspx	**1.** CASTANETUM. Stands of Japanese chestnut (*Castanea crenata*) and Chinese chestnut (*Castanea mollissima*), as well as clonal banks of interspecific hybrids, primarily *C. crenata* × *C. sativa* (72), and cultivars (16). **2.** Cultivars, natural populations, hybrids. **4.** Natural populations, rootstocks. **5.** Cultivars, natural populations. **6.** Cultivars, hybrids, natural populations.	**1.** *Ex situ*, Phenotypic and genotypic characterisation. **2 and 3.** *In situ*, Phenotypic and genotypic characterisation. EU Chestnut Database. DOI 10.1007/s11295-017-1197-x
Switzerland	WSL (Swiss Federal Institute for Forest, Snow and Landscape Research) - Insubric Ecosystems Research Group	https://www.wsl.ch/en/about-wsl/organisation/research-units/community-ecology/insubric-ecosystems/	Ticino. Main chestnut fruit varieties of the southern Alps owned by the Associazione Castanicoltori della Svizzera Italiana.	
Türkiye	**1.** Ondokuz Mayıs University Ali Nihat Gökyiğit Chestnut Research Station **2.** Republic of Türkiye Ministry of Agriculture and Forestry - Black Sea Agricultural Research Institute **3.** Republic of Türkiye Ministry of Agriculture and Forestry - Atatürk Horticultural Central Research Institute **4.** Republic of Türkiye Ministry of Agriculture and Forestry - Aegean Agricultural Research Institute	**1.**https://www.tridge.com/news/ondokuz-mays-university-omu-ali-nihat-gokyigit-res **2.**https://arastirma.tarimorman.gov.tr/ktae/Sayfalar/EN/AnaSayfa.aspx **3.**https://arastirma.tarimorman.gov.tr/yalovabahce/Sayfalar/EN/Anasayfa.aspx **4.**https://arastirma.tarimorman.gov.tr/etae/Sayfalar/EN/Anasayfa.aspx	**1.** Samsun. Chinese chestnut, Japanese chestnut, American chestnut, main chestnut cuiltivars of European chestnut belong to Black Sea Region and some hybrids of mixture species **2.** Samsun. Japanese chestnut, main chestnut cultivars of European chestnut belong to Black Sea Region and some hybrids of mixture species **3.** Yalova. European chestnuts belong to Marmara Region **4.** İzmir. European chestnuts belong to Aegean Region	*Ex situ*. Phenotypic characterisation, genotypic characterisation

Main techniques and methodologies used recently include SSRs, SNPs, genomes, QTLs, genetic transformation, and metabolomics and transcription techniques (Table 5).

Table 5. Main techniques and technologies applied in the genetic improvement on chestnut

Countries	Technique/ technology	Genetic improvement	References
Spain, Italy, France, Portugal	SSRs (EU Database).	EU Chestnut Database	DOI 10.1007/s11295-017-1197-x
France	SNPs	An intensive study plot to investigate chestnut tree reproduction	Single Nucleotide Polymorphism markers (SNPs) using Agena MassARRAY Platform (Larue *et al*., 2021b). doi.org/10.1007/s13595-021-01104-w
Italy	Genome	The de novo, chromosome-level genome assembly of the sweet chestnut (*Castanea sativa* Mill.) Cv. Marrone Di Chiusa Pesio	s12863-024-01245-7.pdf
USA	QTLs	Identifying Host Resistance to *Phytophthora cinnamomi* in Hybrid Progeny of Castanea dentata and *Castanea mollissima*	hortsci-article-p221.pdf
USA, Portugal, Spain	Genetic transformation	A tool for pathogen control	https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2022.951844/full
China	Metabolomics and transcription techniques	Main Floral Volatile Compounds and Key Regulatory Genes of *Castanea mollissima*	10.3390/plants13202865

As indicated in Tables 3, 4 and 5, the EU addresses breeding and genetic resources conservation programs at regional, national, and European levels. However, these programs could benefit from enhanced coordination and increased funding.

In Europe, there are 11 Protected Designations of Origin (PDO) and 11 Protected Geographical Indications (PGI) as indicated in Table 6.

Table 6. Chestnut Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI) in EU and protected figures in Türkiye

Country	Name	Main varieties
Italy	POD Castagna di Vallerano	
	POD Marrone di Caprese Michelangelo	
	POD Marrone di San Zeno	
	IGP Castagna Cuneo	Garrone rosso, Garrone nero, Frattona, Gabiana, Marrone di Chiusa Pesio
	IGP Castagna Monte Amiata	
	IGP Castagna di Montella	
	IGP Marrone della Val di Susa	
	IGP Marrone del Mugello	
	IGP Marrone di Castel del Rio	
	IGP Marrone di Cobai	
	IGP Marrone di Monfenera	
	IGP Marrone di Roccadaspide	
	IGP Marrone di Serino/Castagna di serino	
Portugal	POD Castanha da Terra Fria	Longal, Judia, Boaventura
	POD Castanha da Padrela	Judia
	POD Castanha Soutos da Lapa	Martaínha
	POD Castanha Portalegre Marvão	Baria, Colarinha
Spain	IGP Castaña de Galicia	All Galician cultivars (over 80)
Türkiye	Aydın Kestanesi	All Aegean cultivars
	Bursa Kestanesi	Cultivars from Bursa
	Buldan Kestanesi	-
	Düzce Kestanesi	-
	Kastamonu Kuzu Kestanesi	-
	Simav Kestanesi	-
	Çakıl Kestanesi	-
	İnebolu Kuzu Kestanesi	-

2. Other research centres, networks and projects. Collaboration projects with the industry

Other research centres and networks are working on chestnut, at national or European level, focusing not only in genetics and breeding and in some cases in direct collaboration with the industry. Table 7 lists some of them, while in the following paragraphs we describe some cases at European level, in Italy and in Turkey.

EUROCASTANEA (www.eurocastanea.org) is an association founded in 2024 which derived from the European chestnut network created in 2010 by1 AREFLH (Assembly of the European Regions producing Fruit, Vegetables and Ornamental plant). The founding members are national or regional producer organizations from 6 countries: France, Portugal, Spain, Italy, Austria, Greece. The main goal of EUROCASTANEA is to promote dialogue, collaboration and networking among the organizations that make up the European chestnut production. It represents, defends and promotes the common interests of the European chestnut production, it contributes to the

development of the European chestnut orchards and works on the promotion of the European chestnut consumption.

In Italy, the National Chestnut R&D Center is the Italian reference centre for chestnut research, and joins public bodies, as well as industry and stakeholders (www.centrocastanicoltura.org). The main activities of the Center are aimed at providing scientific and technical answers to chestnut growers and industry, as well to the chestnut nursery sector. The Center was recognized by the Italian Ministry of Agriculture as the reference Center for the conservation and pre-multiplication of chestnut cultivars, leading to the production of basic plants essential for the European nurseries for the production of certified chestnut trees according to the European voluntary certification standards.

In Türkiye, universities and agricultural research institutes work on chestnuts. In the black sea region, the Ali Nihat Gökyiğit research station is dedicated only to chestnut studies. The Ali Nihat Gökyiğit Research Station was established in 2010 to preserve chestnut genetic resources and conduct comprehensive research on cultivars and rootstock breeding. Since its establishment, selection, hybridization, and adaptation studies have been conducted. These efforts have led to the registration of complex hybrid cultivars 'Akyüz,' 'Macit 55,' and 'Ali Nihat.' The station focuses on developing late-maturing and disease-resistant cultivars, rootstock breeding, and clonal propagation. Additionally, projects have been conducted to determine the adaptation abilities of different chestnut species and to conserve genetic resources. The station aims to contribute to more efficient and resilient chestnut production in the Black Sea Region. Also, there are research areas at Bursa Uludag University and Aydın Adnan Menderes University. Recently, Republic of Türkiye Ministry of Agriculture and Forestry Fig Research Institute joined as representing the ministry.

Some relevant European research projects in chestnut are the following:

- The first European chestnut (*C. sativa*) genome. The *de novo*, chromosome-level genome assembly of the sweet chestnut (*Castanea sativa* Mill.) Cv. Marrone Di Chiusa Pesio (4 https://doi.org/10.1186/s12863-024-01245-7). Crowdfunding "Accordo di Ricerca e Cooperazione tecnologica: European Chestnut Genome: Chest-Gen. (2022). AM, PP and CM acknowledge funding support from the European Union–NextGenerationEU.

- LIFE FAGESOS. LIFE21-CCA-IT-LIFE FAGESOS (2022-2026). *Phytophthora*-induced decline of *Fagaceae* ecosystems in Southern Europe exacerbated by climate change: preserving ecosystem services through improved integrated pest management. The development, validation, implementation and dissemination of Integrated Pest Management (IPM) protocols, tailored to the specific target ecosystem, including a strictly scheduled use of new biomolecules and microorganisms with proven efficacy.

- Cascade. EC-EVK2-CT1999-00065 1999/2003: Securing gene conservation, adaptive, breeding potential and utilization of a model multipurpose tree species (*Castanea sativa* Mill.) in a dynamic environment.

- INTERREG VALODOC – The project Interreg Italy-France aims to promote the development of chestnut growers' skills, through specific information and awareness programs in the area, concerning the technical, cultural and regulatory aspects related to the cultivation of the product and the subsequent phases of its management, from the organization of the supply chain to its competitive presence on the market. https://www.interreg-alcotra.eu/it/valodoc-valorizzazione-e-organizzazione-degli-operatori-della-castanicoltura

Other programmes and scientific networks beyond Europe:

- In USA, on-farm evaluation and *in situ* conservation is a new way to focus chestnut improvement In the USA, on-farm evaluation and *in situ* conservation represent innovative approaches to advancing chestnut improvement (10.17660/ActaHortic.2024.1400.33). Chestnut growers in the eastern USA generally favour seedlings over clonally propagated trees due to limited commercial micropropagation of superior *Castanea mollissima* cultivars and reports of graft failure. These limitations are expected to be resolved as chestnut research progresses. Meanwhile, growers continue to establish seedling orchards. The grafted research orchards at the University of Missouri Horticulture and Agroforestry Research Center (HARC) have become the main seed source for the eastern US chestnut nursery industry. Over the past two decades, the distribution of germplasm to hundreds of growers has enabled large-scale, decentralized evaluations of grower selections across diverse environments. In 2020, over 7,000 offspring from more than 20 half-sibling families of *C. mollissima* or complex hybrid cultivars from HARC research orchards were in cultivation throughout the eastern USA. From 2020-2022, 471 elite selections from 12 states were evaluated for 35 traits relevant to commercial production.

- The International Society for Horticultural Science (ISHS) maintains a Working Group on Chestnuts (https://www.ishs.org/chestnuts) to facilitate collaboration among researchers and stakeholders interested in this crop. The VII International Chestnut Symposium (https://www.ishs.org/ishs-book/1400) was recently held, and preparations for the next one are underway (https://www.ishs.org/symposium/850).

Table 7. Main research centers and networks working on chestnut in Europe

Country	Name	Webpage	Competences
Europe	EUROCASTANEA	www.eurocastanea.org	Promote dialogue, collaboration, and networking among European organizations
France	INRAE - l'Institut national de recherche pour l'agriculture, l'alimentation et l'environnement	www.inrae.fr	Research on genetics, breeding, pathology, and pollination
	CTIFL - Centre Technique Interprofessionnel des Fruits et Légumes	www.ctifl.fr	Applied research to help professionals meet the challenges of sustainable production and consumer satisfaction
Greece	Forest Research Institute, N.AG. RE.F. - National Agricultural Research Foundation	www.fri.gr/index.php?lang=en	Integrated Pest Management
	Aristotle University of Thessaloniki. Tree Genetics & Breeding Lab	www.auth.gr/en/	Genetics and Genomics of Forest and Fruit Trees, Epigenetics, Classical and Molecular Breeding of Forest and Fruit Trees, Population & Conservation Genetics
Italy	National Chestnut R&D Center	www.centrocastanicoltura.org	Provide scientific and technical support to chestnut growers, industry, and the nursery sector
	University of Tuscia - Forest Pathology and Mycology Laboratory	www.unitus.it/en/departments/dibaf/	Development of new plant pathogens detection methods, including next generation sequencing approaches, development of control strategies and monitoring
	CNR - National Research Council	www.cnr.it/en	Plant pathology, chestnut ecophysiology
Portugal	CITAB - Centre for the Research and Technology of Agro-Environmental and Biological Sciences	www.citab.utad.pt/	Research on plant breeding, plant pathology, technical inputs to improve production and industry, soil microbiology, Chestnut ecophysiology
	CIMO- Mountain Research Center	cimo.ipb.pt/	Research on plant pathology, carbon sequestration, soil microbiology
	INIAV- Instituto Nacional de Investigação Agrária e Veterinária, I. P.	www.iniav.pt/	Plant breeding, Plant pathology
Spain	USC	www.usc.es	EU Chestnut Database. DOI: 10.1007/s11295-017-1197-x
	UCO	www.uco.es	Molecular markers for water stress
	UEX	www.uex.es	Breeding for water stress
	IRTA Marimon	www.irta.cat/ca/centre/irta-torre-marimon	Selection of forest material and cultivars
	CIFL	Lourizan.xunta.gal/es	Collections of forest material, hybrids, and cultivars
	TRAGSA	www.tragsa.es/es/actividad/innovacion-i-d-i/vivero-de-maceda/Paginas/default.aspx	Propagation
Türkiye	Ondokuz Mayıs University	www.omu.edu.tr	Selection, breeding, propagation, and cultivation
	Bursa Uludağ University	www.uludag.edu.tr	Selection, breeding, propagation, and post-harvest
	Aydın Adnan Menderes University	www.adu.edu.tr	Selection, breeding, propagation, pest, and disease management
	Republic of Türkiye Ministry of Agriculture and Forestry Fig Research Institute	arastirma.tarimorman.gov.tr/incir/Sayfalar/AnaSayfa.aspx	Breeding and propagation

IV – Demands and needs of producers and the industry

In the last few years, the cultivation of chestnut has been experiencing a revival phase, affirming itself as an important fruit crop, especially in the European area. This renewed interest in its cultivation has caused the shifting of its production from being extensive to intensive. The chestnut ideotype is a function of final use (fresh or processed), and production and processing technology. Needs of producers and demands of the industry include: good horticultural traits, product quality, suitability to storage and processing, and easy peeling. Some topics that should drive the future in this sector are listed below.

Plant quality and nursery certification. High-quality chestnut productions require plants of premium quality. The production of certified plant material is well established for most fruit species. Certified crops, especially pome and stone fruits, are among the most profitable ones. The certification process consists of genetic analysis and sanitary tests on the presence of viruses, fungi, phytoplasmas, bacteria, and nematodes. The main purposes of the certification are the production of genetically and phytosanitary standardised materials, quality improvement, and sector traceability. Modern chestnut cultivation, whether intensive or traditional, needs the same operating standards as the major horticultural crops to be competitive.

Increasing orchard density. Semi-compact, medium or low vigour trees are the most suitable features for medium or high density plantations. Other valuable cultivar characteristics that should drive the future of plant materials: early maturity, precocious bearing, regular and high yields, strong branches, good pollinizer ability and intercompatibility with the best cultivars, biotic and abiotic stresses tolerance. Harvesting is one of the costliest aspects of chestnut production. Harvest-related traits include upright habit for mechanical shaking and low detaching force to shake off burs from the tree.

Nut characteristics. The most relevant characteristics are large nut size, desirable for harvesting, handling, fresh marketing and candying (marrons glacé), while a small or medium size nut may be used for dried chestnuts. However, the marketing of peeled or processed chestnuts puts less emphasis on size. Evenness of shape, shiny colour, dark brown stripes, flavour, and firm texture are valuable traits for fresh marketing. Other desirable traits are easy pellicle removal, no pellicle intrusion, no hollow kernel, no multi-embryo nuts, and resistance to *Cydia* spp.*, Curculio elephas* and other pests and to *Gnomoniopsis castaneae* and other storage disease.

Clonal rootstocks and ease of propagation. Good aptitude for vegetative propagation and stock/scion compatibility are of primary importance for the nursery sector. *C. crenata* hybrids are easier to propagate by cutting or layering or micropropagation than *C. sativa*. Ease of propagation by cutting and micropropagation and *Phytophthora*-resistance of the French hybrids ('Marsol' in particular) have increased their use as clonal rootstocks. Graft incompatibility problems with many European cultivars have limited their wider application in the field and studies have identified scion/rootstock clone combinations (Beccaro *et al*., 2019). Although environmental and stress factors may have a role, the success of a particular graft, stock/scion compatibility is most certainly under genetic control (Gamba *et al*., 2022). Graft incompatibility is also affected by ChMV (Desvignes, 1996).

Resistance to biotic and abiotic stresses. Resistance to spring frost is important for Euro-Japanese hybrids, which are early to leaf out. Resistance to drought conditions is desirable to face climate change. Growers need materials with improved resistance to the major fungal pathogens: chestnut blight, ink disease and *Gnomoniopsis*. Ink disease causes still serious damages in Europe. In Europe and North America, *Cryphonectria parasitica* is still today regarded as one of the most destructive pathogens in traditional and new chestnut plantations. Chestnut clones' resistant to blight and hybrids between resistant and susceptible characters are still lacking on the market. More than 50 species of insects are known to damage chestnut. These include Asiatic chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu), several species of weevils (*Curculio elephas* L.),

lepidote moths (*Pammene* spp. and *Cydia* spp.) and wood-boring beatles (*Xyleborus* spp.) which are often serious enough to become limiting factors in chestnut production. Resistance of plant materials to insect pests has been little investigated except for gall wasp.

V. Conclusions and perspectives

In the Mediterranean area, chestnut production is almost entirely supported by European countries. However, production is insufficient to meet the demands for both fresh consumption and industrial use in Europe. Eurocastanea is urging the sector to increase production. *C. sativa* varieties dominate plantations. Due to breeding programs in Europe, hybridizations between *C. sativa* and *C. crenata* (mainly) since the mid-20th century have produced new hybrid genotypes that have been introduced into new plantations since the late 20th century. These genotypes are used as rootstocks for *C. sativa* varieties or even as varieties themselves, such as 'Bouche de Bétizac'.

Globally, around 800 *Castanea* cultivars have been registered, with 577 of them in CIHEAM member countries, including 41 hybrids. In each country, production relies on a short list of varieties, despite the extensive list of secondary ones available, leading to a real risk of genetic erosion.

The significant diversity observed in the countries around the Mediterranean Basin, where chestnuts are grown, suggests that this species has considerable plasticity, offering important possibilities for future research in the context of climate change.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Hazelnut Case Study

Nadia Valentini[1], Veli Erdogan[2], Veronica Casadó[3], Julien Toillon[4], Daniela Farinelli[5]

[1] University of Torino, DISAFA-Dipartimento di Scienze Agrarie, Forestali e Alimentari (Italy)
[2] Ankara University, Faculty of Agriculture, Department of Horticulture (Türkiye)
[3] ADV de l'avellana i cultius del mediterrani, Tarragona (Spain)
[4] ANPN - Association Nationale des producteurs de Noisettes, Cancon (France)
[5] University of Perugia, DSA3-Dipartimento di Scienze Agrarie, Alimentari e Ambientali (Italy)

Abstract. Hazelnut has been cultivated in Europe since ancient times, in particular across the Mediterranean basin. Currently, the main area of cultivation is still located in two countries (Türkiye and Italy) but surface planted area is continuously growing across the world, including in the southern hemisphere. Hazelnuts are mostly destined to the confectionary industry (90%) and production is mainly based on traditional cultivars. Cultivation techniques are modern in the new areas of planting, while for traditional orchards cultural practices are often inadequate and yield is low. In the main Mediterranean field collections (Türkiye, Italy, Spain, France) are conserved 1138 hazelnut accessions, but many are in common between fields (we estimate that about 830 unique accessions are conserved). About 50% of them are Turkish germplasm or cultivars. Several breeding programs started between the 1960s and 1980s that lead to cultivar releases, but at present only some of them are available in European nurseries. Research activity on hazelnut is considerable, focusing on development of biotechnological tools for hazelnut breeding or aimed to test the adaptability of the varietal innovations (cultivar and rootstocks) to various pedoclimatic conditions in Europe. On the contrary, the conservation and implementation of germplasm collection fields needs funding to secure their maintenance.

Key words: Hazelnut – Traditional – Modern – Cropping practices – Cultivars – Accesions – Germplasm collections.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne : étude de cas sur le noisetier

Résumé. *La noisette est cultivée en Europe depuis l'Antiquité, en particulier dans le bassin méditerranéen. Actuellement, la principale zone de culture se trouve toujours dans deux pays (Turquie et Italie), mais la superficie plantée ne cesse de croître dans le monde entier, y compris dans l'hémisphère sud. Les noisettes sont principalement destinées à l'industrie de la confiserie (90 %) et la production repose essentiellement sur des cultivars traditionnels. Les techniques de culture sont modernes dans les nouvelles zones de plantation, tandis que dans les vergers traditionnels, les pratiques culturales sont souvent inadéquates et les rendements faibles. Les principales collections méditerranéennes (Turquie, Italie, Espagne, France) conservent 1 138 accessions de noisettes, mais beaucoup sont communes à plusieurs collections (nous estimons qu'environ 830 accessions uniques sont conservées). Environ 50 % d'entre elles sont des germoplasmes ou des cultivars turcs. Plusieurs programmes de sélection ont été lancés entre les années 1960 et 1980, qui ont abouti à la mise sur le marché de cultivars, mais à l'heure actuelle, seuls certains d'entre eux sont disponibles dans les pépinières européennes. Les activités de recherche sur la noisette sont considérables et se concentrent sur le développement d'outils biotechnologiques pour la sélection de noisettes ou visent à tester l'adaptabilité des innovations variétales (cultivars et porte-greffes) aux différentes conditions pédoclimatiques en Europe. En revanche, la conservation et la mise en œuvre des collections de germoplasmes nécessitent des financements pour assurer leur entretien*

Mots clés: *Noisette – Traditionnel – Moderne – Pratiques culturales – Cultivars – Accessions – Collections de ressources génétiques.*

I – Introduction

Hazelnuts belong to the order *Fagales*, family *Betulaceae*, subfamily *Coryloideae*, genus *Corylus* and are native to the temperate zones of the northern hemisphere (Europe, Asia Minor, Asia, North America) (Botta *et al*., 2020). The number of species within the genus *Corylus* varies between 9 and 25, with 13 major species assigned to four subsections (Molnar, 2011). All *Corylus* species bear edible nuts but their size and seed (kernel) traits vary considerably. *Corylus avellana* L. is the major species cultivated for the commercial production of the kernel, while *Corylus colurna* L. is used as non-suckering rootstocks of *C. avellana* in most places. However, the nuts are collected from the wild and consumed, and even used for candy making in around Bolu province in Türkiye.

Hazelnut has a shrub-like growth habit constituted by a variable number of stems that are generated by the continuous emission of suckers. Hazelnuts are monoecious and wind-pollinated; they flower during the winter and are dichogamous. Reproduction is limited by a sporophytic self-incompatibility system controlled by a single locus designated as the S-locus with 33 alleles (Mehlenbacher, 2014). The fruit is a nut consisting of an achene enclosed in a leafy envelope (cupula, involucre, or husk) that may open letting the nut drop or remain clasping at maturity depending on the cultivar (Fig. 1).

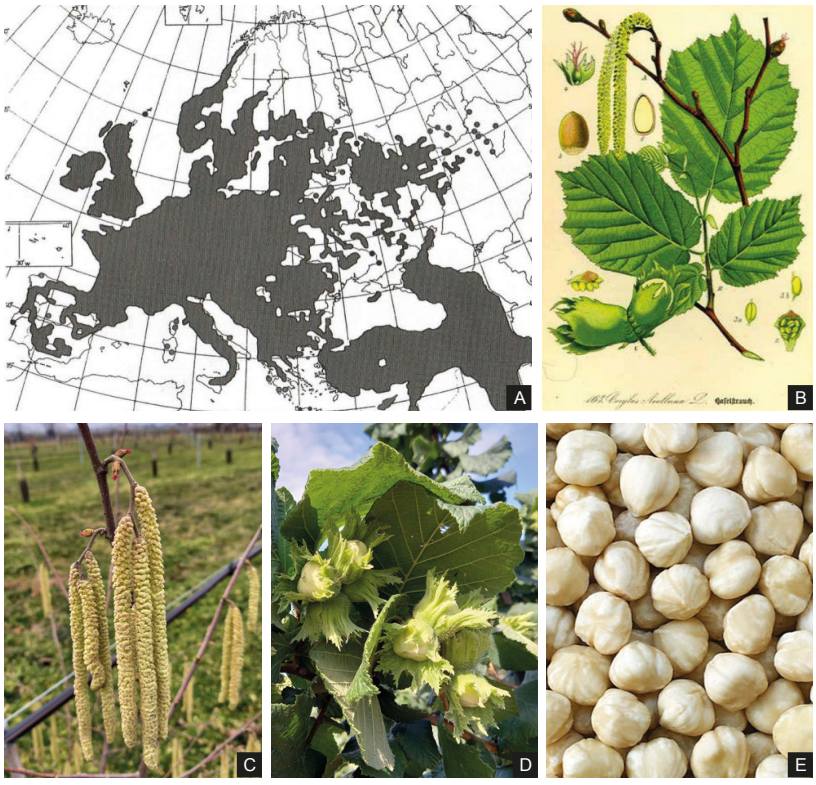


Fig.1. Some aspects of European hazelnut (*Corylus avellana*) biology. Natural distribution (Mehlenbacher, 2003) (A); 19th-century botanical illustration (from Otto Wilhelm Thomé, Flora from Deustchland, Österreich und der Schweiz, 1885) (B); male and female flowers (C); husks and leaves (photos by DISAFA, UNITO) (D); hazelnut kernels after roasting (photos by Veli Erdogan) (E).

The hazelnut is currently rated fifth in the world for surface harvested among the cultivated tree nut species, about 1,049,000 ha in 2022 (FAOSTAT, 2024) (Fig. 2 and Table 1). The annual production (data 2022; FAOSTAT 2024) of in-shell hazelnuts is about 1,220,000 t and is concentrated mainly in two countries: Türkiye (765,000 t) and Italy (98,670 t). The surface area planted and tonnage harvested have shown a trend of continuous growth from 1961 to 2022 (+254%; FAOSTAT, 2024); there are new plantings in multiple countries including in the southern hemisphere were hazelnuts do not grow as natural specie (e.g. Chile).

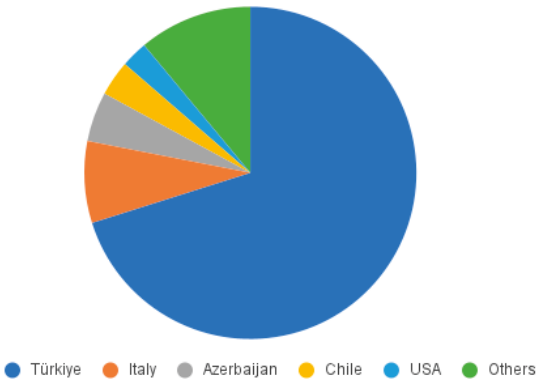


Fig. 2. Hazelnut world harvested area in 2022 (%).

Table 1. Surface area planted in Europe between 2018 and 2022 year and increment

Country	Area (ha) (2018)	Area (ha) (2022)	Increment (%)
Türkiye	728,381	744,047	**+2**
Italy	78,590	84430	**+7**
Spain	13,510	12,660	**-6**
France	6,680	7,560	**+13**
Croatia	4,810	8,240	**+71**
Serbia	4,363	7,115	**+63**
Greece	420	720	**+71**
Portugal	350	550	**+57**

In the traditional area of cultivation across the Mediterranean basin (Türkiye, Italy, and Spain) production still relies on traditional cultivars that were selected from the local, wild vegetation. These cultivars are formed by groups of clones with similar appearance but show minor differences.

Hazelnuts are mostly destined to the confectionary industry (90%) where kernels are roasted and used to produce a large number of foods. Consequently, the confectionary industry defined the quality standards required for processing and only a small number of cultivars with optimal traits for the industry are available and planted in the world. Only 10% of nuts are destined to the in-shell market.

Hazelnut cultivation in main Mediterranean producing countries

Türkiye is the largest hazelnut producer and hazelnut ranks 1st in nut production in the country. The commercial production area extends along the Black Sea coasts with 16 provinces authorized for commercial hazelnut cultivation. The largest producer is Ordu province (31%) followed by Samsun, Sakarya, Giresun and Düzce. The main cultivated cultivars are 'Tombul', 'Palaz', 'Foşa' and 'Çakildak' (traditional cultivars). The production area is classified into two main regions:

(i) The **Eastern Black Sea Region** supplies about 60% of the country's production and provides an optimal climate for hazelnut growing. The area is characterized by narrow coastal lines, immediately rising hills, mountains parallel to the sea and hazelnut orchards are mostly on shallow soils on hills with steep slopes. The orchards are small in size (about 1.4 ha) and mostly old (50 ≤ years) with plants grown in 'ocak' as a clump consisting of about six trees (Fig. 3). The distance between 'ocaks' would be 4-5 m on infertile soils or 5-6 m on fertile soils. Old plants are replaced by one of their suckers and cultivation is dependent on rainfall. In general, cultural practices are inadequate and yield is low (1-1.5 t /ha). The cultivars grown in the eastern region have plants with long clasping husks (manual harvest is requested, Fig. 3) and lower vigor than western cultivars.



Fig. 3. Hazelnut plants grown in 'ocak' (on the left) and manual harvest (on the right) in Eastern Black Sea Region (photo by Veli Erdogan).

(ii) The **Western Black Sea Region** areas have relatively flat land or with gentle slopes with a marine climate that diffuses in as much as 60 km inland. Plantings are mostly on deep and fertile soils of plains such as Çarşamba, Terme, Bafra, Sakarya, Düzce and most of the orchards are young and larger in size (about 1.9 ha) (Fig. 4). Mechanization is somewhat possible and yield is good (2-3 t/ha).

In **Italy** and **Spain** hazelnut cultivation started in ancient times; traditional areas of cultivation are located in hilly areas often with steep slopes. Plants are grown with a multiple stem (bush system) and orchards have low plant density (350 plants/ha), sometimes with low levels of mechanization and absence of irrigation. Pollination is provided by wild hazelnuts in the surroundings. In recent years, the new areas of cultivation are concentrated in flat areas and fertile soils. Plants are growing with a single stem, sometimes with the use of non-suckering rootstocks (*Corylus colurna* L. or hybrids) (Fig. 5). Orchards have high plant density (>500 trees/ha) and they are conducted using modern management techniques with high levels of mechanization and drip irrigation systems. The pollinizers are always provided inside the orchard. The main cultivated cultivars are still the traditional ones: 'Tonda Gentile delle Langhe' (TGdL), 'Mortarella', 'San Giovanni', 'Tonda di Giffoni', 'Tonda Romana' and 'Nocchione' in Italy; 'Negret', 'Pauetet' and 'Tonda di Giffoni' in Spain.



Fig. 4. Ripening time on net in Western Black Sea region (photo by Veli Erdogan).



Fig. 5. 'Tonda Francescana' grafted on seedling of *C. colu na* in Central Italy (3th year in field)(photo by Daniela Farinelli).

Hazelnut cultivation **in France** is more recent (started in the 1970's) and based on foreign cultivars ('Barcelona' and 'Segorbe'). The in-shell market is more relevant than in the other countries and orchards are managed with advanced techniques (irrigation, single stem training system, high orchard density, etc.). Orchards are generally planted at 667 trees/ha (6m between row and 2.5m between trees in the row) to favorize early production. All orchards are mechanized and mechanically pruned from eighth or tenth year old. Now the main cultivars established in commercial orchards are 'Pauetet', 'Segorbe', 'Tonda di Giffoni', 'Lewis', 'Barcelona', 'Corabel', 'Ennis' and 'Feriale'. Today, all orchards in France are established using self-rooted plants (Saphy *et al*., 2023).

II – Plant material catalogue

1. Germplasm repositories & Reference collections - Modern cultivar collections

Hazelnut catalogue

In the Mediterranean field collections are conserved **1138** hazelnut accessions. However, most of the fields contain materials that are in common with other collections, then we estimate that **837 unique accessions** are conserved. The countries of origin of these accessions are: Türkiye (465 accessions) followed by Spain (134), Italy (87), USA (46), France (40) and the United Kingdom (11) (Fig. 6). Cultivars that originate from other European countries such as Germany, Slovenia, Romania, Portugal, Serbia, Greece, Albania, Belgium, Hungary, Netherlands, and eleven cultivars from unknown origin are also listed.

Some cases of synonyms are certainly present in the collections, as reported by Boccacci *et al*., 2013. For example, 'Nocchione' result to have the same genotype of 'Comune di Sicilia', 'Montebello', 'Nostrale', 'Mansa', etc., as well as 'Barcelona' (USA) is known to be synonymous of 'Castanyera' (Spain) and 'Fertile de Coutard' (France). Nevertheless, it is important to maintain all the accessions separated because some clonal differences may exist. As an example, 'Tonda Gentile delle Langhe' and 'Tonda di Biglini' have the same genotype, but showed substantial differences in phenotype (Valentini *et al*., 2014).

Among the 837 unique accessions we listed: 439 Turkish genotypes *(Corylus avellana*) selected from grower orchards (note that this material is keep reserved and no shared with other countries), 291 between major and minor cultivars, 95 selections obtained from breeding (74) or clonal selections (21) in Europe and USA, and 12 are *Corylus* spp accessions. Among the 837 accessions, only 8 are rootstocks.

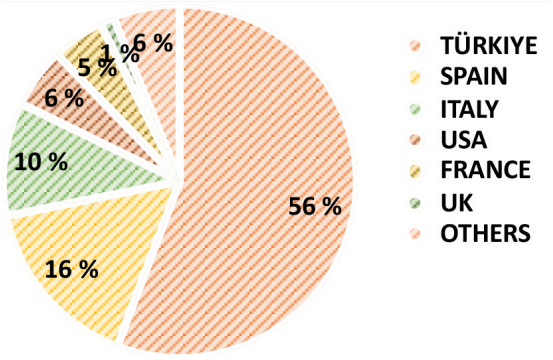


Fig. 7. Percentages of country origin of hazelnut accessions.

Cultivars and rootstocks available in the different countries (45 between cultivars and rootstocks) are shown in Table 2. 'Pauetet', 'Segorbe' and 'Tonda di Giffoni' cultivars are available in Italy, Spain and France. Other cultivars available in more than one country are 'San Giovanni' and 'Corabel', this last one used for the in-shell market; or 'Camponica', 'Nocchione', and 'Merveille of Bollwiller' used often as pollinizers. Out of the 8 rootstocks, only two of them, 'Dundee' and 'Newberg', are available in European nurseries. Also *Corylus colurna* seedlings, often provided as grafted plants in combination with commercial cultivars, are available in some nurseries.

Table 2. List of cultivar and rootstocks available in nurseries for the four countries[1]

Türkiye	Italy	Spain	France
Allahverdi	Barcelona (P)	**Butler**	**Butler**
Cakildak	**Camponica**	**Camponica**	**Corabel**
Foşa	Daria	Castanyera	Ennis
Okay 28	Jefferson	Cosford (P)	Feriale
Palaz	**Mortarella**	Dundee (R)	Fertile de Coutard
Tombul	Nalu'	Ennis	Ferwiller (P)
Turkish tree	**Nocchione**	**Corabel**	Jemtegaard 5 (P)
hazel (R)	**Pauetet**	Gironell	Lewis
Yomrali	**San Giovanni**	Merveille de Bollwiller (P)	Merveille de Bollwiller (P)
	Segorbe (P)	Negret	**Pauetet**
	Theta (P)	Negret clone N-9	Segorbe (P)
	Tonda di Biglini	Newberg (R)	**Tonda di Giffoni**
	Tonda di Giffoni	**Nocchione**	
	Tonda Etrusca	Nottingham	
	Tonda Francescana	**Pauetet**	
	Tonda Gentile Langhe (TGdL)	**San Giovanni**	
	TGdL clones AD17-MT4-MT5-PD6	Segorbe (P)	
	Tonda Romana	**Tonda di Giffoni**	
	Yamhill	Vermellet	

[1]P= pollinizer R=rootstocks; in bold: cultivars available in more than one country.

Hazelnut field collections (repositories)

Hazelnut germplasm is preserved in eight field collections in the four countries of the Mediterranean region: one collection in Türkiye and France, two in Spain and five in Italy (Table 3).

In Türkiye, the Hazelnut Research Institute (HRI) of the Ministry of Agriculture and Forestry is the main institution responsible for hazelnut germplasm collection, classification, characterization and preservation. The collection at HRI contains only Turkish materials: 21 cultivars, 439 *Corylus avellana* genotypes (selected from grower orchards since late 1960's) and one *Corylus colurna* seedling. The Ondokuzmayıs University (OMU) in Samsun has one *Corylus avellana* cultivar ('Yomrali').

In Italy, the main hazelnut field collections are located in the Northwest Italy at University of Torino (UNITO)- Department of Agricultural, Forestry and Food Sciences (DISAFA) (92 accessions) and in Centre Italy at University of Perugia (UNIPG) – Department of Agricultural, Food and Environmental Sciences (DSA3) (79). Other field collections are located in Latium, one field managed by ARSIAL- Agenzia Regionale per lo sviluppo e l'innovazione dell'agricoltura del Lazio, in collaboration with University of Tuscia – Department of Agriculture and Forest Sciences (DAFNE) (Viterbo) (49), and two fields are managed by CREA – Ministry of Agriculture in their research centers of Caserta (48) and Rome (36).

In Spain the main field collection is conserved at IRTA (Institut de Recerca e Tecnologia Agroalimentaries) in Catalonia (262 accessions) and at SERIDA (Servicio Regional de Investigación y Desarrollo Agroalimentario) in Asturias (24 accessions).

In France, the only field collection managed by INRAE/ANPN is located at CVRA - Conservatoire végétal régional d'Aquitaine - Montesquieu (86 accessions).

Table 3. Hazelnut field collections in the Mediterranean region

Country	Field collections	No. of accessions	Local	Foreign	Local accessions (% on total)
Italy	UNITO–DISAFA (Torino)	92	45	47	49%
(304 accessions/	UNIPG–DSA3 (Perugia)	79	34	45	43%
146 genotypes)	ARSIAL/UNITUS - DAFNE (Viterbo)	49	25	24	51%
	CREA (Caserta)	48	23	25	48%
	CREA (Roma)	36	18	18	50%
Türkiye	HRI (Giresun)	461	461	0	100%
(462 accessions)	OMU (Samsun)	1	1	0	100%
Spain	IRTA (Tarragona)	262	126	136	48%
(286 accessions/	SERIDA (Villaviciosa)	24	21	3	88%
265 genotypes)					
France	INRA/ANPN (Cancon)	86	20	66	23%
(86 accessions)					
TOTAL		**1138**	**774**	**364**	

III – Research capabilities, programs and activities on breeding

1. Hazelnut breeding programs

Major modern breeding programs started in Italy, France and the USA in the 1960s, while in China and in Turkey in the early 1980s. In Europe, the aims were to improve productivity and climate adaptability, maintaining or improving kernel quality for industrial use or in-shell market (Botta *et al*., 2020). The new materials originated in Europe from this activity are reported in Table 4.

In Italy, the University of Torino released four selections from the crossing 'Cosford' × 'Tonda Gentile delle Langhe' ('Daria', 'UNITO 101', 'UNITO 119', 'UNITO 3L') and one from 'Payrone' × 'Tonda Romana' ('UNITO G1')(Valentini and Me, 1999). Four clones of 'Tonda Gentile delle Langhe' were also released as tested true-to-type improved material for new orchards (TGdL UNITO AD17, MT4, MT5, PD6; Valentini *et al*., 2001). The University of Perugia has released six cultivars derived from the crossing 'Tonda di Giffoni' × 'Tonda Romana' ('Tonda Francescana®', 'Tonda Etrusca®', 'Volumnia' I, II, III, IV) and 12 clones of 'Tonda Romana' (Farinelli *et al*., 2009). The new cultivar 'Nalù', originating from a grower selection, was recently released.

The breeding activity in **Spain** led to the release of 'Negret' N9 clone (ApMV free).

In **France**, the breeding program conducted at INRAE released three cultivars: 'Fercoril-Corabel' ('Fertile de Coutard' o.p.), a cultivar for the in-shell market (Germain, 1989), 'Ferwiller', a pollinizer ('Hall's Giant' × 'Tonda Romana') and 'Feriale' ['Imperiale de Trebizonde' (='Kargalak') × 'Butler'] for the kernel market.

In **Türkiye**, the breeding program started at HRI in 1981 by crossing the 'Tombul' × 'Kargalak' cultivars released two cultivars ('Giresun Melezi' and 'Okay 28'). Other three cultivars named 'Allahverdi', 'Çetiner' and 'Yomrali' (OMU selection), originating by selections from grower's orchards, was recently released.

Currently, the diffusion of these varietal innovations is slowed down by farmers' cultural mistrust and the limited availability of some material in nurseries. Example of new materials spread in cultivation are: 'Tonda Francescana', with 819.000 plants sold in the 2017-2022 period both in Europe and in Chile; 'Negret' N9 clone that represent about 15% of 'Negret' planted in Spain, and 'Corabel', that is used in France as cultivar for in-shell market (21% of hazelnut orchard in France, Saphy *et al*., 2023).

In the **USA**, the biggest effort for the genetic improvement of hazelnut was initiated in 1969 at Oregon State University (OSU), with an emphasis on suitability to the kernel market and resistance to *Anisogramma anomala*, the cause of EFB. The program has 27 releases, including 12 cultivars, 12 pollinizers and 3 ornamentals. The OSU materials are recently available in Europe thanks to the micropropagation techniques capable to excluding the risk of introduction in Europe of the fungus *A. anomala*. Some of the new OSU cultivars suitable for industrial processing or for the in-shell market are now available in nurseries in some European countries ('Yamhill' and 'Jefferson'). Another important breeding program is ongoing at Rutgers-University (New Jersey), where selections are selected for both their EFB and cold resistance.

Table 4. New plant materials obtained from breeding programs and clonal selection

	European materials	Breeder	Nursery availability
Italy	Daria	UNITO	NO
	Nalu®	PRIVATE GROWER	YES
	Tonda Etrusca®	UNIPG	YES
	Tonda Francescana®	UNIPG	YES
	Tonda Gentile delle Langhe clones (UNITO AD17, MT4, MT5, PD6)	UNITO	YES
	UNITO selections (UNITO 101, 119, 3L, G1)	UNITO	NO
	Volumnia I - II - III - IV	UNIPG	NO
	Tonda Romana clones (12)	UNIPG	NO
Spain	Negret clone N9 (APMv free)	IRTA	YES
Türkiye	Okay-28	HRI	YES
	FAE-1 (Giresun Melezi)	HRI	NO
	Allahverdi	HRI	YES
	Çetiner	HRI	NO
	Yomrali	OMU	YES
France	Corabel-Fercoril	INRA	YES
	Feriale®	INRA	YES
	Ferwiller®	INRA	YES

2. Active breeding programs in Europe

Currently, there are two active breeding programs in the Mediterranean area. One was initiated in **HRI with collaboration of Ankara University (Türkiye)** in 2022 to develop cultivars resistant to spring frosts. Several crossings were made and plants are now at seedling stage. Clonal selection studies on traditional cultivars ('Tombul', 'Çakıldak', 'Foşa') are still in progress (Taylan *et al*., 2023). Activities are mostly funded by the Turkish Ministry of Agriculture and Forestry, and universities.

The second breeding program started in **Italy at University of Sacro Cuore di Piacenza** in 2019 with the aims of obtaining new varieties suitable for industrial processing (using as parental TGdL, 'Tonda Romana', Tonda di Giffoni', 'Nocchione', 'Camponica' and 'Tonda Francescana') and new clonal rootstocks based on *C. colurna* seedings. The program has been financially supported by the Italian confectionery industry Ferrero Hazelnut Company (Ferrero HCo).

3. Hazelnut genetic resources characterisation

Traditional methods to characterize and identify germplasm accessions and cultivars are based on morphological and phenological descriptors (Bioversity International, FAO, CIHEAM, 2008). They are useful but often unreliable or imprecise indicators of plant genotype, being influenced by environmental factors. The complete characterization is performed using also characterization by DNA markers; in particular SSRs (Simple Sequence Repeats) are a convenient method to accurately identify hazelnut cultivars, clarify cases of homonymy and synonymy, study the origin of the cultivated varieties, determine parentage, and assess genetic relationships among cultivars (Gürcan *et al*., 2010; Boccacci *et al*., 2013; Helmstetter *et al*., 2020; Oztolan-Erol *et al*.,

2021; Karakaya *et al*., 2023). The UNITO-DISAFA holds a database consisting of about 250 DNA molecular fingerprinting profiles of national and international hazelnut accessions and offers a cultivar identification service for growers and nurseries (for example to the assignment of protection figures PGI).

4. Research projects

The genetic improvement of hazelnut is particularly difficult since breeding programs are extremely time-consuming, requiring as much as 17 years from the original cross until a new cultivar is released (Botta *et al*., 2020). The genetic development of biotechnological tools for hazelnut breeding is a promising field of research to shorten hazelnut breeding cycles. Nowadays, different biotechnological projects are in progress in Italy.

GWASelnut (Genome Wide Association) is a project aimed to characterize, through genotyping and phenotyping strategies, cultivars and materials collected from representative global orchards (Italy, Spain, Türkiye, Chile, USA). The project is carried out in collaboration between University of Pisa and other institutions (such as IRTA): the aim is the definition of genotypes and identification of variants associated with nut traits. This can be useful also for the molecular traceability of nuts in industrial processes. Another study of GWA analysis was recently performed in Türkiye (Baytar *et al*., 2024).

A research on genetic mapping aimed to understand the genetic interplay affecting phenological, agronomical and fruit traits in hazelnut was conducted at UNITO-DISAFA. The genetic maps were computed on a full-sib population resulting from the cross between 'Tonda Gentile delle Langhe' and 'Merveille de Bollwiller' (Beltramo *et al*., 2016) using a genotyping-by-sequencing (GBS) approach to identify SNP markers in the mapping population progeny. These maps have been extensively utilized to elucidate the inheritance patterns of various traits, including vigor, sucker habit, and timing of budburst (Beltramo *et al*., 2016; Torello Marinoni *et al*., 2018), identifying genomic regions associated with phenology traits such as flowering time, dichogamy, and nut maturity time (Valentini *et al*., 2021) and unraveling the genomic regions that exert influence on nut and kernel traits (Valentini *et al*., 2024). Several genetic diversity and characterization studies (by morphological and molecular techniques) were made in Türkiye (Yılmaz *et al*., 2024).

The research group at UNITO-DISAFA is also working on development of a CRISPR/Cas9 genome editing protocol on hazelnut using somatic tissues (leaves and nodal explant) and on investigation on candidate genes selection for improving tolerance to biotic and abiotic stresses. At the moment, the activity is limited by regeneration problems (low regeneration percentages), then trials on regeneration via somatic tissues are undergoing testing of different media composition.

A protocol of protoplast isolation and transfection via ribonucleoproteins has been developed in collaboration with UNITO-DISAFA and UNITUS-DAFNE, using leaf calli (Pavese *et al*., 2023). A visual system PDS (Phytoene Desaturase Gene) was used to test the ribonucleoprotein transfection system. Currently, protoplast regeneration protocol is in progress. The technology is promising to obtain transgene-free plants with improved traits (e.g. tolerance to disease). The state of the art of biotechnologies and in vitro culture techniques applied on hazelnut in Italy are well described in Ferrucci *et al*., (2023).

Another important field of research refers to the adaptability of the varietal innovations to various pedoclimatic conditions in Europe. Several projects are in progress to test cultivars and rootstocks. In Italy, a project funded by Ferrero HCo (Hazelnut Varietal Field Trials) consists of three varietal field trials spread in Italy, North (UNITO), Centre (UNIPG) and South Italy (UNISA), where adaptability and agronomical performances of new materials from Italian breeding (10), cultivars from OSU (six cultivars) and four references cultivars, are tested using a scientific protocol in

common. A similar research is performed in France (Project Optivar) with five varietal field trials in different French regions aimed to evaluate adaptability to soil and climate conditions of four OSU varieties in comparison to four reference cultivars. In this project, the plasticity of eco and endodormancy of these cultivars are also evaluated in four of the five field trials. In Türkiye, the main problem to face is the spring frost (Erdogan and Aygun, 2017). Research on determination of cold resistance of some Turkish cultivars and genotypes and the performance of new cultivars in different ecologies are in progress at HRI. These researches are also addressed to investigate the adaptation to climate change that is today a challenge of great importance in all Mediterranean countries.

For the same reason, research on the use of grafted materials is also in progress, since grafted plants have shown to be more resistant to drought and to abiotic stresses. Recently, trials on field performance of grafted (on *C. colurna*), micropropagated and own-rooted plants of three Italian cultivars were conducted at Università di Perugia / CNR - IRET Porano (Traini *et al*., 2024; Portarena *et al*., 2022, 2023, 2024), as well as and at HRI in Giresun, where the performance of 'Tombul' and 'Palaz' cultivars grafted on *C. colurna* rootstocks are in progress (Şenel *et al*., 2023). One of the main bottlenecks for the spread of the rootstocks innovations are represented by the propagation system. Indeed, the propagation of *C. colurna* is noted to be difficult: some projects aimed to improve propagation and grafting technology are in progress in collaboration with private nurseries and public institutions funded by FERRERO HCo. Nowadays, there's no international projects addressed to hazelnut breeding conservation. In addition, a small number of researchers are involved in nut species in Europe due to the long time to obtain research results and the lack of funds.

However, hazelnut research has been supported by private industry in the last years funding projects aimed to develop new technologies and techniques (breeding program, biotechnology application, propagation, etc.), as well as test improved material in fields through varietal trials.

IV – Demands and needs of producers and the industry

Hazelnut growers are facing several problems linked mostly to climate changes (extreme climatic events) and globalization (new pests and diseases). The traditional areas of growing are becoming less competitive, in comparison to the new ones, due to the less productivity of traditional cultivation and/or higher costs to maintain good quality of the product.

A list of breeding goals for plant improvement could include the following traits and needs:

- Agronomical traits: upright trees with moderate vigor, late vegetative bud break, low/high chilling requirement, cold hardiness, tolerance to particular soil conditions (high/low pH and heavy soils), or tolerance to drought.

- Reproductive traits: early bearing, abundant female (and male for pollinizers) flowering, high flower fertility and self-compatibility, high yield, early nut maturity and short period of nut drop.

- Resistance and tolerance to pests such as big bud mite (*Phytoptus avellanae*) or nut weevil (*Curculio nucum*), and to diseases (e.g. Eastern filbert blight by *Anisogramma anomala*, powdery mildew by *Erysiphe corylacearum*).

Rootstocks development and improvement is another key issue for modern hazelnut farming. More work is needed on seedlings of *Corylus colurna*, clonal selections of this species (as Sombor and Coco4), or selections of interspecific crossing *C. colurna x C. avellana* (such as Dundee and Newberg).

Another important aspect to improve is linked to hazelnut cultivation with the needs for more accurate design guidance for the use of correct pollinators or rootstocks. The choice of pollinators is complicated by the presence of a complex self-incompatibility system and the need of flowering overlapping, as well as the choice of rootstocks is driven by particular soils and climate conditions (Farinelli *et al*., 2023). In this regard, also the availability of high quality nursery material, with both varietal identity and phytosanitary certifications, are important goals to achieve.

The industrial use of hazelnut is constantly increasing. The confectionery industries have special quality requirements and need consistent and high quality nuts quantities, avoiding fluctuations due to climate conditions. Quality traits demanded by the confectionary industries could be improved by breeding, such as: kernel size (uniform, small to medium, 13-15 mm), round nut and kernel shape, high percent kernel (>45%), low percentage of nut defects, ease of pellicle removal after roasting (>80%), good flavor or high quality in fatty acid content. In-shell market is demanding its particular quality traits such as large nut size (>3 g), attractive and intact shell, kernel with good flavor, and little or no fiber on the pellicle, that can be also attained by breeding.

Some food industries are promoting production in different areas of the world, including countries in the Southern Hemisphere where crops can be harvested in seasons opposite to those in the Northern Hemisphere, ensuring a constant supply throughout the calendar year.

The local hazelnut products are enhanced and supported through specific protection figures (PGI and PDO). In the Mediterranean countries there are several examples of valorization for local and traditional hazelnut production with production systems following specific regulations (Table 5), including the use of specific cultivars. In other cases, the valorization of products is achieved using market brands; for example hazelnuts cultivated in Aquitaine (France) have been grouped as KOKI© market brand since 1983.

Table 6. Valorization of local products through protection figures in Mediterranean region

Denomination	Cultivars	Region/Country	Year
Nocciola Piemonte PGI	'Tonda Gentile delle Langhe' syn. 'Tonda Gentile Trilobata'	Piemonte, Italy	1993
Nocciola di Giffoni PGI	'Tonda di Giffoni'	Campania, Italy	1997
Noisette de Cervione/ Nuciola di Cervioni PGI	'Fertile de Coutard'	Corse, France	2014
Nocciola Romana PDO	'Tonda Romana' and 'Nocchione' (80%), others (20%)	Latium, Italy	2009
Avellana de Reus PDO	'Negret', 'Pauetet', 'Gironell', 'Morell', 'Culplà'	Catalonia, Spain	1999
Giresun Tombul Fındığı PDO	'Tombul' (90%), 'Sivri', 'Kalınkara', 'Palaz' (10%)	Giresun, Türkiye	2022

V – Conclusions and perspectives

Hazelnut cultivation is still based on a few traditional cultivars; but there are some examples of new materials obtained from breeding or clonal selection spread in cultivation, such as 'Tonda Francescana' in Italy, 'Negret' clone N9 in Spain and 'Corabel' in France. The use of non-suckering rootstocks is still limited due to the scarce availability in nurseries and the high cost of the plant material. The diffusion of varietal innovations is also slowed down by farmers' cultural mistrust. In addition, the 'farmer' propagation (use of rooted suckers collected in fields) still exists in some areas (Türkiye, Italy, Spain). A larger availability of certificated materials both for genetic identity and phytosanitary conditions is an important goal still to achieve.

In South Europe and Türkiye, extreme climate events (heat/late frost and drought/flood) are becoming usual, as well as the pressure of previously uncommon or unknown pests and diseases are increasing. In these conditions, traditional cultivars are showing problems of productivity since they have been selected in the past and they are adapted to the climate of specific areas. At present, studies on adaptability of new materials (cultivars, selections and rootstocks) in various areas of cultivation are in progress in several countries.

Nowadays two large breeding programs are in operation in the USA (at Oregon State University and Rutgers University), while for the Mediterranean region, only two programs are in progress in Türkiye (run by HRI and University of Ankara) and in Italy (University of Sacro Cuore di Piacenza), the last one funded by a private food industry.

The maintenance of germplasm collection fields is complicated by small funding from countries or lack of specific EU projects. In the case of Türkiye, the collection field is endangered by the pressure of urban expansion in the Giresun area. In comparison to previous investigations on hazelnut germplasm in some European countries (SAFENUT project, 2008-2010), the number of germplasm accessions has not increased (except for the material released from the USA breeding) and the number of collections is decreasing. In Türkiye, there is a large availability of local germplasm, which is not shared with the other European countries.

However, research activity in hazelnut is considerable: multiple research in different areas (hazelnut propagation, cultivation, varietal field trials, etc.) including biotechnological applications are in progress, also with the financial support of private confectionery industry.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Pecan tree Case Study

Neus Aletà Soler[1], Laia Abelló Argelaga[1] and Margarita López Corrales[2]

[1] Institute of Agrifood and Technology Research of Catalonia (IRTA). Fruit Tree Program. Mas Bové. Ctra Reus-El Morell km.4. 43120 Constantí (Spain)
[2] Finca La Orden-Valdesequera
La Orden-CICYTEX, Junta de Extremadura
A.V. Km 372, Guadajira, 06480 Badajoz (Spain)

Abstract *Carya illinoinensis* (Vangenh) Koch, native to North America, has a very localised area of origin, stretching north across the United States to Ontario in Canada and south to Oaxaca in Mexico. Currently, the search for new crops has made this species a developing nut in new areas of the world, such as Argentina, Australia, Brazil, South Africa, China and very recently in the Mediterranean basin. Pecan production represents less than 5% of the world's nut production, making it a product with great potential due to its quality. The pecan tree, like the walnut tree, belongs to the Juglandaceae family, which it resembles in its reproductive biology. However, there are major productive, adaptive and vegetative differences that must be known when planting in new areas. The development of orchards requires the availability of quality plants and cultivars suitable for different environments. Although some pecan cultivar collections exist in Mediterranean Europe, their availability in the nursery market is not always reliable. Thus, for the development of the pecan in the near future, the main objectives are to know the most appropriate cultivars for each Mediterranean area, to ensure identity in the nursery market and to include this species in the European fruit tree regulations.

Key words: *Carya illinoinensis* − Germplasm banks − Cultivars − Genotype x environment.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne: étude de cas sur le pacanier

Résumé. Carya illinoinensis *(Vangenh) Koch, originaire d'Amérique du Nord, a une aire d'origine très localisée, s'étendant au nord à travers les États-Unis jusqu'à l'Ontario au Canada et au sud jusqu'à Oaxaca au Mexique. Actuellement, la recherche de cultures alternatives a fait de cette espèce une noix en développement dans de nouvelles régions du monde, telles que l'Argentine, l'Australie, le Brésil, l'Afrique du Sud, la Chine et, très récemment, le bassin méditerranéen. La production de noix de pécan représente moins de 5 % de la production mondiale de noix, ce qui en fait un produit à fort potentiel en raison de sa qualité. Le pécanier, comme le noyer, appartient à la famille des Juglandacée, à laquelle il ressemble par sa biologie reproductive. Cependant, il existe des différences importantes en termes de production, d'adaptation et de végétation qu'il convient de connaître avant de le planter dans de nouvelles régions. Le développement des vergers nécessite la disponibilité de plants et de cultivars de qualité adaptés à différents environnements. Bien qu'il existe certaines collections de cultivars de noix de pécan en Europe méditerranéenne, leur présence sur le marché des pépinières n'est pas toujours fiable. Pour assurer le développement de la noix de pécan dans un avenir proche, les principaux objectifs sont donc de déterminer les cultivars les mieux adaptés à chaque zone méditerranéenne, de garantir l'identité des plants proposés sur le marché des pépinières et d'inclure cette espèce dans la réglementation européenne sur les arbres fruitiers.*

Mots clés: Carya illinoinensis − *Banques de ressources génétiques − Cultivars − Génotype x environnement.*

I – Introduction

1. Species world distribution

The pecan tree (*Carya illinoinensis* (Vangenh) Koch) is naturally distributed throughout North America, where it is found mainly from the Atlantic coast to the central regions of the U.S. Its native range includes the states of Texas, Oklahoma, Louisiana, Mississippi and Georgia, extending as a crop into the Atlantic and westward to Arizona. Southwards it reaches Mexico as a wild species and as a crop as far south as Oaxaca. The northern limit is the line that runs from Pennsylvania to Illinois, although the species has been reported as far north as Ontario, Canada (Thompson and Conner, 2012).

Despite its very local origin, the characteristics of the fruit, its qualities as a nut and the great diversity of cultivars selected in different areas of the USA have made this species a new crop alternative in different areas of the world. New plantations have been established in Argentina, Australia, Brazil, South Africa and China. At present, the pecan is also of interest in the Mediterranean area, as it seems to be adapting to the increasing aridity in this part of the world.

2. Nutritional composition (USDA Nutrients Data Base)

The pecan nut has very good press as a healthy food. It contains 70% of fats, of which 22% are polyunsaturated and 41% monounsaturated, 10% of proteins and 14% of carbohydrates. It differs from walnuts in that it is less prone to rancidity.

The kernel, which is usually eaten with the skin, has a very high antioxidant content and is rich in calcium, potassium, phosphorus and magnesium, with no sodium.

3. Characteristics of the international pecan market (INC, 2023)

Pecan production is a very small minority of the world's nut production, accounting for a meagre 5% together with macadamia and pine nut production.

World production is around 150,000 tonnes of kernels and has remained more or less stable over the last 5 years. This production is concentrated in two countries, Mexico and the USA, accounting for 50% and 40% respectively. In terms of exports, Mexico exports more than 65%, while the USA exports 34% of production, on average over the last five years (Fig. 1).

It is therefore a nut that is widely consumed in its area of origin, reaching 500 g per capita in the USA, but also in Germany, Israel and Belgium, countries where pecans are highly appreciated. In some countries, such as Lithuania or the Netherlands, consumption reaches 1 kg per capita, a level that has been maintained in recent years. France, Italy and Spain, which could become European producers in the near future, have a very low consumption of this nut, not even reaching 100 g per capita.

3. Why the interest of new orchards in the Mediterranean region?

Some nut species, particularly walnut or hazelnut, show a poor productive response to recurrent extreme climatic events, such as prolonged heat and drought, which are now common in many areas of the Mediterranean basin (Aletà *et al*., 2021).

Many of the pecan varieties originate from warm areas and have lower chilling requirements for proper development than walnut or hazelnut. This has undoubtedly been the main point taken into consideration by growers in proposing the development of this fruit in southern Europe.

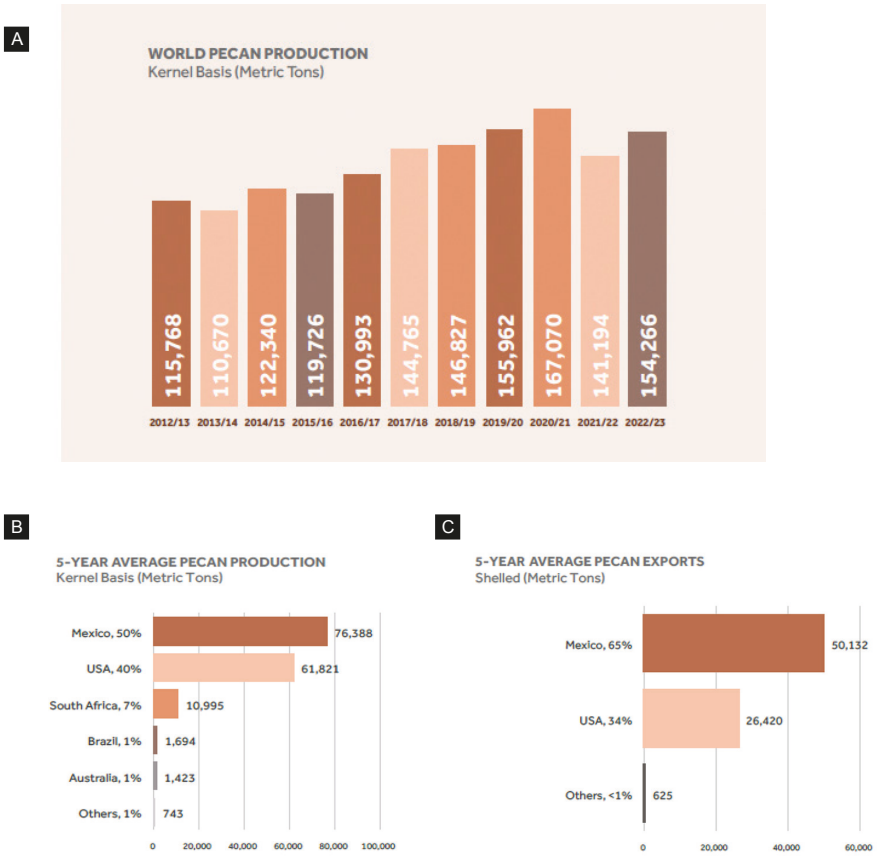


Fig. 1. Pecan nut international market. A. World pecan production; B. Year average production per country; C. Year average export per country.

The choice of nut species is also linked to the Mediterranean tradition of nut production. The adaptation of existing nut tree orchards, or the addition of pecan to these current farms, seems feasible. The main reasons argued are that the machinery requirements are similar, and the farmers are already familiar with nut marketing channels. Moreover, if the farm has plantations of other nuts, the introduction of pecans does not pose any harvesting problems as many of the varieties are late ripening. It is a matter of choosing the right variety for the job. It would be the last nut to be harvested from the nut farm.

Moreover, at a time when walnut prices, for example, are in free fall, finding a high-value crop as a potential substitute or complement may seem like a good business.

4. Reproductive biology

C. illinoinensis belongs to the Juglandaceae, such as the walnut tree, *Juglans regia*, with which it shares a very similar reproductive biology although the productivity of the species is much lower than that of walnut.

The species is monoecious, with the female flowers clustering at the end of the shoot of the year, while the catkins emerge from the previous year's shoot (Fig. 2). It is a mostly protogynous dichogamous species which, despite its self-compatibility, needs pollinators in new plantations, which are often isolated. Pollination is anemophilous

There are selected cultivars already available in nurseries, issued from some breeding programmes of USDA centres or US universities, with good productive performance and low susceptibility to diseases. With the new selections, the fruits usually appear after 3-4 years; with the old varieties, this period can easily be extended for another 2-3 years.



Fig. 2. Pecan tree female flower (A), catkins (B), dehiscent fruits (C), and nuts (D, E).

5. New orchards

The characteristics of a species will have a relevant impact on farm management (Fig. 3), so it is important to be aware of them; in the case of pecans we need to know that:

- The pecan tree is a strictly irrigated species whose requirements are similar, or even lower, to those of the walnut tree.
- Young trees are often difficult to train because it takes time for the branches to thicken and branch out. The genus *Carya* is also characterised by very brittle wood. Care should be taken mainly during these juvenile stages in windy areas.
- Pecan nuts are dehiscent, which means that once the hull is open, harvesting must be fast to achieve high quality nuts. Fortunately, despite being a large tree, mechanical harvesting is widely used on this species.

To date, no significant phytosanitary problems have been noted in existing collections in Spain, although aphid infestation and leaf scab have been observed in some cultivars. However, as pecan stands begin to increase, the rusticity of the species will be diluted. The use of disease prevention techniques is a good way of delaying the onset of phytosanitary problems.

It is important to remember that many plantations are managed as 'natural stands' in their place of origin and their domestication as a fruit crop in these areas is relatively recent. This means that management solutions for new young plantations often have to be sought in other areas where cultivation has only recently begun, such as South Africa, Australia or Argentina.



Fig 3. Pecan tree orchards. Traditional (Texas, USA) (A); CICYTEX collection (Spain) (B); young training trees (C); modern orchard in Italy (D).

II – Plant material catalogue

There are always risks in introducing a new crop, and these are magnified when the crop has a long productive life. In any case, the aim is to minimise errors in the selection of plant material by using the available information (Aletà and Ninot, 1991; Byford, 2005; Wells and Canner, 2015; Madero *et al*., 2017; Domínguez *et al.,* 2018).

When a crop is new to an area, whatever is available in the nurseries is planted and this is often a poor solution for the future. There is still little data on the agronomic response of each pecan cultivar to Mediterranean conditions, but at the very least it is necessary to get a good match between the frost-free period of the planting area and the length of the growing season when selecting cultivars.

It is also useful to know the origin of the material; many of the interesting cultivars come from the US breeding programs, from USDA centres or from various universities, and there is usually plenty of information available on their agronomic and productive behaviour.

Currently, there are germplasm collections and banks in the Mediterranean region where a significant number of cultivars are under evaluation (Table 1). Three are located in **Spain**, managed by CICYTEX (Extremadura), IFAPA (Andalusia) and IRTA (Catalonia). One recently established in **France** (Isère) managed by SENuRA, and two installed in **Italy** (Latium), managed by a private nursery, Exoticplant, and by the CREA-OFA-Rome, respectively.

Table 1. Main germplasm repositories of *C. illinoensis* in southern Europe

Curator	Institution	Institution adress	Collection address
CICYTEX[1]	Centro de Investigaciones Científicas y Tecnológicas de Extremadura.	Instituto de Investigación Agraria Finca 'La Orden'. 06480 Guadajira (Spain)	Finca 'La Orden'. 06480 Guadajira (Spain)
IRTA-Mas Bové[1]	Institut de Recerca i Tecnologia Agroalimentàries	Torre Marimon. 08140 Caldes de Montbui (Spain)	Mas Bové. 43120 Constantí (Spain)
IFAPA- Málaga[1]	Instituto Andaluz de Investigación y Formación Agraria, Pesquera, Alimentaria y de la Producción Ecológica	Centro de IFAPA de Málaga. 29591 Campanillas (Spain)	Finca La Lira. 29591 Campanillas (Spain)
SENuRA[1]	Station d'Expérimentation nucicole Rhône-Alpes	Saint Marcellin. 38160 Chatte (France)	Saint Marcellin. 38160 Chatte (France)
Exoticplant	Nursery of Latio (Italy)	Exoticplant nursery. 04012 Cisterna Latina (Italy)	Exoticplant nursery. 04012 Cisterna Latina (Italy)
CREA-OFA-Rome	Fruit Growing Institute of Rome	Via di Fioranello 52 00134 Fioranello RM (Italy)	Via di Fioranello 52 00134 Fioranello RM (Italy)

[1] Accessions under evaluation.

1. Existing cultivars in Mediterranean regions

The species, *C. illinoinensis*, can be found as scattered trees along the Mediterranean coast. These trees arrived in Spain with the return of the Indians at the end of the 19th century and these seedlings show good vegetative development and in many cases are even highly productive. In Spain, a few outstanding specimens have been identified on the banks of the Ebro (Tarragona) and Guadalhorce (Málaga) rivers, which stand out for their good productive characteristics (Domínguez *et al*, 2018).

In addition, a large number of cultivars with potentially good agronomic characteristics exist in different collections in the Mediterranean area. There are a total of 127 accessions, 58 different. Some of these pecan germplasm banks are providing valuable information on the adaptive and productive response of different materials. This information, although in the juvenile phase, is very useful when deciding on a new plantation; others have not been properly under evaluation and are only planted for conservation purposes (Table 2).

Table 2. Name of accessions existing in each *C. illinoinensis* GB or collection

Institution	Genotype /cultivar	Total accessions	Evaluation/ Conservation
IRTA	**723, 1-169**, Apache, Barton, Bitem T-4, Caddo, Cape Fear, Cherokee, Cheyenne, Chickasaw, Choctaw, Churiana-2, Churriana-5, Comanche, Desirable, Elliot, Forkert, **Frotscher**, Green River, Houma, Ideal (Bradley), Kiowa, Mohawk, **Melrose**, **Moneymaker**, Oconee, Osage, Pawnee, Peruque, Queen Elisabeth, Salopek, Shawnee, Shoshoni, Sioux, Stuart, **Tejas**, Western Schley, Wichita.	38	All under evaluation
CICYTEX	Apache, Badour, Bítem T-4, Caddo, Cape Fear, Choctaw, Churiana-2, Churriana-5, Desirable, Houma, Kiowa, Mahan, Mohawk, Oconee, Osage, Pawnee, Queen Elisabeth, Salopek, Shoshoni, Sioux, Stuart, Western Schley, Wichita.	23	All under evaluation
IFAPA	Badour, Cape Fear, Cheyenne, Kiowa, **Lakota**, Mahan, Mohawk, Osage, Pawnee, Queen Elisabeth, Western Schley, Wichita.	12	All under evaluation
SENuRA	Choctaw, Desirable, Kiowa, Mohawk, Oconee, Osage, Pawnee	7	All under evaluation
EXOTICPLANT	Apache, **Belen**, Cape Fear, Cheyenne, Choctaw, Desirable, Kiowa, **Neviana**, Shawnee, Shoshoni, **Starking hard giant**, Stuart, **Success**, Wichita	14	Conservation
CREA-OFA-Rome	Apache, Barton, Cape Fear, Cheyenne, Chickasaw, **Colby**, Comanche, **Curtis**, Desirable, Elliot, Forkert, **Giles**, **Graking**, Green River, **Harris super**, **Hastings**, Ideal (Bradley), **Kanza**, Kiowa, **Maramec**, Mohawk, **Mount**, Pawnee, Peruque, Queen Elisabeth, **Royal**, Shawnee, Shoshoni, Sioux, Stuart, **Sumner**, Wichita, **Woodart**.	33	Conservation

Bold characters: Existing accession in this collection only.

Current phytosanitary restrictions mean that the exchange of plant material between countries is becoming increasingly difficult, so having such a large number of available in Europe is a great advantage that should be exploited.

Material currently available comes from 21 different zones of its natural range. In addition, at least 15 cultivars from the USDA's Bronwnwood Breeding Programme in Texas, one of the leading breeding centres in the USA, and 10 more from other American institutions are listed as accessions in the germplasm banks (GBs) (Table 3).

Table 3. Geographic and vegetative origin of cultivars

Country	Region or State	Origin	Selection name
Argentina	Catamarca	Chance seedling	Belén
Bulgaria	-	Chance seedling	Neviana
Canada	Ontario	Chance seedling	Mullahy
Mexico	Sonora	Breeding cultivar	Badour
Mozambique		Chance seedling	723
Spain	Catalonia	Chance seedling	Bítem T4
	Andalucia	Chance seedling	Churiana-2, Churiana-5
USA	California	Breeding cultivar	Royal
	Florida	Chance seedling	Elliot, Curtis
	Georgia	Breeding cultivar	Caddo, Hastings, Lakota, Sumner
	Illinois	Chance seedling	Colby
	Kansas	Chance seedling	Giles
	Kentucky	Chance seedling	Green river
	Louisiana	Chance seedling	Frotsche, Mahan, Melrose
	Mississippi	Breeding cultivar	Forkett
		Chance seedling	Delmas, Desirable, Harris Super, Peruque, Stuart, Success
	Missouri	Breeding cultivar	Sioux
		Chance seedling	Starking hard giant
	Nebraska	Chance seedling	Carlson 3
	New Mexico	Breeding cultivar	Salopek
	North Carolina	Chance seedling	Cape Fear
	Oklahoma	Breeding cultivar	Maramec
		Chance seedling	Mount
	Texas	Breeding cultivar	Apache, Chickasaw, Choctaw, Comanche, Houma, Kanza, Kiowa, Mohawk, Oconee, Osage, Pawnee, Shawnee, Shoshoni, Tejas, Wichita
		Chance seedling	Barton, Cherokee, Cheyenne, Graking, Ideal, Western Schley
Unknown		Unknown	Queen Elisabeth

2. Current plant material availability

In addition to repositories of pecan material, there are numerous nurseries in a number of southern European countries that market some grafted cultivars. Most of these are already existing cultivars in the various GBs, but in some cases, such as in French nurseries, they include others (Table 4).

Table 4. Marketable cultivars available in nurseries in different countries

Country	Cultivars
French	Apache, **Barton**, Cape Fear, **Carlson 3**, Cheyenne, Choctaw, **Delmas**, Kanza, Kiowa, Mahan, Mohawk, **Mulhahy**, Osage, **Peruque**, Shoshoni, Starking Hardy Giant, Stuart, Wichita
Italian	Apache, **Belén**, Cape Fear, Cheyenne, Choctaw, Desirable, Kanza, Kiowa, Mahan, **Neviana**, Osage, **Shawnee**, Shoshoni, Starking Hardy Giant, Stuart, **Success**, Wichita
Spanish	Apache, **Caddo**, Cape Fear, **Cherokee**, Cheyenne, Choctaw, Desirable, Kiowa, Mahan, Mohawk, **Oconee**, Osage, **Pawnee**, **Queen Elisabeth**, **Salopek**, Shoshoni, **Sioux**, Stuart, Wichita

In bold: Existing accessions in this market, country, only.

The grafted plant stock available in European nurseries is generally of good quality. Fig. 4 shows grafted pecan in pots. This fact should be a point of great strength for the development of this crop in a short period of time.



Fig. 4. Italian nursery production. *(Photo courtesy of D. Avanzato).*

However, the availability of this material should be considered with caution as pecan is not yet specifically regulated as a fruit tree in Europe and therefore the production of grafted planting stock is poorly controlled to offer real guarantees of identity.

At present, little attention is paid to the rootstock in plant production and no pecan seedlings have been specifically used for rootstocks.

Despite this potential availability, care must be taken when selecting cultivars, as there is still little information on their productive and adaptive behaviour under different environmental conditions. Preliminary results presented at the last ISHS Pecan Congress (Grenoble, France, 2023) show

that the phenology of the cultivars evaluated in the southwest of Spain, Extremadura (Institute La Orden-CICYTEX), and in the northeast of Spain, Catalonia (Centre de Mas Bové-IRTA), is sufficiently different to be considered when selecting cultivars for planting. Significant differences were observed in the timing of bud break, the degree of overlap between male and female flowering, and on fruit ripening time (Fig. 5).

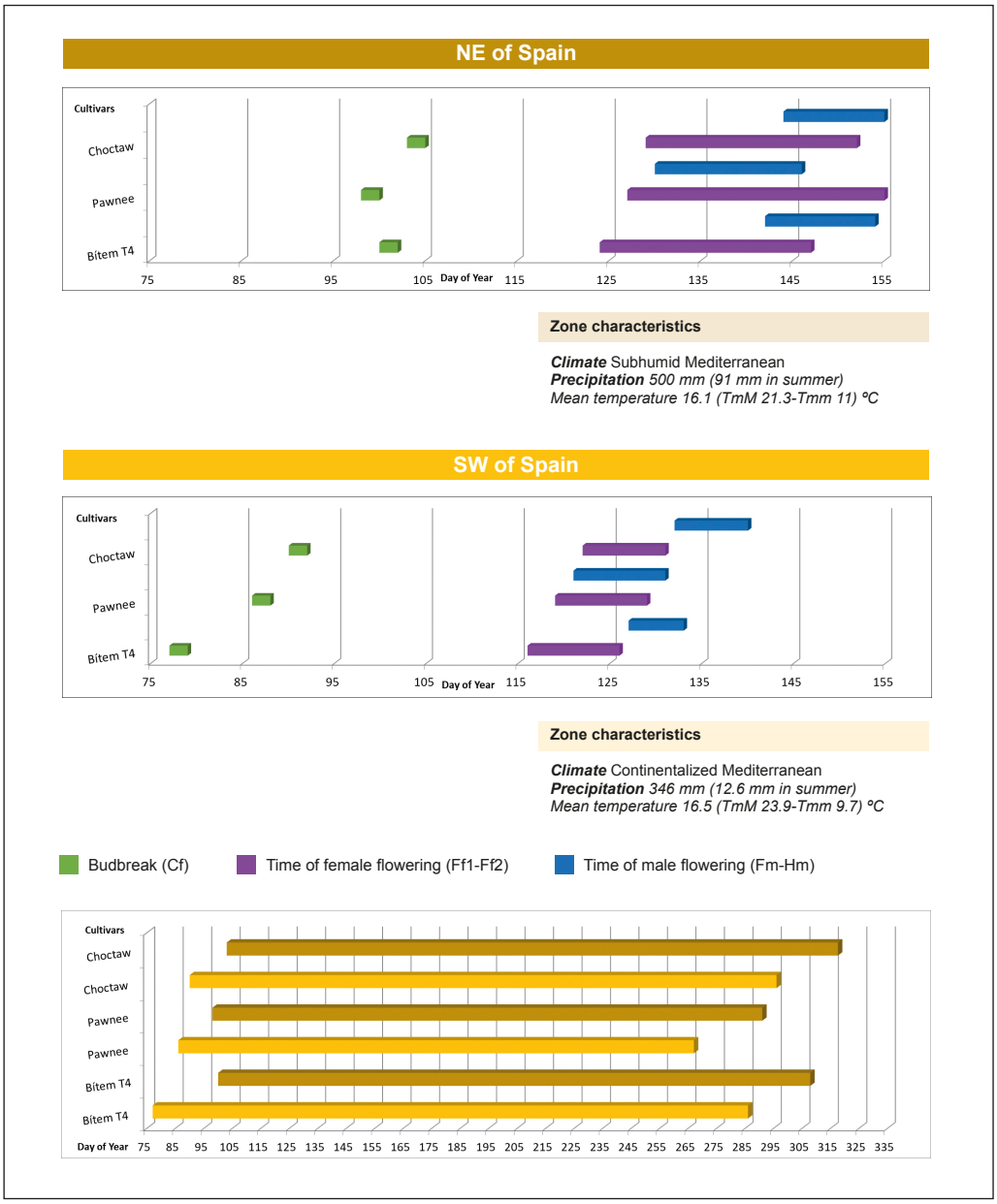


Fig. 5. Phenology of pecan cultivars in two well differentiated regions of Spain.
Source: Domínguez *et al.*, 2023. Walnut & Pecan Congress of ISHS (Grenoble, France, 2023).

III – Research capabilities, programmes and activities on breeding

In all countries where interest in this species is growing, there are a variety of collections in order to evaluate the potential adaptive and productive behaviour of the different cultivars. Most of them are still at the juvenile stage (Fig.3C). It is worth mentioning the results obtained by Domínguez *et al*. (2018) regarding yield and varietal characterisation.

The agronomic-productive evaluation in different collections should make it possible to pool the behaviour of cultivars in different environments and, after a multi-environmental analysis, provide criteria for the use of the most important ones. The first pooling of data between Extremadura (CICYTEX) and Catalonia (IRTA) has already shown (Fig. 3) and the conclusion was that adaptive traits are strongly influenced by the environment.

In some southern Mediterranean countries, pecan is currently being included in the modern concept of agroforestry systems for evaluation purposes.

In Spain, interest is also focused on carrying out varietal identification studies to guarantee varietal identity at the nursery level. Different organisations are involved in these research activities, CICYTEX in Extremadura and IRTA and CRAG in Catalonia.

CICYTEX and the University of Extremadura are carrying out nutritional studies on 34 pecan tree varieties and extensive studies on the presence of mycotoxins in the nut and the evaluation of bioactive and antimicrobial compounds in the pecan hull.

In a newly introduced species, management is often conservative and a cut and paste from the productive areas of the world. However, this is a very traditional crop in its area of origin and many of the management techniques will be difficult to extrapolate to the needs of this crop in Europe. In this respect, tree formation is a great unknown. In order to shed light on the new plantations in Andalusia, IFAPA has established a network of pecan tree training trials.

IV – Demands and needs of producers and the industry

If we are realistic and we summarise the current advantages and the main weaknesses of the sector for the proper development of pecan orchards in Mediterranean regions, we have the following strenghts and weaknesses analysis (Table 6).

Table 6. Strenghts and weaknesses of pecan sector development in the Mediterranean region

Strengths	Weaknesses
• Appreciated quality of the fruit, supported by the well-known benefits of nut consumption. • Currently a high selling price of the pecan nut, much higher than other nuts, such as walnut. • There is a wide range of varieties available in nurseries. • Information of the various American breeding programmes are available. • No major phytosanitary problems have been identified. • Varieties with low chilling requirements are available on the market.	• Pecan nut is very little consumed and unknown in the south of Europe. • The species is not yet subject to the regulations for fruit trees. • Not always the most suitable cultivars are planted. • No information on rootstocks. • Crop technology on development. • Poor information on pests and diseases.

In such a situation, it is essential to get quick answers to some of the key requirements or demands:

- Access to quality grafted plants in nurseries with varietal guarantees.
- Have a set of criteria for using the main cultivars.
- Good technological development of the crop.

In broad terms, this means that studies on plant material are essential and must be focused on:

- Developing a genotype x environment network between all the regions concerned to provide the best possible answers to cultivar behaviour and adaptation, cropping techniques, etc.
- Above all, it is necessary to promote the consumption of this nut, to make it known and to distinguish it from other nuts. We are in a part of the world where the qualities of nuts are appreciated, but the markets are already very crowded with other nuts that are traditionally consumed and also highly valued nutritionally, dietetically and organoleptically.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Mediterranean Stone Pine Case Study

Carlos Guadaño-Peyrot[1], Alexandra Pires Correia[2], Youssef Ammari[3], Neus Aletà[4]

[1]Institute of Forest Sciences (ICIFOR-INIA), CSIC. 28040 Madrid (Spain)
[2]Instituto Nacional de Investigação Agrária e Veterinária I.P. (INIAV)
Avenida da República, Quinta do Marquês. 2780-157 Oeiras (Portugal)
[3]Institut National de Recherches en Génie Rural, Eaux et Forêt (INRGREF). 2080 Ariana (Tunisia)
[4]Institute of Agrifood and Technology Research of Catalonia (IRTA)
& Forest Science and Technology Centre (CTFC)
Torre Marimon, 08140 Caldes de Montbui (Spain)

Abstract. The Mediterranean stone pine is a coniferous species that has seen an increasing expansion in recent decades, both within and beyond its natural distribution area. This is due to both the role of the species in ecological restoration and also the growing demand for pine nut production on the international market. The high nutritional properties of the Mediterranean pine nut and its limited production have made it a high-priced gourmet food. This has led to a change in the management of the species towards an agroforestry approach, accompanied by technological innovations, breeding programmes and selection of elite clones to maximise fruit production. Despite the challenges that Mediterranean pine nut production faces, such as unequal competition with other pine species or the yield reduction due to climate change and/or the appearance of new invasive pests, the sector has a promising future due to the species' tolerance to harsh environments, its optimistic economic forecasts and the existence of developed improvement programmes. This article locates and describes the existing *P. pinea* germplasm banks in Portugal, Spain and Tunisia, and the Forest Reproductive Material available for planting. Ongoing research and development activities in the Mediterranean for its management as a nut crop are also presented.

Keywords: *Pinus pinea* − Mediterranean pine nuts − Agroforestry − Elite clones − Breeding programmes.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne: étude de cas sur le pin pignon

Résumé. *Le pin pignon méditerranéen est une espèce de conifère qui a connu une expansion croissante au cours des dernières décennies, tant à l'intérieur qu'à l'extérieur de son aire de répartition naturelle. Cela s'explique à la fois par le rôle de l'espèce dans la restauration écologique et par la demande croissante de pignons sur le marché international. Les propriétés nutritionnelles élevées du pignon méditerranéen et sa production limitée en ont fait un produit gastronomique très prisé. Cela a conduit à une évolution de la gestion de l'espèce vers une approche agroforestière, accompagnée d'innovations technologiques, de programmes de sélection et de sélection de clones d'élite afin de maximiser la production de fruits. Malgré les défis auxquels est confrontée la production de pignons de pin méditerranéen, tels que la concurrence inégale avec d'autres espèces de pins ou la réduction des rendements due au changement climatique et/ou à l'apparition de nouveaux ravageurs envahissants, le secteur a un avenir prometteur en raison de la tolérance de l'espèce aux environnements difficiles, de ses prévisions économiques optimistes et de l'existence de programmes d'amélioration développés. Cet article localise et décrit les banques de germoplasmes de* P. pinea *existantes au Portugal, en Espagne et en Tunisie, ainsi que le matériel forestier de reproduction disponible pour la plantation. Les activités de recherche et développement en cours en Méditerranée pour sa gestion en tant que culture de noix sont également présentées.*

Mots clés: Pinus pinea − *Pignons de pin méditerranéens − Agroforesterie − Clones d'élite − Programmes de sélection.*

I – Introduction

Pinus pinea L., commonly known as the Stone pine or Umbrella pine, is a Mediterranean conifer valued for restorative afforestation, dune stabilization, landscaping, and its production of highly sought-after pine nuts. Naturally distributed across the Mediterranean basin—from the Portuguese Atlantic coast to the Black Sea—it thrives in heliophilous, xerophilous, and thermophilus conditions (Fig. 1a). This species tolerates dry, hot summers and mild, rainy winters, making it well-suited for restoration (Fig. 1b) and agroforestry purposes due to its drought tolerance, frugality and plasticity (Montero *et al*., 2004).

The cones of *Pinus pinea* are ripen over three years (Fig. 1c), weighing approximately 250–300 grams and with nuts (50 g) and kernels (10-12 g) constituting respectively about 18% and 4% of the cone's weight. To produce 1 kg of shelled kernels, around 25 kg of cones must be harvested (Küçüker and Baskent, 2017). Renowned for their culinary value, Mediterranean pine nuts are prized for their quality and nutritional benefits. Rich in protein (over 30%), omega-6 and omega-9 fats (under 50%), and essential vitamins (including B1, B2, and E) and minerals (especially potassium and phosphorus), they are a gourmet product competing with lower-cost Asian pine nuts (i.e. *P. koraiensis*, *P. gerardiana*), which have significantly different nutritional profiles (Mutke *et al.,* 2012; Yalim *et al.,* 2022, Evaristo *et al*, 2010).

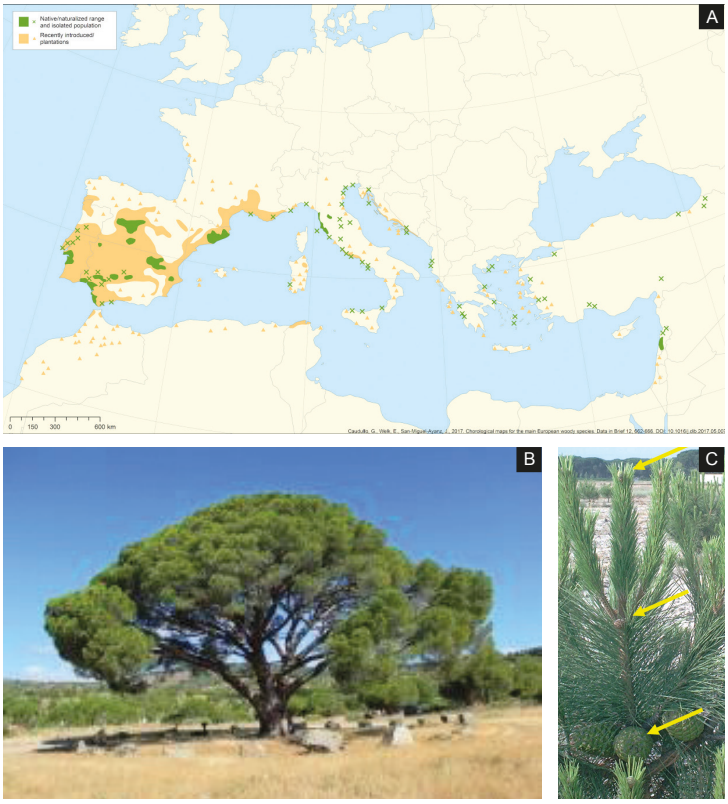


Fig. 1. **A. *Pinus pinea* distribution in the Mediterranean basin;**
B. Species well-suited for restoration in drought areas;
C. Three different ages of cones on the same tree.

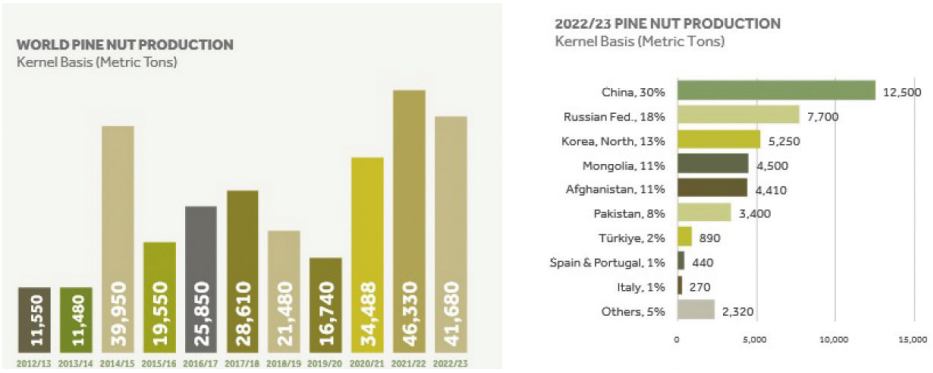


Fig. 2. Pine nut statistics (INC, 2023). Pine nut production evolution and main producing countries. Statistics comprises all pine nut species production.

Pinus pinea has been expanding worldwide for the last half century due to the high price valorisation of pine nuts in international trade, and its agroforestry management. Portugal and Turkey have quadrupled their respective species area, with Portugal observing a 21% increase in *Pinus pinea* forested area between 2005 and 2015 (ICNF,2019). North African countries, including Tunisia, Algeria, Morocco, and Lebanon, have also embraced this species for its agroforestry potential. Worldwide, countries such as Chile, Argentina, South Africa, Australia and New Zealand are already using *Pinus pinea* to produce nuts. However, Spain still represents nearly half of the species' global distribution, with approximately 500,000 hectares of *Pinus pinea* forests (Table 1).

Table 1. Estimated area of *Pinus pinea* in Mediterranean countries (from Mutke *et al.*, 2017)

Country	Area (ha)
Spain	490,000
Turkey (x4)	195,000
Portugal (x4)	175,000
Italy	46,000
Tunisia	21,000
Albania	20,000
France	13,500
Lebanon	12,000
Syria	5,500
Morocco	3,000
Israel	2,000
Greece	1,600
Total	**984,600**

In some regions of Turkey, incomes from pine nut production (about 7 million US$) were three times greater than incomes from timber in early 90s (Geray *et al*., 1993). Currently, Turkey is the main producer and exporter of Mediterranean pine nuts worldwide (INC, 2023).

Historically, Mediterranean *Pinus pinea* forests were managed primarily for timber production, and were characterised by high tree density, narrow crowns and limited yields of cones, which were harvested by climbing. This widespread expansion of stone pine stands demanded changes in forest management practices, which has moved towards the mixed production of wood and cone production. To increase the production of cones the trees need to be planted/managed at lower densities in order to increase canopy lateral growth and demanded a change in harvesting techniques with the introduction of mechanised cone harvesting.

Despite this, the Mediterranean pine nut sector worldwide is still facing major problems, such as: the interannual production irregularity which is very difficult to counteract by management and is greatly increased by climate change; the hard market competition with other *Pinus* sp. kernels; robbery and black market; and the negative impacts of invasive and emerging pests and diseases which are affecting cone production and kernel yield.

The domestication of the species is currently occurring in many parts of the world with the objectives of:

- Managing pines in open woodlands together with pastures or crops, favouring the development of wide crowns to maximize cone production (Fig. 3)
- Developing crop techniques adapted to stone pine namely grafting (Fig. 4), training/pruning, control of pests and diseases, etc.
- Using selected genotypes in new plantations, elite clones with high productive capacity (breeding programs).
- Selecting rootstock to use in the field and also in nursery grafting.



a. Plants grafted in nursery. Caldes de Montbui. Spain



b. Plants grafted on the field. Arenys d'Empordà. Spain

Fig. 3. Stone pine orchards at 12 years old grafted in nursery (a) and on the field (b).



a. Grafting on the field South Portugal



b. Grafting in Forestal Catalana nursery. Spain



c. Grafting in INRGREF nursery. Tunisia

Fig. 4. Recently grafted stone pine on the field (a) and in nurseries (b and c).

Reproduction by grafting is a key factor in the agroforestry innovation of the sector. Grafting anticipates the economic income by 10-15 years than natural stands by skipping juvenile stages. Grafted trees increase cone production efficiency, facilitating the harvesting because the trees are productive while young and small, and allowing de use of elite clones (Bono and Aletà, 2013; Guadaño *et al.,* 2016; Loewe *et al*., 2022).

However, breeding programs to develop promising agroforestry management of the species have encountered two major problems. First, there is a crucial bottleneck in the multiplication by grafting of selected material due to the current scarcity of scion orchards and the phenological characteristics of the species that restrict the time frame in which the scions are viable for grafting. Second, the certification of selected material does not allow a classic DUS test (UPOV Official test of Distinctness, Uniformity and Stability) to distinguish among genotypes due to the low genetic variability of the species, making it only possible by molecular markers.

II – Plant material catalogue

Under EU legislation, *Pinus pinea* is classified as a forest species and therefore its production and trade are subject to the Council Directive 1999/105/EC (RD283, 2003 in Spain) on the marketing of forest reproductive material (FRM), according to which FRM must only be harvested from approved and registered basic material (BM).

Selected FRM are classified into four categories by the knowledge of the source (Table 2)

Table 2. Forest reproductive material classification following Council Directive 1999/105/EC (RD283, 2003 in Spain)

(i) (ii)	Source-identified Selected	*In situ* conservation. Natural stand/forest
(iii) (iv)	Qualified Tested	*Ex situ* conservation. Seed or scion orchards

Portuguese regulation: *P. pinea* is subject to a mandatory certification with more stringent requirements. FRM must belong to only three categories: “selected”, “qualified” and “tested”.

Portugal, Spain and Tunisia have been carrying out breeding programs for selection of elite clones as well as genetic x environment trials for the last few decades.

In Portugal, there are 10 Provenance Regions defined for *Pinus pinea* (Marques *et a*l., 2012), and a total of 40 Basic Material registrations: 38 stands and 2 clonal seed orchards. These last ones are in Coruche and Alcacer do Sal. They were planted in 2001 and grafted with FRM from the national catalogue of Plus trees, category “qualified”, all from provenance region (RP5). There are 64 clones (Plus trees) replicated in both orchards. Since 2008, the grafts collected in the orchards have been sold by regional forestry associations (APFC & ANSUB) to landowners.

In Spain, there are defined seven provenance regions and five genetic remains (Prada *et al*., 1997). The overall Basic Material registration includes 112 stands (100 identified and 12 selected), 10 qualified clones and five tested clones. All registered clones come from four provenance regions and are in the National Catalogue of Base Materials since 2015 (Table 3). They have been the result of a breeding program carried out by different national institutions (MITECO,

INIA-CIFOR-CSIC) and the regional government Junta de Castilla y León. Seven microsatellite markers (Pinzauti *et al.,* 2012) were used for clone identification. Clone evaluation (Mutke *et al*., 2007) established a degree of clonal genetic determination (H^2) of about 20%, and a potential stand production gain of + 20-40% using the top 10% of selected clones.

Table 3. Elite clones registered in the Spanish National Catalogue of Basic Materials

Commercial name	Provenance region	BM Categories
Portillo-11	Meseta Norte (ES1)	Tested
Portillo-12	Meseta Norte (ES1)	Tested
La Vega	Meseta Norte (ES1)	Tested
Íscar	Meseta Norte (ES1)	Tested
Valdegalindo	Meseta Norte (ES1)	Tested
Hoyo de Pinares	Valles del Tiétar y Alberche (ES2)	Qualified
Almorox	Valles del Tiétar y Alberche (ES2)	Qualified
San Martín de Valdeiglesias	Valles del Tiétar y Alberche (ES2)	Qualified
El Provencio	La Mancha (ES3)	Qualified
Pozoamargo	La Mancha (ES3)	Qualified
Casas de Haro	La Mancha (ES3)	Qualified
El Picazo	La Mancha (ES3)	Qualified
Sta. Coloma de Farnés	Cataluña Litoral (ES6)	Qualified
Llagostera	Cataluña Litoral (ES6)	Qualified
Dosrrius	Cataluña Litoral (ES6)	Qualified

Currently, all registered clones are commercially available in nurseries. In Spain 15 elite clones as individual genotypes and in Portugal 64 as a mixture of genotypes.

In Tunisia, *Pinus pinea* provenance regions have not been established yet, although there are two regions well differentiated: the coast and the inland. Two clonal orchards were planted by INRGREF, one in Dar Chichou (coast) and the other in Mellègue (inland) with grafted plants. Both orchards host replicates of 16 clones, including 10 Spanish genotypes, 2 of them are qualified Spanish clones.

Other Mediterranean countries such as Turkey and Lebanon do not have established provenance regions either.

A summary of the existing gene banks in Portugal, Spain and Tunisia, and the institutions that manage them, is given in Table 4.

Table 4. Stone Pine Germplasm collections existing in Portugal, Spain and Tunisia

Acronym	No. of accessions	Collection address	Institution
MITECO-ES6	90	CNRGF. Puerta del Hierro. 28040 Madrid (Spain)	Ministerio de Transición Ecológica Address: Gran Via de Sant Francisco 4-6-5ªpl. 28005 Madrid (Spain)
MITECO-ES2	90	CNRGF. Puerta del Hierro. 28040 Madrid (Spain)	
MITECO-ES3	78	CNRGF. Puerta del Hierro. 28040 Madrid (Spain)	
MITECO-ES1	73	CNRGF. Puerta del Hierro. 28040 Madrid (Spain)	
MITECO-ES6	16	CNRGF. El Serranillo. 19080 Guadalajara (Spain)	
MITECO-ES1-ES2-ES3	48	CNRGF. El Serranillo. 19080 Guadalajara (Spain)	
JCyL-1-ES1	98	Finca de Quintanilla. 47350 Quintanilla de Onésimo (Spain)	Junta de Castilla y León Address: Rigoberto Cortejoso 14.47014 Valladolid (Spain)
JCyL-2-ES1	66	V. El Molinillo, 47100 Tordesillas (Spain)	
JCyL-3-ES1	30	Finca de Mayorga. 47680 Mayorga (Spain)	
JCyL-4-ES1	37	Finca La Pedraja. 47196 Pedraja de Portillo (Spain)	
JCyL-5- ES2-ES3-ES6	48	V. El Molinillo. 47100 Tordesillas (Spain)	
Diput. VA-ES1	50	Finca de Matallana. 47639 Villalba de los Alcores (Spain)	Diputación de Valladolid Address: Rigoberto Cortejoso 14.47014 Valladolid (Spain
IMIDRA-ES1-ES2-ES3	48	CTT La Isla. 28500 Arganda del Rey (Spain)	Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario Address: Leganitos 43. 28013 Madrid (Spain)
IRTA-ES1-ES2-ES3-ES6	64	Torre Marimón. 08140 Caldes de Montbui (Spain)	IRTA-CTFC Address: Torre Marimon. 08140 Caldes de Montbui (Spain)
Hernán Pérez council-ES1-ES2-ES3-ES6	49	Herrerías 7. 10868 Hernán-Pérez (Spain)	HP Council Address: Herrerías 7. 10868 Hernán-Pérez (Spain)
JEX-1-ES1-ES2-ES3-ES6	15	V. San Marcos. 10829 Holguera (Spain)	Junta de Extremadura Address: Virgen de la Montaña 3. 10071 Cáceres (Spain)
JEX-2-ES1-ES2-ES3-ES6	15	V. De Palazuelo. 06716 Villar de Rena (Spain)	
JEX-3-ES1-ES2-ES3-ES6	15	V. La Moheda de Gata. 10860 Gata (Spain)	
JEX-4-ES1-ES2-ES3-ES6	15	V. Ruda Chica. Puebla del Guadiana (Spain)	

Acronym	No. of accessions	Collection address	Institution
FC-ES6	24	Forestal catalana Viveros. 17451 Sant Feliu de Buixalleu (Spain).	Forestal Catalana SA Address: Torrent de l'Olla 218-220. 08012 Barcelona (Spain)
FC-ES1-ES2-ES3-ES6	15	Forestal Catalana Torrefarrussa. 08130 Sta Perpètua de la Moguda (Spain).	
APFC-Quinta Grande	64	Herdade da Quinta Grande, Coruche (Portugal)	Associaçao de Produtores Florestais Address: 5 de Octubro 8. 2100-127 Coruche (Portugal)
ANSUB-Grandola	64	Monte de São Brás, Alcácer do Sal (Portugal)	Associaçao de Produtores Florestais do Vale do Sado Address: Rua Joaquim Soeiro Pereira Gomes, Apartado105 EC, 7580-909 Alcácer de Sal (Portugal)
INRGREF Dar Chichou	16	8090 Dar Chichou (Tunisia)	Institut National de Recherches en Génie Rural, Eaux et Forêt Address: Hédi Elkarray BP.10. 2080 Ariana (Tunisia)
INRGREF Mellègue	16	Oued Mellègue (Tunisia)	

III – Research capabilities, programmes and activities on breeding

1. Selection and breeding

In Portugal and Tunisia, the work in Stone pine materials is focused on clone evaluation and on genotype x environment studies. Moreover, currently in Portugal, forest management is also studying the possibility of mixing well adapted mediterranean species like *Quercus suber* and *Pinus pinea* in the valorisation of non-timber forest products, the conservation of biodiversity and the use of these mixed plantations as a means of preventing forest fires. Also, in Portugal a couple of experimental sites are studying the effects of interannual climate variability on cone production using long term permanent plots (Marcelo *et al.,* 2022).

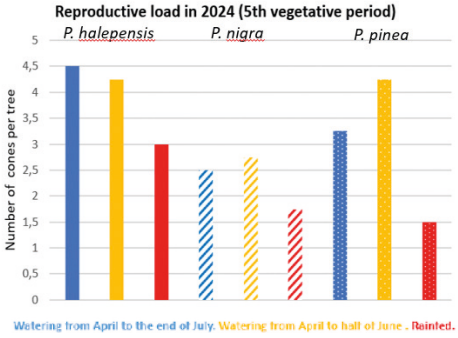
In Spain, there are already stablished 21 grafted orchards with clones from four provenance regions. Six of these orchards contain clones representing all of the aforementioned provenances: Meseta Norte (ES1), Valle del Tiétar y del Alberche (ES2), La Mancha (ES3) and Litoral Catalán (ES6) (Table 3). In addition, grafted pines were planted at four sites under the same statistical design, allowing data pooling for genotype x environment studies. The aim is to establish criteria for the best selection of a clone or a mixture of them, or to know how much provenance matters for adaptive and productive behaviour.

Selection of seedling rootstocks of different *Pinus* sp. carried out by IRTA-CTFC and Forestal Catalana nursery started in 2020. The aim is twofold: (i) at the nursery level, the selection of vigorous and homogeneous progeny of *Pinus pinea* and *P. halepensis* species to be grafted as

soon as possible with *P. pinea* and with high grafting success; (ii) at the field level, the selection of *Pinus* sp. rootstocks with emphasis on grafting compatibility, early entry into the adult stage, cone production, and adaptation to different edaphoclimatic conditions and water scarcity (Fig. 5), (Guàrdia *et al*., 2021).



a. Trial for selection of *Pinus* sp. rootstocks for tolerance to water restrictions. Caldes de Montbui. Spain.



b. Reproductive load at the 5th vegetative period on three Pinus species. Caldes de Montbui. Spain.

Fig. 5. Selection of rootstocks of *Pinus sp*.

2. Research on new genetic techniques and technologies

Recently, research on genomic characterization with Single Nucleotide Polymorphism (SNP) markers was carried out in Spain by INIA-CIFOR-CSIC under the European 4Tree project, in collaboration with IRTA-CTFC aimed to overcome the existing limitations in the species genetic identification. The outcome allows an accurate clonal identification and a better identity check (post-hoc traceability) than by those obtained using nuclear microsatellite markers (Olson *et al*., 2025).

All this work, based on molecular markers such as SNPs, is progressing very rapidly and should soon allow us to have a better knowledge of the species. This will make it easier to identify genotypes and to know the real possibilities for improvement of this genetically impoverished species.

3. Worldwide: management and technology

To develop pine as a nut, other ongoing R&D programmes are working to learn how to manage the species from many angles, from mechanising harvesting using vibrators, to provide sustainable fertiliser and water supply recommendations and also on the control of pests and diseases. Within this framework, activities are being developed in many Mediterranean countries, such as Portugal, Spain, Turkey, Tunisia and Lebanon, and also outside its area of origin, without which it will be very difficult to make progress with this crop (Kattar *et al*., 2017; Loewe-Muñoz *et al.,* 2020; Naves *et al*, 2023; Correia *et al*, 2024).

IV – Demands and needs of producers and the industry

The sector has solid strengths but also challenging weakness as depicted in Table 5.

Table 5. Strengths and weaknesses of the Mediterranean Stone Pine sector

Strengths	Weakness
Exceptional quality product	Competition with Asian pine nuts
Increasing prizes and international demand	Main bottle neck: not enough grafted plant production to cover current demand
Advanced breeding programs	The black market of crop theft
	Reduction of production and yield due to Climate Change
	Damages for emerging pests and diseases[1]

[1] It is worth highlighting two invasive exotic pests: *Leptoglossus occidentalis*, a yield destroying bug (Farinha *et al.,* 2018; Calama et al., 2020), and *Toumeyella parvicornis*, which is currently severely affecting Italian stone pine populations (EFSA-PLH, 2022; Di Sora *et al.,* 2023).

Therefore, the sector is demanding actions focused on:

- Increasing the availability on the market (nurseries) of reproductive material from breeding programs.
- Solutions for the control of new emerging pests.
- Selection of material adapted to Climate Change previsions.
- Implementation of a certification system to prevent market of stolen cones.
- Promotional campaigns and product label information regarding the botanic species and origin (UNECE, 2013; Mutke *et al.*, 2024).

Perspectives on plant material activities with the aim of promoting and meeting the demands of the sector are the following:

- Improvement and facilities to transfer clonal material to the sector to increase grafted plants production.
- Revision of current catalogued material using SNIPs markers in new and old clonal trials to increase de number of elite clones.
- In Spain, moving towards the selection of 'Mixed clones' as tested material to maintain as much as possible the species biodiversity.
- Sharing data between regions and countries to advance in Genotype x Environment trials and establish criteria for the use of selected Clones.
- Defining quality standard features of grafted plants, as in Portugal has already done.

V. Conclusions and perspectives

The international market for Mediterranean pine nuts is a promising industry with an increasing demand that the agents involved should take advantage of to promote the development of this crop.

In fact, if Mediterranean pine nut industry does not act soon, the product will be replaced in a few years by others with a nutritional and organoleptic quality far from the *P. pinea* pine nut.

In an area of the world with foreseeable serious drought problems, having the opportunity to develop a low-demand water crop is a great opportunity from the perspective of rural development and ecosystem services.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Pistachio Case Study

Mohammed Ghrab[1], Bekir Erol Ak[2], Esaú Martínez[3], George I. Zakynthinos[4], Ossama Kodad[5], Sid Ahmed Boualem[6], Azza Chelli Chaaboluni[7]

[1] Institut de l'Olivier, Olive Institute, Sfax (Tunisia)
[2] Department of Horticulture, Faculty of Agriculture
Harran University (Türkiye)
[3] Instituto Regional de Investigación y Desarrollo Agroalimentario
y Forestal de Castilla-La Mancha (IRIAF). Ctra de Porzuna s/n, 13071 Ciudad Real (Spain)
[4] Dept. of Public and Community Health, University of Western Attica, 196 Alexandras Avenue,
11521 Athens (Greece)
[5] Dept. Arboriculture Fruitière Viticulture, Ecole National d' Agriculture de Meknés (ENA Meknes) BP S/40,
50000 Meknès (Morocco)
[6] Dept. of Agronomy, Fac. of Natural and Life Sciences, Univ. Mustapha Stambouli, Mascara (Algeria);
[7] National Institute of Agronomic Research of Tunisia (INRAT)
Rue Hédi Karray, 2049 Ariana (Tunisia)
E-mail:mghrab@gmail.com; mohamed.ghrab@iresa.agrinet.tn

Abstract. Plant materials play a key role in the success and wide spreading of nut trees in many production areas and under various climatic conditions. Pistachio is one of the most important nut crops in the Mediterranean region. *Pistacia* spp., well adapted to extreme drought and marginal soils, enables farmers to grow this nut without irrigation in arid and semi-arid lands. With increasing demand for nuts, more attention is given to new production systems, including irrigation management and new rootstocks. However, there are serious problems to be solved related to climate change adaptation and quality of healthy products. Genetic diversity was considered as a mitigation strategy for climate change. Around the Mediterranean area, large and rich germplasm was repertoried, gathering more than 90 female and 50 male cultivars. Various wild species were identified; some of them are used as rootstocks. However, few potential cultivars and rootstocks are widely used and commercially available, due to lack ofselection programs. Initially, the development of nuts industry was supported by multi actions research programmes (GREMPA Initiative and FAO-CIHEAM Nuts Network), while with lack of funding and coordination all these initiatives ended without new prospective. For this reason, fruitful collaborations are requested, including the private sector and research, to consolidate prominent projects in improving the resilience of pistachio to climate change.

Keywords. *P. vera* − Germplasm – Mediterranean area – Inventory.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne: étude de cas sur le pistachier

***Résumé**. Le matériel végétal joue un rôle clé dans le succès et la large extension des fruits secs à travers de nombreuses zones de production et sous diverses conditions climatiques. Le pistachier est l'une des espèces les plus importantes de la région méditerranéenne.* Pistacia *spp., bien adapté à la sécheresse et aux sols marginaux ce qui permet aux agriculteurs de la cultiver en pluvial dans les zones arides et semi-arides. Avec une demande croissante pour les fruits secs, une plus grande attention est accordée à des nouveaux systèmes de production, intégrant la gestion de l'irrigation et de nouveaux porte-greffes. Cependant, de sérieux problèmes doivent être résolus en ce qui concerne l'adaptation au changement climatique et la qualité des produits sains. La diversité génétique est considérée une des stratégies d'atténuation du changement climatique. Autour de la région méditerranéenne, un matériel génétique important et riche a été répertorié rassemblant plus de 90 cultivars femelles et 50 cultivars mâles. Diverses espèces sauvages ont été identifiées, dont certaines sont utilisées comme porte-greffes. Cependant, peu de cultivars et de porte-greffes potentiels sont largement utilisés et disponibles commercialement* à cause de peu des travaux *de sélection. Initialement, le développement de la filière autour de la Méditerranée, a été soutenu par des programmes de recherche multi-actions (Initiative GREMPA et Réseau FAO-CIHEAM). Toutefois, faute de financement et de coordination, toutes ces initiatives ont pris fin sans de nouvelles perspectives. Pour cette raison, des collaborations fructueuses sont désormais nécessaires, intégrant le secteur privé et la recherche, pour consolider des projets visant l'amélioration de la résilience du pistachier au changement climatique.*

Mots-clés. P. vera – *Germoplasme – Méditerranée – Inventaire.*

I – Introduction

The genus *Pistacia* of the family *Anacardiacea* includes 11 species; some of them play an important role in vegetation at the Mediterranean and Asian regions, proving successful as rootstocks (Zohary, 1952). *Pistacia* species grown at 30-40º altitude are suited for microclimate areas all over the world (Isgin and Ak; 2011, Ak, 2019). Pistachio (*Pistacia vera* L.) is the only species of the genus that produces edible nuts (Shokraii and Esen, 1988). It is a deciduous, dioecious, and wind-pollinated fruit species, which requires an appropriate distribution of male and female cultivars among the orchard for efficient pollination and fruiting (Ak, 2001; Isfendiyaroglu *et al*., 2001; Vargas *et al*., 1995).

Pistachio tree is well adapted to severe conditions and it can be cultivated under hot, arid, and saline conditions (Metheney *et al*., 1998; Ghrab and Ben Mimoun, 2014; Ak and Acar, 2018; Ak, 2019). Its nuts are quite important in terms of nutrient value and much appreciated for their human health benefits, thanks to their phenolic and antioxidant concentration (Tomaino *et al*., 2010). The pistachio kernel is a rich source of fat, fatty acids and sterols (Agar *et al*., 1998; Arena *et al*., 2007; Ghrab*et al*., 2010), with high amounts of proteins (23%), carbohydrates and minerals (Kuçukoner and Yurt, 2003).

In the Mediterranean region, pistachio is one of the most important nut crops. The Mediterranean countries gave more attention to this crop, with gradual increases of cultivated area and yield, occurring over the last two decades. The total cultivated area reached around 525,000 ha, with Turkey, Syria, Tunisia, Spain, Greece and Italy accounting for the majority of the surface area, while only three countries (Turkey, Syria and Greece) accounted for more than 80% of the average production (Fig. 1) (FAO, 2022). As regards nuts consumption around the world, 30% of pistachio nuts were used in the Mediterranean area, mainly Turkey and Syria (INC, 2020). These two countries showed the highest respective consumption value per capita (Fig. 2).

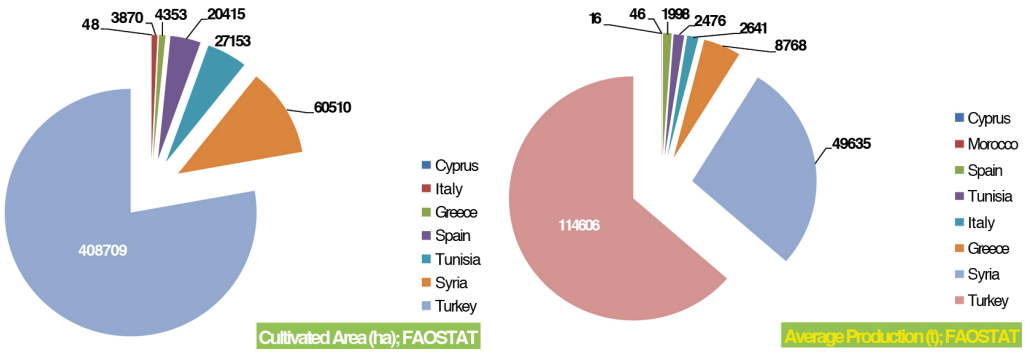


Fig. 1. Cultivated area and average production for pistachio in the Mediterranean region (FAO, 2022).

The pistachio nuts productivity presented high variability around the Mediterranean countries from around 2 t ha^{-1} to less than 100 kg ha^{-1} (Fig. 3). Some of the constraints are linked to plant materials used and horticultural practices. Climate change, with increasing temperature and precipitations variability, has harmful effect of nuts trees production (Elloumiet *et al*., 2013; Benmoussa et al., 2020).

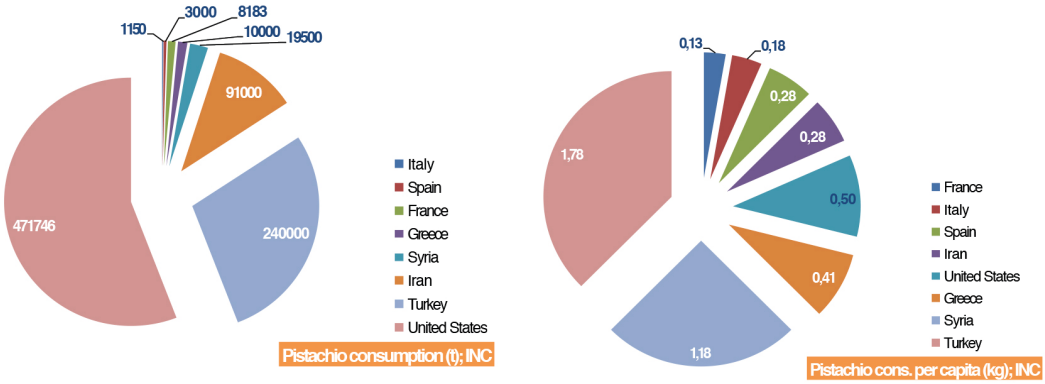


Fig. 2. Pistachio nuts consumption around the world and the respective consumption per capita (INC, 2020).

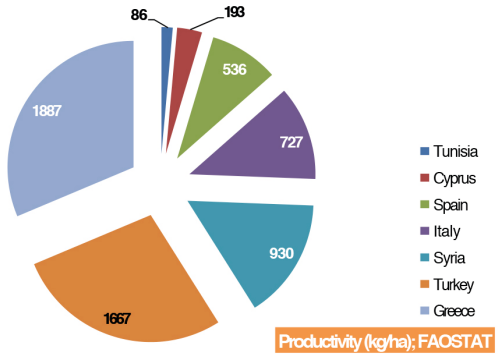


Fig. 3. Pistachio nuts productivity (kg ha^{-1}) around the Mediterranean countries.

Different production systems are implemented across the large rain-fed cultivated area in the Mediterranean. Rain-fed orchards consider large-spacing trees (8*8m, 10*10m, 12*12m, 14*14m), depending on precipitation. The trends for new production systems have moved towards irrigated orchards and organic production system to improve small farmers' net incomes. With the newly released rootstocks, such as UCB1, intensive and irrigated orchards are being adopted, while the few commercial female cultivars are commonly used.

II – Plant material catalogue

Plant materials

Wild species: various wild species were prospected around the Mediterranean basin (Table 1) (Ak, 2019; Ghrab *et al*., 2010; Kaska, 1990). Some of them were highly appreciated as rootstock such as *P. atlantica* in North Africa and *P. khinjuk* in the Middle East region (Turkey and Syria).

Table 1. Wild species wide spreading around the Mediterranean countries

Species	Algeria	France	Greece	Italy	Morocco	Spain	Syria	Tunisia	Turkey
P. atlantica	x				x	x	x	x	x
P. lentiscus	x		x	x	x	x	x	x	x
P. terebinthus	x		x	x	x	x		x	x
P. palaestina			x				x		x
P. khinjuk							x		x

Local genotypes of pistachio: Large and rich germplasm was repertoried by different authors, gathering more than 90 female cultivars and 50 male cultivars (Table 2) (Ak, 2019; Ayadi *et al*., 2024; Baroni and Marra, 2004; Benmoussa *et al*., 2017; Boualem *et al*., 2021; Pontikis, 1986; Rovira *et al*., 1998; Vargas *et al*., 1995; Villasenor *et al*., 2005).

Table 2. Inventory of female and male cultivars of pistachio around the Mediterranean countries (F: female; M: male)

Cultivar	Type	Algeria	France	Greece	Italy	Morocco	Spain	Syria	Tunisia	Turkey
Pontikis	F		x	x						
Larnaka	F		x	x			x			
Aegina	F		x	x			x			
Napoletana.Bianca	F		x		x		x		x	
Insolia	F				x				x	
Femminella	F				x					
Cappuccia	F				x					
Cerasola	F				x					
Natalora	F				x					
Agostana	F				x					
Silvana	F				x					
Santa Cruz	F						x			
Hellín	F						x			
Piedrola	F						x			
Mariana	F						x			
Lazwardy	F						x	x		
White Oleimy	F						x	x		
Red Oleimy	F						x	x	x	
Bayadhi	F	x						x		
Boundoky	F						x	x		
Nab Al-Djamal	F	x						x		
Adjmi	F	x						x	x	
Ajami	F			x			x	x	x	
Batoury	F	x					x	x	x	

Table 2. Inventory of female and male cultivars of pistachio around the Mediterranean countries (F: female; M: male)

Cultivar	Type	Algeria	France	Greece	Italy	Morocco	Spain	Syria	Tunisia	Turkey
White Batoury	F							x	x	
Batoury Ezraa	F							x		
Achoury	F	x		x			x	x	x	
White Ashoury	F							x		
Red Aleppo	F			x				x	x	
Antaby	F							x		
Red Jalab	F							x		
White Jalab	F							x		
Jalleb	F							x	x	
Marawhy	F							x		
Ein El-Tainah	F							x		
Lesan El-Tair	F							x		
Zaaroury (Gehasshy)	F							x		
Mateur	F			x		x	x		x	
El Guetar	F						x		x	
Meknassy	F								x	
Nouri	F								x	
Thyna 1	F								x	
Thyna 2	F								x	
Uzun	F						x			x
Siirt	F									x
Sultani	F						x			x
Keten Gömlegi	F						x			x
Beyazben	F						x			x
Değirmi	F						x			x
Halebi	F						x			x
Kirmizi	F						x		x	x
Tekin	F									x
Barak Yildizi	F									x
Cakmak	F						x			x
Sirora	F		x	x			x			
Ohadi	F			x			x		x	x
Lassen	F						x		x	
Safeed	F						x		x	
Sefidi	F									x
Amiri	F								x	

Table 2. Inventory of female and male cultivars of pistachio around the Mediterranean countries (F: female; M: male)

Cultivar	Type	Algeria	France	Greece	Italy	Morocco	Spain	Syria	Tunisia	Turkey
Jawad	F								x	
Jabari	F								x	
Sharifi	F								x	
Mumtaz	F						x		x	
Razzai	F								x	
Bilgen	F									x
Vahidi	F									x
Kalegouchi	F						x			
Iraq	F						x			
Libye Rouge	F								x	
Libye Blanc	F								x	
Avidon	F						x			
Avdat	F						x			
Kastel	F						x			
Sfax	F			x			x			
Joley	F						x			
Lost Hills	F						x			
Golden Hills	F						x			
Gumdrop	F			x			x			
Bronte	F						x			
Chica	F						x			
Kerman	F	x	x	x	x	x	x	x	x	x
Adam	M	x						x		
Maschio	M		x	x						
C-Special	M		x	x			x			
Selection A	M			x						
Selection B	M			x						
Selection C	M			x						
Selection D	M			x						
Peter	M			x						
Guerrero	M						x			
G1	M						x			

Table 2. Inventory of female and male cultivars of pistachio around the Mediterranean countries (F: female; M: male)

Cultivar	Type	Algeria	France	Greece	Italy	Morocco	Spain	Syria	Tunisia	Turkey
Chaparrillo	M						x			
Randy	M						x			
Famoso	M						x			
Tejón	M						x			
P-1	M						x			
Kris	M						x			
T-41	M						x			
Egino	M						x			
M-B	M						x			
M-C	M						x			
M-Ohadi	M						x			
M-1	M						x			
M-502	M						x			
Nazar	M						x			
Askar	M						x			
M-38	M						x			
M-11	M						x			
Mateur M	M						x			
M-40A	M						x		x	
M-25A	M						x		x	
02-18	M						x			
M-36	M						x			
Jamil	M								x	
Brahim	M								x	
M42	M								x	
M57	M								x	
Peter	M								x	
21B	M								x	
Ozturk	M									x
Kaska	M									x
Uygur	M									x
Atli	M									x

Germplasm repositories and reference collections

Limited information are available on the germplasm repositories around the Mediterranean, although the great efforts done through different initiatives. Table 4 lists the germplasm repositories and their locations and the gathered materials.

Table 3. List of germplasm repositories and their characteristics around the Mediterranean countries

Country	Germplasm repositories	Material	Location
Algeria	University of Mascara, ITAFV – Tighennif	06	Exp. station (35°22'N, 0°11'E)
Spain	IRIAF-Chaparrillo	11	
	IRTA-Mas Bove	45	
	Centro de Investigacion y Tecnologia Agroalimentaria (CITA)	76	
Tunisia	Institut National de Recherche Agronomique de Tunisie	25	Exp. station-Mornag(36°38′N, 10°16′E)
	Institut de l'Olivier	13	Exp. station- Taous (34°56'N,
	Centre Régionale de Recherche Agronomique de Sidi Bouzid	03	10°36'E) Exp. Station (35°01'N, 9°26'E)
Turkey	Ceylanpinar State Farm, in Sanliurfa	-	Exp. station (36° 50' N, 40° 2' E)
	Pistachio Research Institute in Gaziantep	79	Exp. station (37° 3'N, 37° 20'E)

Cultivars and rootstocks commercially available

For pistachio, few potential cultivars and rootstocks are widely used and commercially available in nurseries. It represents the main constraint in face to climate change and the high demand for nuts.

Cultivars: Less than 10 cultivars commercially cultivated around the Mediterranean basin as Achoury, Aegina, Bianca, Kerman, Siirt, Tekin, Kirmizi, Uzun, Mateur and Sirora.

Rootstocks: the use of wild species and pistachio as rootstocks is common in the Mediterranean region. Seedling of *P. vera*, *P. atlantica*, *P. Terebinthus* and *P. Khinjuk* are produced by nurseries. These species are grafting compatible with pistachio cultivars. New released rootstocks are nowadays propagated as UCB1 and Platinum.

III – Research capabilities, programmes and activities on breeding

With initial cooperation connecting many research institutes around the Mediterranean countries and other producing countries, efforts were oriented to collect different cultivars for trial purposes. Germplasm collections were implemented around the Mediterranean region as in Spain, Tunisia and Turkey (Table 4).

Different research programmes were implemented dedicated to characterization of genetic diversity, selection of female and male combinations for efficient pollination, rootstocks and wide spreading pistachio cultivation, horticultural practices and pest and diseases.

However, breeding activities and selecting new cultivars are somewhat limited. New cultivar development studies were initiated with the breeding of male and female cultivars in Spain (Vargas and Romero, 2005; Vargas *et al*., 2001).

In Turkey, breeding selection programme is going on, with around 10000 hybrid plants (8500 plants female) obtained based on molecular marker system and some new cultivars released (Ak, 2019). Moreover, different national research programs are ongoing.

Nuts crops are receiving more interest via international projects and different funding initiatives. For example, projects implemented by PRIMA foundation included pistachio, when highlighting aspects related to sustainable production, water management and climatic requirements. SUPROMED Project, funded by PRIMA "Sustainable Production in water limited environments of Mediterranean agro-ecosystem", aims to enhance the economic and environmental sustainability of Mediterranean farming systems through a more efficient management of water, energy and fertilizers and to provide effective advice for more efficient crop management, including pistachio. AdaMedOr Project "Adapting Mediterranean Orchards- science-based design of resilient fruit tree portfolios for the Mediterranean region" harnessed recent advances in phenology modeling and a wealth of phenology data to produce the first reliable framework for predicting climate change impacts on tree crops of the Mediterranean. With Horizon 2020, the project BIOCONTROL-A "Biocontrol of Aflatoxin Contamination Using Atoxigenic Strains from Almond and Pistachio Orchards" addressed the problem of nuts quality.

Table 4. Research institutions working on pistachio in the Mediterranean countries

Country	Institution	Material	Programmes
Algeria	Univ Mascara, ITAFV – Tighennif	Germplasm	- Plant materials performances
Spain	IRIAF-Chaparrillo IRTA-Mas Bove CITA	Germplasm Germplasm Germplasm	- Pollination studies: phenological monitoring of male and female flowering - Examination of new pistachio cultivars and rootstocks for the EU-CCPV (protected cultivars, DUS examination) - Official certification of good quality pistachio seedlings - Private plant breeding programs (in their initial phase).
Tunisia	IO INRAT INAT CRRA SB	Germplasm Germplasm - Germplasm	- Agroclimatic requirements - Selection of male pollinators - Plant materials performances - Scion-Rootstock interactions - Healthy Products: Organic
Turkey	Ceylanoinar State farm, Sanliurfa Pistachio Res. Institute Gaziantep Univ at Southeast Anatolian Region Siirt University	Germplasm Germplasm - -	- Female & Male tree selection - Research on cultivars & rootstocks (*P. khinjuk*, *P. atlantica*, UCB-1) - Propagation of rootstocks including tissue culture - Pest &Diseases Management

IV – Demands and needs of producers and the industry

With the experts exchange on defining the demands and needs of producers and industry around the Mediterranean some key elements were summarized onthe Table 5.

Table 5. Main constraints, demands, needs and challenges for pistachio plant materials and breeding

Constraints	Demands/needs	Challenges
Climate change Increasing temperature	Low-chill cultivars	Appropriate estimation methods Valorization of phenological data set
Drought & water scarcity Saline water	Salt-tolerant rootstocks	Promising results as UCB1, *P. atlantica*
Pest & diseases Foliar & Fruit Fungi Bacterial Diseases Fungal Diseases	Tolerant cultivars Tolerant rootstocks	Integrate Pest Management
Nuts quality	High industrial quality (deep green kernel) High table quality (salt, dehiscent) Healthiness quality (mycotoxin free)	Genetic dependence & early harvesting Genetic dependence & appropriate horticultural practices Appropriate horticultural practices, harvest & storage
Alternate-bearing	Low alternate bearing Index Short juvenile period	Genetic dependence & appropriate horticultural practices

V. Conclusions and perspectives

The Mediterranean region presents interesting potential for pistachio cultivation with favorable conditions as climate and land of different types of soils. However, few potential cultivars are widely used. Less than 10 cultivars are commercially cultivated around the Mediterranean basin as Achoury, Aegina, Bianca, Kerman, Siirt, Tekin, Kirmizi, Uzun, Mateur and Sirora, while pistachio is highly demanded by the food industry and consumers for various uses and highly appreciated products. Moreover, Mediterranean countries present variable nuts productivity, which is highly linked to germplasm and practices as using alternate bearing cultivars, inappropriate male/female ratio and repartition in orchards.

New trends for commercial production orchards are being developed driven by increasing nuts consumption, increasing the adoption of irrigation and the use of new rootstocks. More skills are being gained on irrigation water management and the use of saline water, as well as the release of new rootstock as UCB1, and Platinum.

With increasing demand for pistachio more care for healthy products is needed. Nuts and kernel quality assessments must be a key action to achieve this objective. Sanitary and phytosanitary measures to prevent pollution included appropriate agricultural practices, plant materials and certifications (e.g. as organic products). The lack of information exchange on plant materials performances could induce planting unsuitable cultivar with climatic requirements not well adapted to the farm context. Moreover, the development of nuts industry around the Mediterranean was initially supported by international actions and programmes dedicated to nuts as the GREMPA initiative and the FAO-CIHEAM Nuts Network. However, the lack of funding and coordination of further international initiatives has been the rule, and only few cooperation projects have been funded that included nut crops. For this reason, fruitful collaborations are now requested including private sector and public research efforts.

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Plant Material for the Future of Nut Production in the Mediterranean Region: Walnut Case Study

Fabrice Lheureux[1], Erica Adele Di Pierro[2] and Eloïse Tranchand[3]

[1]CTIFL, centre de Lanxade28 route des Nébouts 24130 Prigonrieux (France)
[2]Fruit Crop Genetics and Breeding Unit, Fondazione Edmund Mach
Via Mach 1, 38098 San Michele all'Adige (TN) (Italy)
[3]Station expérimentale de Creysse,
30 route de Perrical – 46600 Creysse (France)

Abstract. The walnut tree is of significant economic importance in Mediterranean regions. It is a versatile crop for farmers by providing both fruit and valuable timber. From the mid-20th century to the present, walnut production has continued to grow. Currently, almonds and walnuts vie for the highest production among nuts. In 2023, global walnut production experienced a 4.8% decline, amounting to 3.7 million tons. Due to the ancient origin of walnut in Mediterranean countries, each region has developed many local varieties adapted to their specific pedoclimatic conditions. From the mid-20th century to the present, walnut developments have resulted in a mosaic of orchard types, ranging from extensive orchards with traditional varieties, often grouped together under a quality label, to intensive orchards with high-yielding varieties. Many diverse management methods are used in Europe to grow walnuts, mainly according to local climatic conditions and traditional practices. European research and development activity related to walnut varietal improvement is very limited. Like many fruit species, walnut must cope with a growing number of biotic and abiotic stresses. Given these challenges, the walnut industry must adopt a holistic response encompassing multiple challenges, with plant material being a crucial component.

Keywords. Walnut – Orchard types – Cropping methods – Local varieties – Characterization – Adaptation.

Matériel végétal pour l'avenir de la production de fruits secs dans la région méditerranéenne : étude de cas sur le noyer

Résumé. *Le noyer revêt une importance économique considérable dans les régions méditerranéennes. Il s'agit d'une culture polyvalente pour les agriculteurs, car elle fournit à la fois des fruits et du bois précieux. Depuis le milieu du XXe siècle jusqu'à aujourd'hui, la production de noix n'a cessé de croître. Actuellement, les amandes et les noix se disputent la première place parmi les fruits à coque. En 2023, la production mondiale de noix a connu une baisse de 4,8 %, pour atteindre 3,7 millions de tonnes. En raison de l'origine ancienne du noyer dans les pays méditerranéens, chaque région a développé de nombreuses variétés locales adaptées à ses conditions pédoclimatiques spécifiques. Du milieu du XXe siècle à nos jours, les développements dans le domaine du noyer ont donné lieu à une mosaïque de types de vergers, allant des vergers extensifs avec des variétés traditionnelles, souvent regroupées sous un label de qualité, aux vergers intensifs avec des variétés à haut rendement. De nombreuses méthodes de gestion sont utilisées en Europe pour cultiver les noix, principalement en fonction des conditions climatiques locales et des pratiques traditionnelles. Les activités de recherche et développement européennes liées à l'amélioration variétale des noix sont très limitées. Comme de nombreuses espèces fruitières, la noix doit faire face à un nombre croissant de stress biotiques et abiotiques. Compte tenu de ces défis, l'industrie de la noix doit adopter une réponse holistique englobant de multiples défis, le matériel végétal étant un élément crucial.*

Mots-clés. *Noyer – Types de vergers – Méthodes culturales – Variétés locales – Caractérisation – Adaptation.*

I – Introduction. Economic importance and cultivation in the Mediterranean region

1. History and science

The Persian walnut (*Juglans regia* L.) is a widespread monoecious tree species within the order Fagales and family Juglandaceae, which comprises approximately 50 species across 11 genera (Fig 1). The genus *Juglans* includes over 20 species classified into four sections, with Dioscaryon containing only *J. regia*.

Persian walnut domestication likely originated in Central Asia, specifically in the foothills of the Western Himalayas, extending from Tajikistan to Kyrgyzstan. The species subsequently dispersed westwards to region including Uzbekistan, northern Iran, the Caucasus, and eastern Turkey, and eastward into northern India, Nepal, and western China.

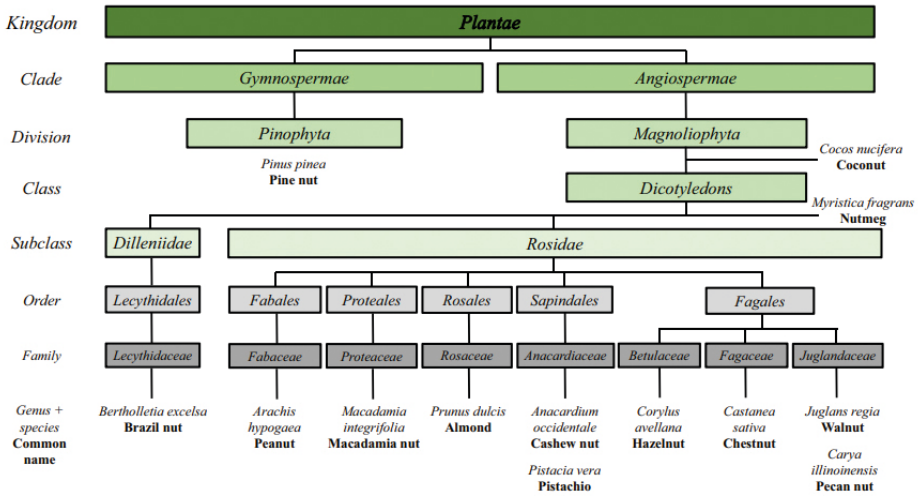


Fig. 1. Botanical classification of nuts adapted from Jacquenet and Moneret-Vautrin (2007) and according to the Angiosperm Phylogeny Group (APG III 2009).

Persian walnut was introduced into Europe and the Balkans before the last glacial period (~ 50.000 ya). During the Ancient Greek era, Alexander the Great (~350 B.C.) facilitated the species dispersal. Human-mediated distribution continued into the Roman Empire period (~ 27 B.C. to ~ 395 A.D.), spreading the walnut to regions such as Spain and North Africa.

Tree nuts, including *J. regia,* represent one of the oldest food sources for humans, birds and wild animals, with extensive cultural and historical roots in Mediterranean societies. Some references for walnut importance in ancient and moder times are given by Casas-Agustench *et al.* (2011) and Salas-Salvadó *et al.* (2011):

- In ancient Persia (modern-day Iran), walnuts were considered a royal food, used in various culinary applications.
- Greeks and Romans valued walnuts not only for food but also for medicinal purposes, hair dyes, and fabric colouring.

- In France, walnuts were served at royal banquets as early as the 14th century, often preserved in honey and spices.

The walnut tree is of significant economic importance in Mediterranean regions. It is a versatile crop for farmers by providing both fruit and valuable timber. In the 18th century, despite substantial production, the trade primarily focused on walnut oil rather than fruit. Approximately 75% of farmers used walnut oil exclusively for cooking. Beyond its culinary applications, walnut oil was extensively used for lighting, painting, decoration and soap making. The wood of *J. regia* was highly prized in cabinetry as well as for the manufacture of clogs and oxen yokes. Despite high production, dedicated orchards were absent; trees were planted along roadsides and field boundaries, or harvested in forest conditions. The exploitation of walnut fruits through their transformation for daily use represents the first innovation.

Especially in France, walnut production declined sharply in the mid-19th century. Several extreme cold weather events, notably one in 1830, caused the death of many trees. Additionally, and the development of oil derived from cereals and palm trees further diminished the prominence of walnut oil production. This period marks the end of the first revolution and the beginning of the second one which could be related to an industrial revolution, even if, as we will see later, we are still very far from the industrialization of walnut cultivation. It was only at the beginning of the 20th century that systematic cultivation of walnut began, this time with the development of the fruit market itself. In 1950, the walnut sector mobilized to create, on a modern basis, new walnut groves from traditional varieties. The first real orchards appeared.

2. Economical data

From the mid-20th century to the present, walnut production has continued to grow. Currently, almonds and walnuts vie for the highest production among nuts. In 2022, global walnut production as slightly surpassed almond production, reaching over 3.8 million tons (Fig. 2). In 2023, global walnut production experienced a 4.8% decline, amounting to 3.7 million tons.

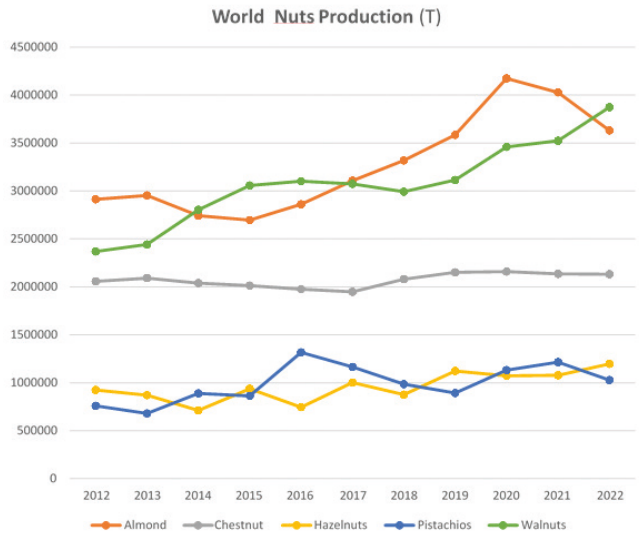


Fig. 2. World nuts production (FAOSTAT 2022).

Production is dominated by five main countries: China, the USA, Iran, Turkey and Chile, which collectively contribute 66% of global output. Including Burkina Faso, Mexico and Ukraine, each exceeding 100,000 tons in 2022, these eight countries account for 78% of world production. Greece, ranking 9th, is the leading European producer, followed by France in 12th place (Fig. 3). Well behind Turkey, Greece and France are the largest walnut producers among Mediterranean countries (Table 1 and Fig. 4). Other notable producers include Italy (21 870 metric tons), Spain (16 590 metric tons) and Morocco (12 736 metric tons).

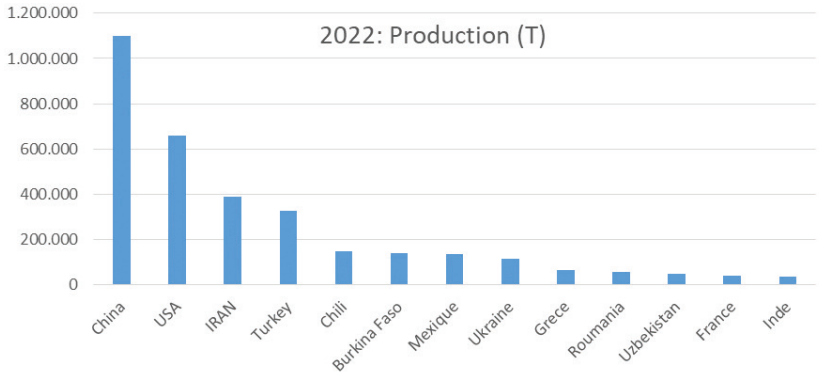


Fig. 3. Main walnut producing countries (FAOSTAT, 2022).

Despite being a significant producer, the European Union (EU) is a net importer of walnuts, with regional consumption exceeding domestic production, leading to increased imports (USDA, 2024). For instance, Italy imports about 80% of its walnut consumption, despite producing 11% of the EU's walnuts imports primarily come from Chile and the USA.

Until 2021, walnut prices were relatively high, ranging from €2.5 to €3.5 per kilogram, and favourable to producers. However, exceptionally high production in 2022, combined with very high stocks, led to a market collapse. Walnuts were trading at 1€/kg, plunging the global industry into a deep crisis. This crisis led to the uprooting of orchards, the extent of which remains unquantified. This crisis is global, affecting all producer countries. In the USA, similarly to Europe, the production cost in California in 2022 was approximately €1.5/kg, while purchase prices ranged between €0.60 and €0.80 per kg. The severe crisis is unprecedented for the sector, unlike recent economic disruptions such as the COVID-19 pandemic or the subprime mortgage crisis.

Table 1. In shell walnut production in the Mediterranean countries (FAOSTAT data, 2022)

Country	Production (t)	Surface (ha)
Turkey	335,000	166,495
Greece	60,680	16,710
France	49,680	27,000
Italy	21,780	5,440
Spain	16,590	12,710
Morocco	12,736	7,040
Portugal	7,130	5,490
Total	**503,596**	**240,885**



Fig. 4. Main walnut producing regions in the Mediterranean countries.

3. Cultivation

From the mid-20th century to the present, walnut orchards have evolved significantly due to advancements in technology, agricultural practices, and varietal development. However, these developments, have resulted in a mosaic of orchard types, ranging from extensive orchards with traditional varieties, often grouped together under a quality label, to intensive orchards with high-yielding varieties. Many diverse management methods are used in Europe to grow walnuts, mainly according to local climatic conditions and traditional practices. The main methods of walnut cultivation in Europe are as follows (Fig. 5):

Fruting type	Vigour	Type of Orchard	Habit	Planting rate
Terminal fruiting varieties (Old French varieties)	High	Semi-intensive	Goblet	12m x 13m (64 trees /ha)
	Average	Semi-intensive	Goblet	10m x 11m (91 trees /ha
		Intensive	Goblet / free axis	7m x 8m (180 trees /ha)
Lateral fruiting varieties (Fernor, Lara, Chandler)	High	Intensive	Goblet/free axis / structured axis	7m x 8m
		Hedge system	free axis/ structured axis	9m x 4,5m
	Average	Hedge system	free axis/ structured axis	8m x 4m
	low	Hedge system	structured axis	7m x 3,5m

Fig. 5. Different walnut cultivation methods.

Traditional cultivation

Traditional walnut growing in Europe is characterized by low-density planting, with spacing of 10m x 10m to 12m x 12m, meaning 70 to 100 trees per hectare.

Intensive cultivation

More intensive methods have been developed mainly in the USA and are now being adopted in Europe, involving high-density orchards with spacings ranging from 3m x 3m to 8m x 8m depending on the variety and local conditions. This method utilizes highly productive lateral-fruiting and early flowering American varieties and hybrids, such as Lara, Chandler, Hartley or Fernor.

Agroforestry

Walnuts are integrated into agroforestry systems, planted in fields or gardens alongside other crops or livestock, optimizing the use of space between trees.

Timber production

Some cultivation methods are aimed at producing high-quality wood, with trees planted at wider spacings (10-12m) to reduce competition for light.

These different cultivation methods reflect the walnut's adaptation to diverse environmental conditions and production objectives (fruit, timber, or both) across Europe. Despite this diversity in cultivation methods, most modern orchards have converged on a similar structure characterized by (Fig. 5 and Fig. 6): (i) medium density planting with 180 - 240 trees per hectare (7m x 6m or 8m x 7m); (ii) grass cover between rows and weed control along the rows; (iii) manual or mechanical pruning; (iv) irrigation under foliation using drop by drop or spray methods and (v) adoption of mechanical harvesting.



Fig. 6. Modern walnut production techniques. Tree spacing (7m x 6m or 8m x 7m) (A); Manual or mechanical pruning (B); Drip and sprinkler irrigation (C); mechanised harvesting (tree shaking and integrated harvester) (D).

II – Plant material catalogue summary

1. Some examples of local varieties

Due to the ancient origin of walnut in Mediterranean countries, each region has developed many local varieties adapted to their specific pedoclimatic conditions. Some examples are illustrated in Fig. 7. These varieties are often found in small areas within old orchards or conserved in germplasm collections. To date, we have listed five germplasm collections, including both local and foreign varieties as well as new hybrids (Table 2), but we're convinced there are more out there. Additional collections likely exist, and the list can be expanded.

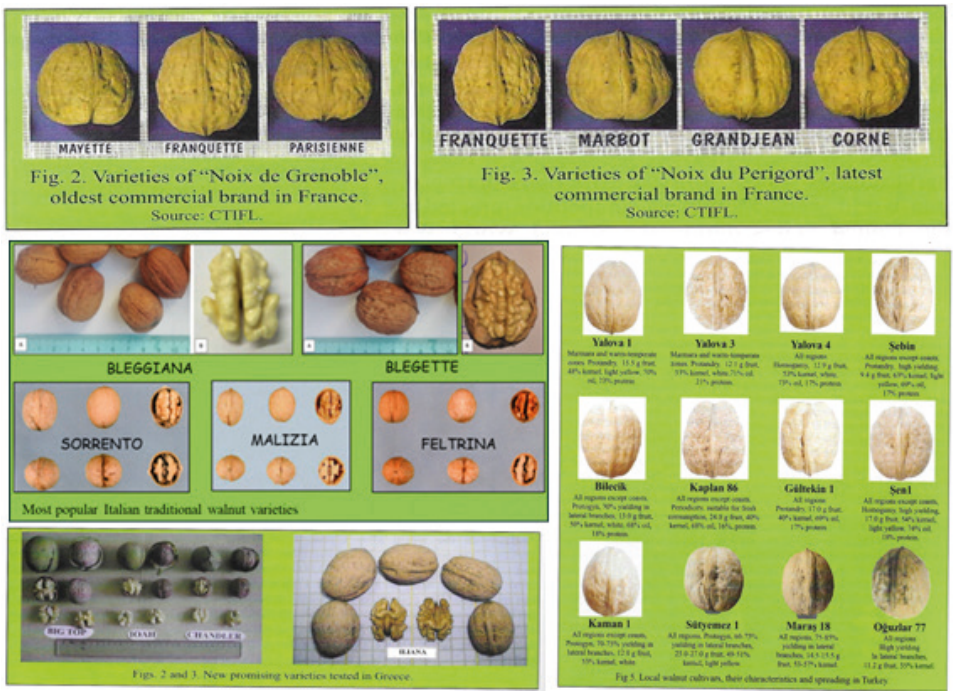


Fig. 7. Exemple of some local varieties from France, Italy, Greece and Turkey.

In modern plantations across the Mediterranean zone, only a few varieties have become predominant due to their productivity and more efficient breaking yield. Notably American varieties, such as Chandler, dominate, along with French varieties like Fernor and Lara. Despite its terminal fruiting characteristic, the Franquette variety remains widely planted due to its hardiness and high kernel quality and superior taste.

The main commercial varieties are produced by most nurseries, with traditional or local varieties available upon request. In specific cases, producers may graft and propagate their own plants.

Table 2. Some germplasm collection and experimental sites

Country	Institution	Germplasm collection	Experimental sites
France	INRAE	X (Near Bordeaux) more than 300 varieties and species	
	CTIFL		X (Bergerac)
	CREYSSE	X (Core collection)	X
	SENuRA		X
Greece	Univ. of Thessaly & IPB&GR-DEMETER	X	
Italy	FEM CREA	Germplasm collection Germplasm collection	X
Spain	IRTA	X	X (site for inscription)
Turkey	University of Kahramanmaraş Sütçü Imam (SEKAMER)	(Near Kahramanmaraş) more than 250 varieties and species Germplasm collection - work in progress	

2. Rootstocks

Regarding rootstocks, the majority of walnut varieties are currently grafted onto *J. regia* seedlings. Occasionally, *J. nigra* or interspecific *J. nigra* x *J. regia* hybrids are used.

The University of California, Davis, has seen increased use of clonal rootstocks. The oldest developed rootstock is Vlach, an interspecific hybrid (*J. regia* x *J. hindsii*). Recently, two additional interspecific rootstocks, RX1 and VX211 have been introduced in Europe, involving 3 species*: J. regia*, *J. hindsii* and *J. microcarpa*. Two additional rootstocks are likely to have been developed in Europe by a Portuguese nursery. They are either pure *J. major* or a *J. major* x *J. regia* hybrids.

III – Research capabilities, programmes and activities on breeding

1. Overview in Mediterranean Europe

Compared to institutions such as the University of California, Davis in the USA, and research bodies in China and Iran, European research and development activity related to walnut varietal improvement is very limited, particularly in Mediterranean countries. Nevertheless, Table 3 highlights ongoing in certain countries.

These programmes include the characterization of local varieties or native populations, as in Greece, Turkey and Italy, as well as varietal creation (e.g. in Turkey), and the evaluation of new varieties and rootstocks from former programs, such as those overseen by Eloïse Tranchand at the Experimental Station of Creysse, in France. Although Spain has ceased walnut research for fruit production, its partnership with France for examinations is noteworthy. Finally, Italian researchers are focusing on effective tools for germplasm genotyping and characterization.

Table 3. Research on walnut genetic resources and breeding in Mediterranean Europe

Country	Organism	Research program
Greece	Univ. of Thessaly & IPB&GR-DEMETER	Characterization of local varieties/native population
France	INRAE, CTIFL, Creysse and SENuRA	Evaluation and characterization of new varieties and rootstock from INRAE breeding program (initiated 1970)
Italy	FEM	Characterization of local varieties/native population Tools for germplasm genotyping
Spain	IRTA	Partnership with France (GEVES) for DUS testing of new varieties DUS tests are carried out for different purposes: • Registering new varieties in the Catalogue of plant varieties (CTPS) • Protecting a variety with a French Plant Variety Right (INOV) • Protecting a variety with a European Plant Variety Right (CPVO) • On behalf of other European or non-European Examination Offices.
Turkey	University of Kahramanmaraş Sütçü Imam	Hybridization breeding programs (variety and rootstock) Characterization of local varieties/native population

2. Research capabilities for the characterization of local varieties: the example of Italy

Walnut cultivation in Italy has experienced significant changes over the decades, with a marked decline from 33,000 hectares in the 1960s to just 3,441 hectares in 2011. Recently, there has been a slight increase to approximately 5,000 hectares. Despite the decline, Italy's climate and environmental conditions are well-suited for walnut cultivation, ranging from the Alps to Sicily at elevations from sea level up to 1,200 meters. Traditional cultivation systems are prevalent in specific regions, such as the Bleggio area in Trentino, where local varieties like 'Bleggiana' and 'Blegette' are grown (Fig. 8). These systems often utilize environmentally sustainable practices, fostering the conservation of genetic diversity and promoting high-quality production.



Fig. 8. In Italy, the project 'NoBle' aimed at the valorization and characterization of the locally grown varieties: the two traditional 'Bleggiana' and 'Blegette' and the commercial one 'Lara'.

Characterization of walnut germplasm and local Varieties: the example of the project "NoBle" in Italy

The NoBle project, spearheaded by the Edmund Mach Foundation (San Michele all'Adige, Italy) and co-funded by CARITRO Foundation, aimed to enhance the value of traditional walnut varieties in the Trentino region. The project employed a multidisciplinary approach to characterize the genetic, nutritional, and consumer preference aspects of the local varieties, 'Bleggiana' and 'Blegette', compared to the commercial cultivar 'Lara'. The ultimate goal was to promote the cultivation of these traditional varieties and establish a high-quality local market.

Varietal identification and genetic diversity

Genetic characterization using Single Sequence Repeat (SSR) and the Axiom® Walnut 700K Single Nucleotide Polymorphism (SNP) array (Krauß et al., 2020) markers confirmed the uniqueness of 'Bleggiana' as an autochthonous cultivar (Fig. 9). The study also identified 'Blegette' as a newly described local variety, distinct from the French 'Franquette' (Marrano *et al*., 2019). These findings highlight the rich genetic diversity of the local walnut germplasm, which is essential for breeding programs and the preservation of traditional varieties.

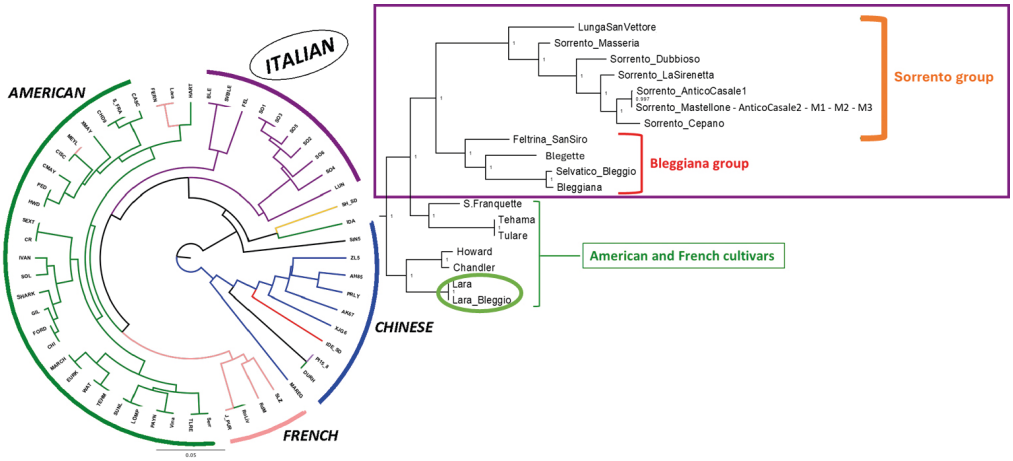


Fig. 9. UPGMA dendrogram of 56 varieties, produced with PHYLIP (v3.697; bootstrapping = 1000). The Axiom® Walnut 700K SNP array was used to explore the Italian walnut genetic diversity by genotyping of Italian accession and international varieties from the WIP UC Davis. In the violet square on the right, a close-up of the Italian varieties group is provided to highlight its subgroups.

Nutritional properties

A comprehensive metabolic profiling was conducted to compare the nutritional content of traditional and commercial walnut varieties. The analysis focused on the polyphenol content and the ω-6/ω-3 fatty acid ratios. Results demonstrated that 'Bleggiana' and 'Blegette' have higher polyphenol content (Fig. 10) and more favourable ω-6/ω-3 fatty acid ratios compared to the commercial 'Lara', cultivated in the same environment. 'Bleggiana' exhibited the highest relative amount of ω-3 lipids and ellagitannins, which are associated with various health benefits, including cardioprotective effects. These local varieties exhibit superior nutraceutical properties, supporting their potential role in promoting health and well-being.

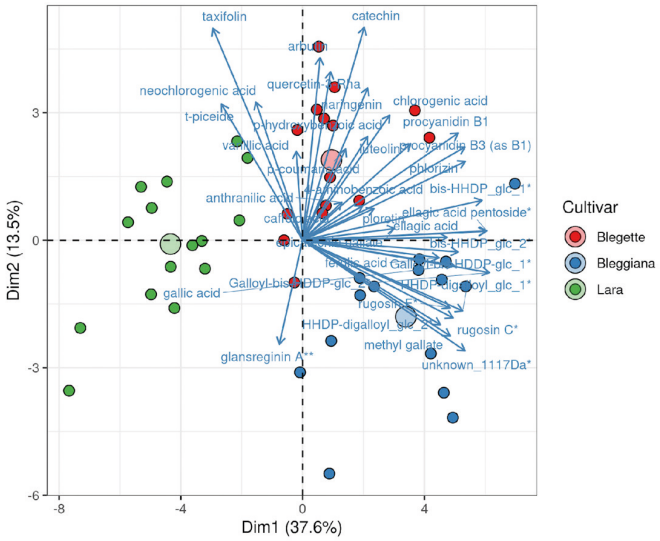


Fig. 10. Principal component analysis (PCA) of three walnut cultivars ('Bleggiana', 'Blegette' and 'Lara') based on 35 polyphenolic constituents after removal of the year effect. The score plot shows the first two PCs, which account for 50% of the total variance, and a clear separation between the three cultivars; large circles show the centroid of each cultivar cluster. (Modified from di Pierro et al., 2022).

Consumer acceptance

A consumer acceptance test was conducted to evaluate the sensory attributes (visual and taste) of 'Bleggiana', 'Blegette', 'Lara', and 'Chandler', one of the most popular commercial walnut varieties. Participants received background information on the provenance, agronomic practices, and nutritional value of each walnut variety. to assess how this knowledge influenced consumer preferences.

Results showed that 'Blegette' received the highest scores for visual appeal and taste quality. Notably, consumer preferences were more influenced by the provenance, agronomic practices, and nutritional value of the walnuts, rather than cost, emphasizing the importance of these factors in driving consumer choices. These findings support the promotion of traditional and locally adapted walnut varieties, like 'Bleggiana' and 'Blegette', in the market.

Geographical traceability

Geographical traceability is crucial for maintaining the authenticity and quality of traditional walnut varieties. Within the NoBle project, an innovative approach to trace the origin of walnuts was tested, aiming to ensure the unique characteristics of local cultivars are preserved and promoted. The exploratory analysis investigated the capability of hydrogen (H), oxygen (O), carbon (C), nitrogen (N), and sulfur (S) stable isotope ratios, coupled with 56-element profiles, to differentiate Italian walnuts on a regional and global level (Krauß *et al*., 2020**)**.

The analysis highlighted that the combination of stable isotope ratio and trace element analysis of walnut kernels can effectively discriminate the geographical origin of walnut. However, using each individual approach separately does not suffice for fully discriminating the provenance (Fig. 11).

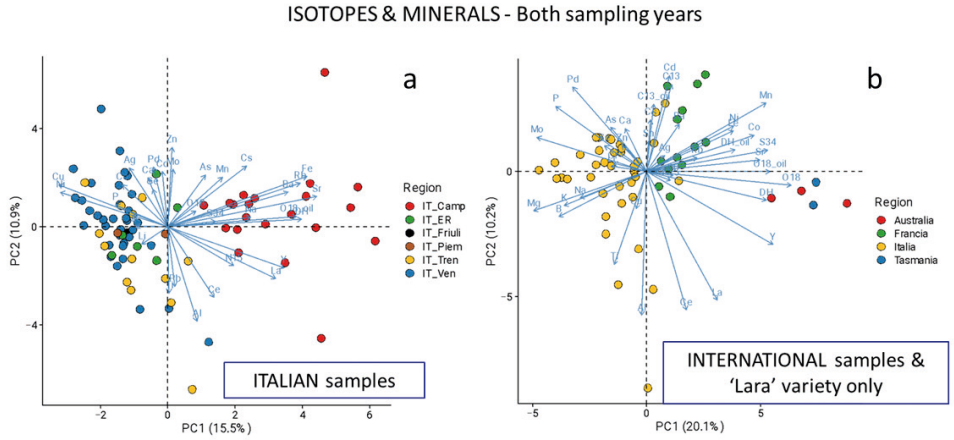


Fig. 11. The unsupervised Principal Component Analysis (PCA) score plot with variable contributions indicates that the integrated analysis of isotopic profiles and mineral elements can potentially trace the geographical origin of walnuts. The PCA conducted on Italian samples (a) reveals a clear distinction between those from the Sorrento Peninsula, cultivated on volcanic soil, and those from northern Italy. Additionally, an analysis focused solely on the Lara variety (b) suggests a possible differentiation between Italian samples and those from France, and a more pronounced distinction from samples originating in Australia and Tasmania.

Overall, the preliminary results obtained reinforces the potential of chemical signatures for tracing nuts to their geographic origin. However, developing a reference collection of stable isotope signatures and chemometrics is essential. This methodology must be tested with a larger number of samples from each region of walnut cultivation and production, and a reference database, particularly for isotope ratio data, should be provided annually to account for the harvest year effect. Additionally, samples from the same sites should be collected for more than two consecutive years to obtain a clearer understanding of annual weather variations.

In conclusion, the NoBle project provides a comprehensive characterization of traditional walnut varieties, highlighting their genetic uniqueness, superior nutritional properties, and consumer appeal. These findings support the promotion and conservation of local walnut germplasm, contributing to sustainable agricultural practices and high-quality walnut production in Italy.

IV – Demands and needs of producers and the industry

Before discussing future advancements, it is essential to reflect on the state of the art we have inherited. The longevity of the walnut tree parallels the extended process of plant breeding which historically spans 35 to 45 years to obtain a new variety. Initial selection criteria were limited, focusing primarily on improving productivity. Specifically, breeding efforts prioritized lateral fruiting through crosses involving American varieties and aimed for larger nut size. Rootstock improvement programs concentrated on enhancing vigor.

The industry's sole quality criterion was achieving varieties with clear kernels. Additionally, albeit secondary, tolerance to bacterial blight and anthracnose (*Gnomonia lepstostyla*) for varieties and tolerance to black line disease for rootstocks were evaluated. The diseases mentioned above were major pathological challenges when the improvement programs began in the 80s and 90s.

Contemporary walnut producers in the Mediterranean face several major challenges, reflecting an expanded list of demands and needs. This list echoes the increase in the number of biotic stresses affecting walnut, with the emergence of new diseases, new pests and heightened pressure from existing pests. Moreover, climate change poses significant abiotic stresses, such early frost, high temperatures, intense rainfall, drought and mild winters. Adverse weather conditions, such as summer drought and high autumn humidity, have led to significant crop losses, reaching up to 50% in 2023 (Reussir, 2024) (Fig. 12).

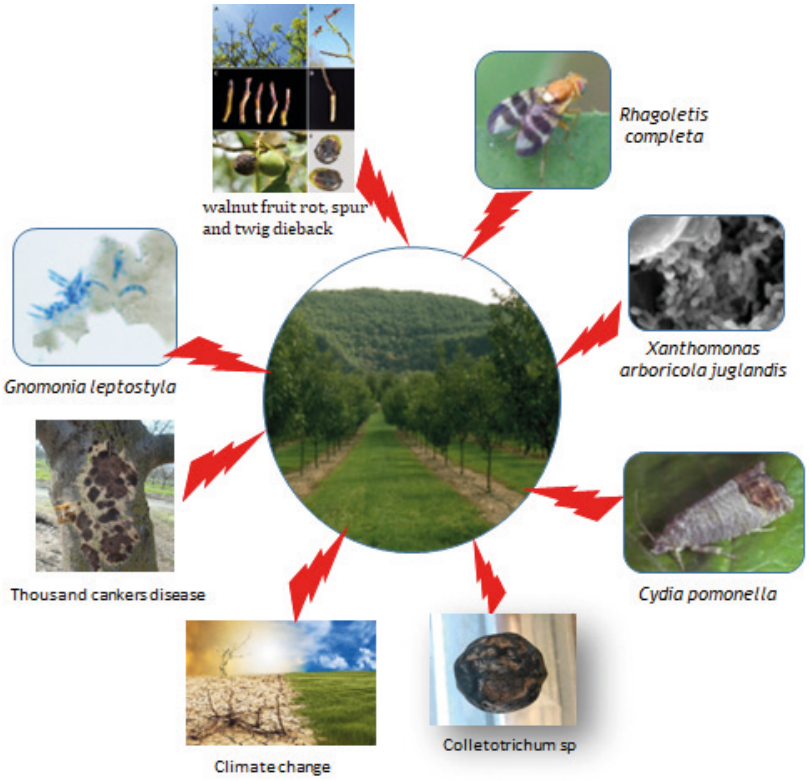


Fig. 12. Biotic and abiotic stress affecting walnut.

These health and environmental issues are exacerbated by price volatility, where producers experienced major fluctuations in market prices, often below production costs. Furthermore, international competition, particularly from new 'players' like Chile, has disrupted established value chains and intensified market competition in Europe Lastly, in an inflationary context, declining consumption arises as walnuts are perceived as a non-essential.

V. Conclusions and perspectives

Given these challenges, the walnut industry must adopt a holistic response encompassing multiple challenges and actors, with plant material as a crucial component. The escalating abiotic and biotic stresses on walnut trees necessitate the rapid development of new varieties. Two complementary approaches can be pursued:

- The first is the characterization of existing varieties from natural populations or germplasm collections. This approach allows a direct selection of potential new varieties with desirable traits or identifying new breeding material for targeted traits. The genetic mapping of selected varieties helps identifying specific genes associated with desirable traits and advanced molecular techniques (like marker-assisted selection) can then be used to quickly select plants that carry these genes, bypassing the lengthy traditional breeding cycle. Another important step of this approach is phenotyping. Detailed phenotypic characterization allows for precise selection of varieties that exhibit desired characteristics under specific environmental conditions. The precision would reduce the number of generations needed to achieve the desired traits in new varieties.

- The second approach consists of implementing new breeding programs using selected varieties and new breeding material. Once potential new varieties are identified, they can be used as parent plants in new breeding programs. Cross-breeding these selected varieties with other promising candidates can produce offspring that combine multiple desirable traits more quickly. Techniques like genomic selection, CRISPR gene editing, and somatic hybridization can significantly speed up the breeding process Jeon *et al*., 2023). These technologies allow for precise modifications and faster development of new varieties, reducing the time from initial crossbreeding to market-ready plants. Additionally, high-throughput screening methods could help to quickly evaluate large numbers of breeding lines for target traits, accelerating the selection process, and automation and machine learning could further enhance the efficiency and accuracy of this screening.

Traditional breeding processes are definitely time-intensive; but together, these innovative approaches, leveraging advanced technologies, streamline the breeding process, making it faster and more efficient reducing the time for developing new varieties and meet growers' need more efficiently.

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Conclusions

1. In response to increasing demand, nut tree cultivation techniques are evolving considerably in general, although the stage of development varies according to species. **Modern systems co-exist with traditional systems**. Intensive almond, pistachio and hazelnut production systems and associated technologies are developing rapidly in Mediterranean countries. Walnut production is less dynamic and diverse in terms of cultivation systems, whereas chestnut production integrates modern intensive plantations (agro-chestnut systems) and traditional agroforestry systems. Stone pine has traditionally been managed within forestry systems but plantations under agronomic management are now being established. Pecan is a minor species in the Mediterranean, but has considerable potential under Mediterranean growing conditions, as some cultivars have low chilling requirements and therefore are more adaptable to emerging climatic conditions.

2. Breeding programmes

In parallel to the dynamics of the production systems, **there are significant differences between species and Mediterranean countries in the volume and progress of breeding activities.** Almond currently accounts for the greatest level of activity, particularly in the development of new protected varieties. The lowest level of activity is found in pecan, which has a lower economic value and limited crop surface area.Studies on rootstock breeding are limited, and more studies need to be carried out in this field.

A tentative ranking of breeding activity in the region would be: almond - hazelnut - chestnut - pistachio - walnut – stone pine – pecan, although this ranking would differ on a global scale.

Breeding goals in Mediterranean nut trees are diverse, responding to the particular characteristics of each species. In general, however, they can be grouped into three general categories: **nut quality, tolerance to abiotic stresses such as drought and salinity, and tolerance to biotic stresses.** Industry and markets require sufficient volume, consistent quality and stability in supply. Breeding programmes should take these requirements into account, as they will influence demand, as well as farmers' needs in terms of plant adaptation and crop yield. They must also maintain the levels of genetic diversity required to cope with biotic and abiotic stresses and respond to future challenges.

There is a general need for **funding to maintain and characterise germplasm banks and plant repositories in all countries**, as they are the basis for breeding programmes and contribute to the conservation of genetic resources. One pending task is to identify and unify synonimies affecting cultivar nomenclature in several species.

3. Internationally spread cultivars or local cultivars?

Some cultivars have spread internationally, coexisting with others that have spread on a more local scale. This distinction reflects t**wo different cultivation models and market trends**. The first model seeks to produce large volumes for national/international commerce, treating nuts as commodities associated to health, organoleptic properties, and convenience attributes in general. The second is based on more traditional production systems and markets, supported by geographical indications, quality schemes and brands that aim to link genetic resources to particular production systems and territories, and satisfy demand for additional product attributes. Each model requires a different breeding strategy.

The **international trade model requires homogeneous quality and a stable supply** (see Point 2). Modern cultivation techniques that use varieties that respond to these needs are being developed, particularly for almond, pistachio and walnut). The l**ocal or traditional production model adds value to traditional cultivars** as well as to modern cultivars grown under production systems governed by specific regulations. Examples include: (i) Walnut PGIs in France (e.g. Grenoble and Périgord, with 'Franquette', 'Mayette', 'Parisienne', 'Corne' and 'Marbot'), Italy and Spain ('Pedroso' and 'Nerpio'); (ii) Hazelnut PGIs in Italy ('Nocciola Piemonte', 'Nocciola di Giffoni'), and PDOs for 'Nocciola Romana' in Italy and 'Tombul' in Türkiye; (iii) Chestnut PGIs in Spain, and PDOs in Portugal and Italy; (iv) An almond PGI in Italy (Mandorla di Avola, with 'Pizzuta d'Avola', 'Fascionello' and 'Romana'), and a Portuguese PDO (Amêndoa Douro, from several cultivars).

In some cases, there is a **risk of one cultivar dominating the market**, for example the walnut cultivar 'Chandler', and the chestnut hybrids 'Bouche de Bétizac' and 'Marsol' grown extensively worldwide. This situation may contribute to genetic erosion and increase the risk of plantation failure when growing conditions are not appropriate. Other species, such as hazelnut, do not experience this cultivar dominance.

It has also been observed that several cultivars are represented in numerous germplasm collections or grown in different countries.

4. There are not enough trials to test all the material in germplasm banks or available at commercial scale, and this is a serious bottleneck.

The **full potential of this material may not be exploited** and important information on its performance under different agroecological conditions may be overlooked. In some cases, only limited plant material has been evaluated and this may lead to the same material being used for new plantations everywhere, increasing the risks of biodiversity loss, the spread of pests and diseases, and poor adaptation of varieties to local conditions.

Some countries have **established national trials** that provide more accurate and locally-relevant information of the performance of species and cultivars under different conditions. Examples include walnut in France, hazelnut in Italy, chestnut in Portugal, pistachio in Spain, Turkey and Tunisia, or stone pine in Portugal, Tunisia and Spain. The structure of research in each country determines the feasibility of national trial networks.

5. The importance of genomic tools at international scale

In molecular genetics, researchers have made progress in the **development of genomic tools for germplasm identification, including reference genomes and SNP arrays in almond, walnut and hazelnut**. These advances have been made at EU and Mediterranean scale, and similar progress is likely to have been made in other production areas. An EU chestnut database has already been published, while advances have been made in stone pine research in Portugal and in Spain. These tools are essential for **reducing time in breeding and selection** and for implementing more efficient **plant certification systems**.

Genetic characterisation and genomic identification tools can also **help to protect products and ensure market traceability and nut quality**. This is particularly important for specific brands and products covered by geographical indications, brands or other quality schemes. This is especially challenging for stone pine nuts, where the current problem is not confusion between cultivars or geographical origins, but the marketing of nuts from different pine species that differ considerably in quality and price. This creates unequal competitive conditions for Mediterranean stone pine products.

Examples of **international initiatives for molecular characterisation and databases** with nut tree species include:

- Almond breeding programmes and germplasm collections are collaborating to develop a core collection based on genotyping using the Axiom® platform in an initiative led by IRTA (Spain).
- The chestnut research community has carried out important work on the characterisation of chestnut material, within the framework of the EU project (EUFORGEN).
- In hazelnut, the European Union project SAFENUT (AGRI GEN RES 068) carried out significant research on molecular and morphological characterisations of surviving on-farm landraces in southern Europe. The work was conducted to identify duplicate accessions and material of particular interest. It also contributed to the development of a core collection representing the genetic diversity of hazelnut conserved in European ex situ and in situ germplasm collections.
- Stone pine material of Spanish provenance and selected genotypes have been characterised using the Axiom® 50K array (TF) within the 4TREE initiative led by CSIC-CIFOR-INIA (Spain)

6. Plasticity of species is an important trait

Phenotypic plasticity is an important trait that requires further research, first to establish a clear definition and then to assess, quantify and characterise plasticity responses in different species. Very little is currently known about plasticity in nut tree species, despite its importance for the adaptation of species and cultivars to different environments.

Chestnut has considerable plasticity with regard to the xerothermic index, occurring in areas with index values ranging from 0 to 118, although soil pH constrains its cultivation. Stone pine plasticity has also been widely studied, its high phenotypic plasticity contrasting with its low genetic diversity.

7. Collaboration with industry in research programmes

Nuts are important ingredients in the confectionary industry. Collaboration with this sector is therefore needed to strengthen research in nut tree genetics and breeding. The support provided by the Ferrero Company for hazelnut research in Italy is a particularly noteworthy example. In the chestnut sector, the Eurocastanea network is coordinating research aimed at improving disease management, with the participation of producers.

8. Common research on nut tree species

We need to **reinforce the presence of nut trees in cooperative research projects** and other joint research activities. Current research and innovation programmes normally focus on transversal topics such as abiotic stress, pests and diseases, enabling technologies for better characterisation, registration of varieties, soil and water conservation, rather than on individual species. Nut researchers should therefore seek to work as a compact group in this type of project, and joining forces with researchers working on other permanent crops.

An example of such a project was SAFENUT, a European research project addressing several crop species that ran from 2007-2010. AdaMedOr, FreeClimb, VALMEDALM, SUPROMED or MEDPOMESTONE are further examples of Mediterranean projects supported by PRIMA and focusing on several fruit species including nuts.

There will certainly be opportunities on a larger or smaller scale in PRIMA, COST, INTERREG or HORIZON calls. The group will be attentive to any opportunity that may arise and will share information on calls for proposals or other interesting news when possible.

The European Cooperative Programme for Plant Genetic Resources (ECPGR) aims at ensuring the long-term conservation and facilitating the increased utilization of plant genetic resources in Europe. ECPGR is starting a European Evaluation Network (EVA) on perennial crops that would include nut tree species.

At global level the Temperate Tree Nuts division from the International Society for Horticultural Sciences - ISHS (https://www.ishs.org/temperate-tree-nuts) covers almond and pistachio, walnut and pecan, chestnuts, hazelnuts as well as two cross cutting working groups on orchard management and on propagation and certification.

9. The importance of interprofessional boards for research

The interprofessional organisations or boards play a key role in self-regulating and improving nut production, markets and consumption. **These organisations can also support breeding and research efforts, either directly or indirectly, by helping to align the needs of the sector with research strategies.**

The almond and pistachio boards in the USA and Australia provide good examples of this type of interprofessional organisation. They do not currently exist in Mediterranean countries, but there is interest in establishing them. In the European chestnut sector, the EuroCastanea network (http://www.eurocastanea.org/) connects representatives from Portugal, Spain, France, Italy, Austria and Greece and collaborates periodically with Türkiye, Chile and Japan.

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INTERNATIONAL SEMINAR

PLANT MATERIAL FOR THE FUTURE OF NUT PRODUCTION IN THE MEDITERRANEAN REGION

CIHEAM Zaragoza (Spain) | 25-26 September 2024








BACKGROUND AND OBJECTIVES

The cultivation of nuts in the Mediterranean region relies heavily on the quality of plant material and genetic resources. This area, with its favourable climate, is ideal for growing nuts; however, future challenges require advances in plant breeding and genetic improvement. The development of new, resilient varieties is crucial to withstand climate change, pests, and diseases and to match the growing and changing demands of these fruits. Ongoing research focuses on identifying and conserving valuable genetic material to enhance breeding programmes. Access to diverse genetic resources allows breeders to select traits for improved yield, drought resistance, and pest tolerance. Moreover, biotechnology and genomic tools can play a significant role in accelerating the selection process, enabling the creation of superior cultivars. Ensuring the sustainability of nut cultivation in the Mediterranean region depends on these efforts in genetic improvement and the continuous adaptation of plant material to meet environmental and market demands.

This seminar aims to:

- Assess the current situation of the plant material (varieties, ecotypes, rootstocks - commercially available or in collections) of the main nut species with the greatest potential for the Mediterranean region: **almond, hazelnut, chestnut, walnut, pecan, stone pine, and pistachio.**
- Draw up a list of existing plant materials in Mediterranean countries and their situation in terms of protection and commercial availability.
- Establish the main lines that should guide the identification, conservation, genetic improvement and selection of these plant materials to meet the needs of Mediterranean nut production in the future.
- Identify needs on research, innovation and knowledge exchange to support the development of the sector for more adapted plant materials.

The seminar will be held over two days:

- Day 1: a keynote lecture on the challenges of the industry to guide nut tree plant material of the future, followed by presentations per species, a general discussion, and conclusions.
- Day 2: a field trip to the area of Caspe (near Zaragoza) where we will have the opportunity to see plantations and nurseries working with several species.

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ORGANISATION

The Seminar is organised by CIHEAM Zaragoza (Mediterranean Agronomic Institute of Zaragoza, Spain) and the Agri-Food Research and Technology Centre of Aragon (CITA, Spain), with the collaboration of El Vivero de Abel (nursery) and Afruccas (Association of fruit growers of Caspe). English will be the working language.

The working sessions of Day 1 (25 September) will be open to participation in person (upon registration and limited to 60 available places) and/or via streaming. The registration details are available here.

The field trip of Day 2 (26 September) will be restricted and upon invitation due to limited availability of places.

PROGRAMME

Day 1 – Wednesday 25 September	
Opening - Raúl Compés, Director of CIHEAM Zaragoza - María Aitziber Lanza Goicoechea, Director General for Food Quality and Safety, Government of Aragon - Maria José Rubio-Cabetas, Agri-Food Research and Technology Centre of Aragon (CITA)	**09:00-9:30**
Keynote lecture: Future prospects for the nut industry and the needs of plant material to satisfy production and consumption demands Antonio Pont – INC and SAT Crisol (Spain)	**09:30-10:30**
Coffee break	*10:30-11:00*
Current situation and needs of plant material in Mediterranean nut production Moderators: Maria José Rubio-Cabetas (CITA) and Ramzi Belkhodja (CIHEAM Zaragoza) - **Almond (45')** | Gaetano Distefano, Univ. Catania (Italy) - **Pistachio (45')** | Mohammed Ghrab, Institut de l'Olivier (Tunisia) - **Hazelnut (45')** | Nadia Valentini, Univ. Torino (Italy)	 **11:00-11:45** **11:45-12:30** **12:30-13:15**
Lunch	*13:15-14:45*
Current situation and needs of plant material in Mediterranean nut production (cont.) Moderators: Maria José Rubio-Cabetas (CITA) and Antonio López-Francos (CIHEAM Zaragoza) - **Walnut (45')** | Fabrice Lheureux, CTIFL (France) - **Chestnut (45')** | José Gomes Laranjo, UTAD (Portugal) - **Pecan and Stone Pine (60')** | Neus Aletà, IRTA, and Carlos Guadaño, CIFOR-INIA/CSIC (Spain)	 **14:45-15:30** **15:30-16:15** **16:15-17:15**
Debate and conclusions Maria José Rubio-Cabetas (CITA) and Antonio López-Francos (CIHEAM Zaragoza)	**17:15-18:15**
Day 2 – Thursday 26 September	
Field trip (full day) around the area of Caspe (Zaragoza province) to see experimental and commercial orchards, and nurseries	**08:00-18:30**

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Contributor	Role	Species	Country	Institution
María José Rubio-Cabetas	**Scientific Coord.**	**–**	Spain	CITA Aragón
Antonio López-Francos	**Technical Coord.**	**–**	Spain	CIHEAM Zaragoza
Antonio Pont	**Keynote speaker**	**–**	Spain	INC (International Nut Council)
Mohammed Ghrab	**Focal point**	**Pistachio**	Tunisia	Institut de l´Olivier
Nadia Valentini	**Focal point**	**Hazelnut**	Italy	University of Turin
Fabrice Lheureux	**Focal point**	**Walnut**	France	CTIFL, Centre Technique Interprofessionnel des Fruits et Légumes
José Gomes Laranjo	**Focal point**	**Chestnut**	Portugal	Univ. Trás-os-Montes e Alto Douro
Neus Aletà	**Focal point**	**Stone Pine**	Spain	IRTA
Gaetano Distefano	**Focal point**	**Almond**	Italy	Univ. Catania
Ignasi Batlle	**Expert**	**Almond**	Spain	IRTA
Mehdi Ben Mimoun	**Expert**	**Almond**	Tunisia	INAT
Federico Dicenta	**Expert**	**Almond**	Spain	CEBAS-CSIC
Henry Duval	**Expert**	**Almond**	France	INRAE
Ossama Kodad	**Expert**	**Almond**	Morocco	ENA Meknes
Iban Eduardo Muñoz	**Expert**	**Almond**	Spain	IRTA
Raquel Sánchez-Pérez	**Expert**	**Almond**	Spain	CEBAS-CSIC
Ana Wunsch Blanco	**Expert**	**Almond**	Spain	CITA Aragón
Burak Akyüz	**Expert**	**Chestnut**	Turkey	Ondokuz Mayıs University
Gabriele Beccaro	**Expert**	**Chestnut**	Italy	University of Turin
Santiago Pereira Lorenzo	**Expert**	**Chestnut**	Spain	University of Santiago de Compostela
Verònica Casadó	**Expert**	**Hazelnut**	Spain	ADV de l'avellana i cultius del Mediterrani
Veli Erdogan	**Expert**	**Hazelnut**	Turkey	University of Ankara
Daniela Farinelli	**Expert**	**Hazelnut**	Italy	University of Perugia
Julien Toillon	**Expert**	**Hazelnut**	France	ANPN
Azza Chelli-Chaabouni	**Expert**	**Pistachio**	Tunisia	INRAT
Bekir Erol Ak	**Expert**	**Pistachio**	Turkey	University of Harran
Esaú Martínez	**Expert**	**Pistachio**	Spain	CIAG-El Chaparrillo
Georgios Zakynthinos	**Expert**	**Pistachio**	Greece	UNIWA (West Attica University)
Youssef Ammari	**Expert**	**Stone pine**	Tunisia	INRGREF
Alexandra Pires Correia	**Expert**	**Stone pine**	Portugal	INIAV
Carlos Guadaño	**Expert**	**Stone pine**	Spain	CIFOR-INIA/CSIC
Erica Di Pierro	**Expert**	**Walnut**	Italy	Fondazione Edmund Mach
Mehmet Sütyemez	**Expert**	**Walnut**	Turkey	Kahramanmaras Sutcu Imam University
Eloïse Tranchand	**Expert**	**Walnut**	France	IRFEL-Station Creysse

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OPTIONS méditerranéennes

SERIES A: Mediterranean Seminars
2026 – Number 130

Plant Material for the Future of Nut Production in the Mediterranean Region

Edited by:
M. J. Rubio-Cabetas and A. López-Francos

The global consumption of nuts is increasing due to their nutritional value, health benefits, and versatility. Traditional nuts in the Mediterranean region include almonds, chestnuts, hazelnuts, walnuts, pistachios and pine nuts, while pecan is emerging as a promising crop.

Although Mediterranean countries account for around half of the global cultivation area of these species, they produce only about a quarter of the world's output. Despite favourable climatic conditions and the global importance of some Mediterranean countries for specific crops, there is considerable scope to improve yields by introducing better varieties and more advanced cultivation and post-harvest practices. In particular, the sustainability of nut production will depend on conserving and using genetic resources alongside breeding, biotechnology and genomic tools to develop resilient, high-yielding cultivars that can withstand climate change, pests, diseases and evolving market demands.

The International Seminar 'Plant Material for the Future of Nut Production in the Mediterranean Region' was organised by CIHEAM Zaragoza and the Agri-Food Research and Technology Centre of Aragon (CITA) on 25–26 September 2024. The seminar brought together 45 experts on the seven species from Algeria, France, Italy, Hungary, Morocco, Portugal, Spain, Tunisia and Turkey. The experts assessed the current situation of plant material, existing collections, genetic technologies, breeding and conservation strategies, and the main research, innovation and transfer needs to support the development and use of more suitable plant materials.

This edition of Options Méditerranéennes contains reports on the seven species (almond, chestnut, hazelnut, pecan, stone pine, pistachio and walnut), which were prepared by experts invited to the seminar. Each report provides an overview of the situation and needs of plant materials and their conservation and improvement in the main Mediterranean producing countries.

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