

Taxonomic and botanical retrospective review of *Pistacia atlantica* Desf. (Anacardiaceae)

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Pistacia atlantica, an Irano-Touranian member of the Anacardiaceae family, is known for its distinctive ecological plasticity. Both ecological plasticity and phenotypic plasticity are closely related. This latter concept is defined as the variability of phenotypic expression of one genotype exposed to different environmental conditions and producing a large phenotypic range. It is likely that phenotypic plasticity plays an important role in diversification. The morphological features are very important for species characterization. They have mono or a polygenic determinism but they can be influenced by the environmental factors. In the current review, a taxonomic retrospection of *Pistaciaatlantica* is exposed focusing essentially on its taxonomic status evolution, followed by a botanical characterization of *Pistaciaatlantica* subsp. *atlantica*, the only observed representative of the species in North Africa.

Key words: *Pistacia atlantica*; ecological plasticity; Diversification; taxonomy; botanical characterization

1. Introduction

The Mediterranean region is located between Laurasia and the Gondwana vestiges where vegetation is originated from both areas (Quezel, 1960, 1985; Suc et al., 1995; Pons and Quezel, 1998; Fauquette et al., 1999). The flora in this region was predominantly Mediterranean with a number of tropical and temperate elements (Le Houerou, 1997). The Mediterranean region has known between -3.5 Ma and -2.6 Ma a subsequent dry phases which modified the Mediterranean Landscape (Suc, 1984; Suc et al., 1995). The climatic changes following the last glacial retreat have greatly influenced the vegetation structure in the region (Bazile-Robert et al., 1980). In North Africa, those changes favored the installation

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of thermo and meso-mediterranean vegetation to the detriment of some taxa which are mostly in extinction or which have found a refugium in particular zones (Van Campo, 1975; Van Zinderen Bakker and Maley, 1979; Maley, 1980; El Hamouti et al., 1991; Stambouli-Essassi, 2003; Benslama et al., 2010). Many studies are focused on the impact of climatic changes on the genetic variability and the long-term survival of living beings (Asch et al., 2007; Willis et al., 2008; 2010; Hoffmann and Sgrò, 2011). This issue is the most important since the current fragmentation of natural habitats strongly restricts the opportunities of the dispersal of species, as well as, the gene flow among populations. When species exhibits a large range, the fragmentation of the habitats and the adaptive potentialities to the ecological variability may lead to intra-specific subdivisions, breeding subspecies, varieties, and ecotypes. This is the case of the Atlas Pistachio, *Pistacia atlantica* Desf. [Fl. Atlant. 2:364. 1799] (Desfontaines, 1799, 1800). It is an Irano-Touranian species with a large geographic range (Zohary, 1952). Irano-Touranian plants would have existed in the Mediterranean region during the dry and the cold climatic phases of the Miocene (Benslama et al., 2010; Biltekin et al., 2015). The Plio-Pleistocene glaciations were propitious for their establishment in the region. Even if its range is more or less discontinuous, *Pistacia atlantica* is one of the most widely distributed wild species of the genus. It occurs from the Canary Islands to Pamir Mountains (Zohary, 1952). Over this large area and under different ecological conditions, *P. atlantica* populations adapt differently; the morphological characters of the species are very variable, leading to taxonomic confusion mainly in the infraspecific level. Until then, 3 subspecies are admitted (*P. atlantica* subsp. *atlantica*, *P. atlantica* subsp. *cabulica*, *P. atlantica* subsp. *mutica*) (Yaltirik, 1967a, 1967b; Al yafi, 1979), while Rechinger (1969) and Al yafi (1978) recognized *P. atlantica* subsp. *kurdica* (already described by Zohary (1952)) as a subspecies. This taxon is considered by Yaltirik (1967a, 1967b) and Al yafi (1979) as a distinct species. *Pistacia atlantica*'s subspecies are qualified as eco-geographical ecotypes (Rechinger, 1969; Browicz, 1988). Morphologically, they are related by intermediaries and they transgress geographically, more or less, the areas assigned to them (Monjauze, 1968). In fact, the subspecies *atlantica* which is qualified as the North-African representative (Zohary, 1952) and considered to be native to Maghreb countries (Browicz, 1988) is nevertheless cited among the subspecies studied in the Asiatic area of the species (eg. Syria and Turkey) (Karimi et al., 2009b). The current paper aims to outline a pertinent data on the taxonomic and monographic review of the genus *Pistacia* and especially the species *P. atlantica*. It will bring

to date our knowledge through previous relevant researches to the topic of the evolution of the genus taxonomic status.

2. Historical overview

The name pistachio probably derives from the word Pista-pistak in the ancient Persian language Avestan (Joret, 1976). The origin of the genus *Pistacia* is still questionable. Based on fossil records (Weyland, 1941), Zohary (1952) supposed that the origin center of *Pistacia* species is placed in central and Southwestern Asia and that the genus as a whole probably developed more than 80 million years ago. Numerous archaeological excavations (Ramirez and Cevallos-Ferriz, 2002) report the finding of pistachio nuts in Neolithic settlements, West of the Zagros Mountains (mountain range situated in Western Iran) from the eighth until the sixth millennium B.C. (in Hormaza, 1995). Nevertheless, other researchers did not agree with this hypothesis, since Anacardiaceae pollen and wood first appear in the Paleocene epoch, 65 to 55 million years ago and is found throughout the world (Hsu, 1983; Muller, 1984). The origin for the order in which the Anacardiaceae occurs, Sapindales, dates back approximately 84 to 65 million years before present (Magallon and Sanderson, 2001; Wikstrom et al., 2001). In fact, Al-Saghir (2006) hypothesizes that *Pistacia* originated in the Paleocene epoch and postulates that ancestral species of *Pistacia* came from North America since Anacardiaceae is pantropical in its distribution and North and South America represent major diversification centers of the family. Given the geographical distribution of *Pistacia*, Al-Saghir's hypothesis (Al-Saghir, 2006) is supported by *Pistacia* fossil records from the Paleocene of Wyoming and Colorado (Edwards and Wonnacott, 1935). Migration may have taken place from Western Laurasia (North America) to Eastern Laurasia (Europe and Asia) ending up in Central Asia via Europe where the genus radiated within Asia (West Asia and Mediterranean Basin) as hypothesized by Weeks et al. (2005) for the Burseraceae (a family closely related to Anacardiaceae). This migration may have been facilitated by the boreotropical land bridge (Tiffney, 1985; Tiffney and Manchester, 2001), which spanned the North Atlantic during the early to middle Eocene. Global temperatures during the Eocene were highest during this time period and tropical vegetation is known to have occurred in this land corridor (Wolfe, 1978; Zachos et al., 2001). Cooler temperatures during the Middle Eocene extirpated frost tolerant taxa in this region and the physical land connections disappeared sometime afterwards (Weeks et al., 2005). Al-Saghir's hypothesis (Al-Saghir, 2006) may also be supported by the cladistic analysis of NIA-i3 gene region which showed

astonishing close relationships between the *P. atlantica* - *P. khinjuk* - *P. vera* clade and the *P. mexicana* - *P. texana* clade (Yi et al., 2008). The last two species represent the genus in America (Zohary, 1952). Nevertheless, it is believed that the Eastern part of Zagros Mountains is one of the main centers of diversity for *Pistacia*. However, the pistachio nuts found in Neolithic settlements in the region and reported as true pistachio nuts (from *P. vera*) could easily be nuts from other *Pistacia* species such as *P. palaestina* or *P. atlantica* which are indigenous to those areas and whose seeds are eaten by local people (Hormaza, 1995). The genus extended its distribution range by passive dispersal mediated by wind, water, birds or even by people (Al-Saghir, 2006). This is supported by evolution toward a smaller seed with a hard endocarp paralleling a change in reproductive strategy from distribution by ground squirrels (burying the seed, as with walnuts and oaks) to bird- or wind-mediated distribution, which would require a seed capable of passing through a bird's digestive system or being blown by the wind (Jordano, 1989).

3. Evolution of *Pistacia* taxonomic status

The genus *Pistacia* has known a long taxonomic history and several revisions in all its higher hierarchical levels. The genus members were grouped separately by Tournefort (1700) into two genera (*Lentiscus* and *Terebinthus*). In his '*Species Plantarum*', Linnaeus (1753) was the first to establish, officially, the genus *Pistacia*.

3.1 The class level

In '*Systema Naturæ*', Linnaeus (1735-1758) places the genus into the class *Dioecia*, *Pistacia* has been merged, afterwards, into many classes: *Terebinthineæ* (Spach, 1834; Endlicher, 1836-1840), *Magnoliopsida* (Subclass: Rosidae) (Cronquist, 1981), (Subclass: *Malvidae*) (Throne and Reveal, 2007). The Angiosperm Working Group (APG, 1998, 2003, 2009, 2016) places the genus in Eudicots; core Eudicot; Rosid; **Eurosid II**.

3.2 The order level

Linnaeus (1735-1758) places the genus into the order *Pentandria*., then the genus appears with the oak trees and the walnut trees into the order '*Amentaceæ*¹'. This classification was done on the base of the resemblance of some characters of the flowers (reduced, small and

¹ The endings 'ceæ' was given in this classification for the orders.

unisexual flowers). Subsequently, several orders have been proposed (*Terebinthinae*, *Terebinthaceae*¹, Terebinthales, Sapindales, Rutales and Burserales) (Table 1).

The **Sapindales** are mostly woody plants with a synapomorphic prominent nectariferous disc and a syncarpous gynoecium usually with one or two ovules per locule (Gadek et al., 1996). Besides these features, the recent molecular studies retain the classification of the genus into the Sapindales (Fig. 1) (Gadek et al., 1996; Chase et al., 1993; APG, 1998, 2003, 2009. Bremer et al., 1999; Savolainen et al., 2000a, 2000b; Stevens, 2008).

Table 1. Proposed ordinal affinities of *Pistacia* based on morphological or molecular data

Order	References	
	Morphological data	Molecular data
<i>Amentaceae</i> ²	Linnaeus (1735-1758)	
Rutales	Gundersen, 1950; Thorne 1992	
Burserales	Takhtajan, 1997	
Sapindales	Engler, 1892; Rendle, 1925; Hutchinson, 1926; 1973; Takhtajan, 1954; Dahlgren, 1980; Cronquist, 1968, 1981, 1988; Bhattacharyya and Johri, 1998.	Chase et al., 1993; Gadek et al, 1996; APG 1998, 2003; 2009; Bremer et al., 1999, Savolainen et al., 2000; 2000
<i>Terebinthaceae</i> ²	A.L. De Jussieu (1789)	
<i>Terebinthinae</i>	Eichler (1875-1878) ; Hallier, 1908 (<i>Terebinthinae</i>); Wettstein, 1935 & 1944 (Terebinthales)	

Modified from Pell (2004)

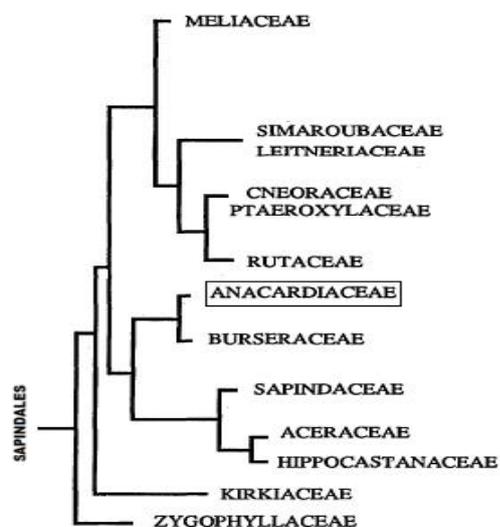


Fig.1 Position of the Anacardiaceae family (framed) in the phylogenetic tree of the Sapindales order (modified from Gadek et al., 1996)

3.3 The Family level

Based on morphological details, the genus *Pistacia* was firstly the unique representative of its own family, *Pistaciaceae* by Adanson (1763). Many studies showed the particularity of certain characteristics of the genus. *Pistacia* species are dioecious, have reduced perianth, unusual pollen morphology (with up to eight apertures, and plumose styles with the associated increased stigmatic surface area) (Erdtman, 1971; Mabberley, 1997; Pell, 2004; Belhadj et al., 2007a). All These morphological features are adaptations for wind pollination. In 1825, De Candolle, working on the order of *Terebinthaceae* of A. L. De Jussieu (1789), establishes the Family '*Terebinthaceae*' (cited 'Térébinthacées' in his 'Mémoire sur la famille des légumineuses'). In 1830, Lindley, in his 'An Introduction to the natural system of botany', states that he agrees with the botanists who abandon the name '*Terebinthaceae*'. He validates, so, the family of the *Anacardiaceae*. This family was firstly proposed by Brown (1818) who constitutes it by the species related to the *Anacardium*. Lindley (1830) gives the diagnosis, the anomalies, the essential character, the affinities, the geography and the properties of the validated family and cites the genus *Pistacia* as member of this family with the Cashew and the Mango. Working on the class of *Terebinthinae* Barling, Spach (1834) includes the genus *Pistacia* in the family of *Cassuviaceae*. This opinion was not adopted for a long time. Lindley's classification dominates. The flowers of the *Anacardiaceae* are generally not highly prominent but are discerning by an intrastaminal nectariferous disc. Based on the synapomorphies of a single apotropous ovule (an ovule with a raphe that is ventral when ascending and dorsal when descending). The morphological data exposed by Wannan and Quinn (1991) and many molecular data (Pell, 2004; Yi et al., 2004, 2007) support this classification.

3.4 The infrafamilial level (Subfamily and Tribe)

Eichler (1875-1878) treated *Pistacia* as a distinct group. Takhtajan (1997) divided the *Anacardiaceae* into four subfamilies (*Anacardioideae* Link, *Spondioideae* Link, *Julanioideae* and *Pistacioideae* Burnett.) and puts the genus *Pistacia* in the last one. On the basis of wood anatomy, fruit and flower morphology, and flavonoid chemistry, Wannan and Quin (1991) divided the *Anacardiaceae* into two groups, A and B. These groups overlap the subfamilies *Spondioideae* and *Anacardioideae* within molecular studies of Terrazas (1994) and Pell (2004). *Pistacia* was placed in the subfamily *Anacardioideae* in both studies. The genus

Pistacia was classified in the tribe *Anacardiaceae* by certain authors as Spach (1834) and De Candolle (1928), then treated as a distinct tribe or a subfamily (*Pistacioideae*) (Marchand, 1869; Eichler, 1875 1878; Takhtajan, 1987, 1997; Mitchell et al., 2006). Engler (1876) placed *Pistacia* in the tribe *Rhoideae* (= *Rhoeae*). This treatment was followed by Engler (1883, 1892). The *Rhoeae* was cited by Takhtajan (1997) included within the subfamily *Spondioideae*. The most widely accepted classification divides the *Anacardiaceae* into five tribes: *Anacardiaceae*, *Semecarpeae*, *Spondiadeae*, *Dobineae* and *Rhoeae* (Mitchell and Mori, 1987; Wannan and Quinn, 1991). *Pistacia* was assigned to the last one (Mitchell and Mori, 1987); in fact, it resembles the *Rhoeae* members by having three syncarpous carpels, unilocular fruits, and a thin exocarp. If the last subfamily classification (Terrazas, 1994; Pell, 2004) and the last tribe classification (Mitchell and Mori, 1987; Wannan and Quinn, 1991) are the most accepted, the *Rhoeae* could not be included within the *Spondioideae* (*sensu* Takhtajan, 1997) but in the *Anacardiaceae* (*sensu* Terrazas, 1994 ; Pell, 2004). Terrazas (1994) and Pell (2004) placed *Pistacia* in the subfamily *Anacardiaceae*.

3.5 The genus level

As it was mentioned above, *Linnaeus* (1753) was the first to establish the genus, recognizing six species: *Pistacia lentiscus* L., *P. terebinthus* L., *P. vera* L., *P. narbonensis* L., *P. trifolia* L. and *P. simaruba* L. Many other species was added to the genus; Desfontaines (1799) described *P. atlantica* while Humboldt et al. (1824) described *P. mexicana* as a new species. Marchand (1869) included to the genus four species (*P. chinensis* Bunge. (described by Bunge (1835)), *P. mutica* Fisch. (described by Fischer and Meyer (1838)), *P. Khinjuk* Stocks (described by Stockmans (in Stockmans and Hooker, 1852)) and *P. palaestina* Boiss. (described by Boissier (1849)). Engler (1883) provides the first monograph of the genus and withdraws from *Linnaeus's* list: *P. trifolia* (considered as synonym of *P. vera*) and *P. narbonensis* (considered as a hybrid between *P. vera* and *P. terebinthus*). He suggests that *P. palaestina* is a subspecies of *P. terebinthus*; when *P. simaruba* is *Bursera simariba* (L.) Sarg., a member of the closely related *Burseraceae*. Subsequently, many species are described and added to the genus *Pistacia*: *P. falcata* (Martelli, 1886) *P. weinmannifolia* (Franchet, 1886) and *P. texana* (Swingle, 1920). It is known that the first and the most complete classification of the genus is done by Zohary (1952). He considers 11 species for the genus and puts them, on the basis of the morphology of leaves, leaflet, inflorescence, flowers, fruits, and the seedlings, into four sections: ***Lenticella* (Zoh.)** (Sub-persistent leaves, including *P.*

mexicana, *P. texana* Swingle), ***Eu Lentiscus* (Zoh.)** (Persistent and paripinnate leaves, including *P. lentiscus*, *P. saportae* Burnat, *P. weinmannifolia* Poiss. ex Franch.), ***Eu Terebinthus* (Zoh.)** (Deciduous and pari/imparipinnate leaves, including *P. chinensis*, *P. khinjuk*, *P. palaestina*, *P. terebinthus*, *P. vera*) and ***Butmela* (Zoh.)** (deciduous and imparipinnate leaves, where *Pistacia atlantica* is the only member).

Besides the leaf and seed morphological characters, on the basis of restriction fragment length polymorphism analysis of the *Pistacia* cpDNA, Parfitt and Badenes (1997) suggest to divide the genus into two sections, ***Lentiscus*** and ***Terebinthus***. Section *Lentiscus* (including Zohary's sections *Letiscella* and *Eu Lentiscus*) consists of the evergreen species with paripinnate leaves and smaller seeds. Section *Terebinthus* (*Butmela* and *Eu Terebinthus* Zohary's sections) includes the deciduous species with imparipinnate leaves and large seeds. Many molecular studies support this division (Kafkas and Perl-Treves, 2001, 2002; Golan-Goldhirsh et al., 2004; Kafkas, 2006). Zohary (1972) revises his last classification and suggests *P. saportae* to be an interspecific hybrid. The genus *Pistacia* has known after Zohary's classification several new species. The taxonomic status of the genus members has been continually reviewed. Yaltirik (1967a, 1967b) adds a new species (*P. eurycarpa*) which was described by Zohary (1952) as *P. atlantica* var. *kurdika*. The data shown by the phenotypic cluster analysis made by Kafkas and Perl-Treves (2001) and Al-Saghir (2006) confirms the taxonomic placement of *P. eurycarpa* as a separate species. Yaltirik (1967a, 1967b) considers *P. palaestina* as a variety of *P. terebinthus*. In fact, the same consideration was done by Engler (1883); but *P. palaestina* has been raised to the rank of a species by Zohary (1952). Yaltirik's opinion is shared by other authors suggesting close relationships between the two species; the two entities are morphologically, ecologically and genetically similar (Zohary, 2000; Kafkas and Perl-Treves, 2002; Al-Saghir, 2006). This opinion is supported mainly by molecular data (Golan-Goldhirsh et al., 2004; Yi et al., 2008). According to Kokwaro and Gillett (1980), a new species from East Africa, *P. aethiopica* Kokwaro, is described by Kokwaro. However, its status has not been confirmed. This taxon was described by Zohary (1952) as a variety of *P. lentiscus*. Al-Saghir (2006) supports Zohary's classification considering *P. aethiopica* as *P. lentiscus* var. *emarginata*. Then, Al-Saghir (2006) suggest that this taxon should be treated as a subspecies of *P. lentiscus*, not as a variety (*Pistacia lentiscus* subsp. *emarginata* (Engl.) Al-Saghir, Comb. Nov.). Other species are cited in the different studies concerning the genus. Their taxonomic position within the genus

remains to be discussed. *P. integerrima* is considered as a separate species (Parfitt and Badenes, 1997; Yi et al., 2008) but as a subspecies of *P. chinensis*. Finally, fifty-five binomials for *Pistacia* species were listed in the International Plant Name Index (IPNI, 2010). Nevertheless, most of them are not recognized. The most important studies which treat the systematic of the genus admit the following list: *P. chinensis* (including the subspecies: *chinensis*, *falcate*, *integerrima*), *P. eurycarpa*, *P. khinjuk*, *P. lentiscus* (including the subspecies *emarginata*, *lentiscus*), *P. mexicana*, *P. palaestina*, *P. terebinthus*, *P. texana*, *P. vera*, *P. weinmannifolia*. *P. atlantica* (including the subspecies: *atlantica*, *cabulica*, and *mutica*).

4. Evolution of *Pistacia atlantica* taxonomic status

As cited previously, Man has known *Pistacia atlantica* for very long. However, the botanists before 1779 have always considered it as a variety of *Pistacia terebinthus*. The distinction between the two taxa was done by René Louiche Desfontaines when he saw the tree in Gafsa (Tunisia), during his botanical exploration he led in Tunisia and Algeria from 1783 to 1786. He published so 'Flora Atlantica' (Desfontaine, 1798, 1800) (Fig. 2) where he described the species and gave it the scientific name *Pistacia atlantica* according to the Atlas Mountains of the Maghreb (Desfontaines, 1799, 1800). Later, De Candolle (1825) and Engler (1883) recognised the species in the revision of the genus. Nevertheless, even after Desfontaines's description, and Engler's monograph a degree of confusion still reigns and many explorers, mainly in the Maghreb, reported El buttum as 'Terebinthe' and cited it as a subspecies or variety of *Pistacia terebinthus*. Battandier and Trabut (1888) described in the genus *Pistacia* the two species separately, however; *P. atlantica* is cited again as a subspecies of *P. terebinthus* by Battandier and Trabut (1902). Then in 1910, Battandier noted that *P. atlantica* should be treated as a variety of *P. terebinthus*.

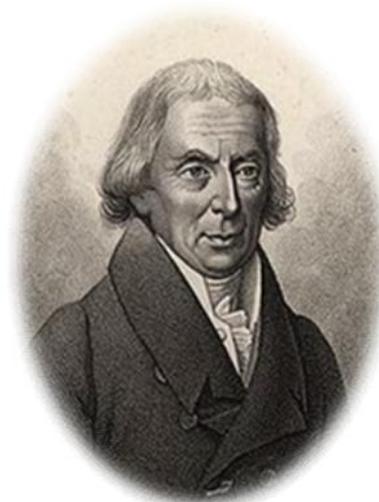
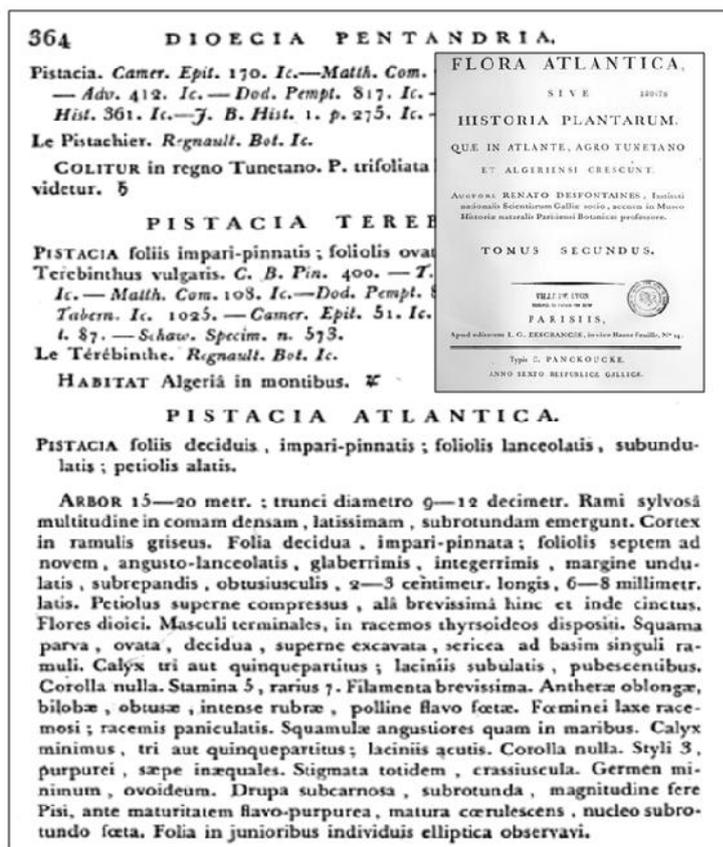


Fig. 2 Desfontaines's description of *Pistacia atlantica* in *Flora Atlantica*²(Desfontaines, 1800) (on the left); Portrait of Rene Louiche DESFONTAINES [1750-1833] (on the right)

In his thesis, Lapie (1909) did not distinguish between the two species and called *P. atlantica* 'Terebinthe'; as well, Mathey-Dupraz (1924) cited the species as *P. atlantica* vel *terebinthus* Desf. Lapie and Maige (1924) considered *P. atlantica* as a big variety *P. terebinthus* of with small leaves. In 1952, Zohary removed any confusion, agreed with Desfontaines (1799), De Candolle (1825) and Engler (1883); and stated *P. atlantica* as a species. Many synonyms are known for *P. atlantica* (*P. cypricola*, *Pistacia atlantica* Desf. subsp. *cypricola* H. Lindb., *Pistacia chia* Desf., *Pistacia choulettei* Gand., *Pistacia muticaf. multijuga* Engl...) however, *P. atlantica* is the only name considered as validly published (IPNI, 2010).

4.1 Taxonomic review of *Pistacia atlantica* complex

4.1.1 Morphological studies

²Digitized version; (accessed on 31/10/2014)

Pistacia atlantica is one of the Irano-Touranian taxa which is largely distributed in the Mediterranean region (Zohary 1952). The Mediterranean and the Irano-Turanian regions have many common taxa because they belong to the same climate type and are in contact since ancient geological times (Eig, 1932). Monjauze (1980) describes it as the most ubiquitous tree in North Africa and the Middle East. In Europe, the species grows in Greece (in Attica region and in the islands of Rhodos and Chios) (Rouskas, 1996), in Serbia (Al-Saghir, 2006) and in Ukraine (Krym) (USDA/ARS/GRIN, Online Database). In Asia, *Pistacia atlantica* is found from Northern and Western Pakistan to central and South Afghanistan, South and West Iran, the Southeast Caucasus, North Iraq, South Turkey, Syria, Lebanon, Palestine to Jordan.

In this large area, Zohary (1952) subdivides *P. atlantica* into two subspecies (*P. atlantica* subsp. *Kurdica* and *P. atlantica* subsp. *latifolia*). He does not list *P. mutica* and *P. cabulica* which were added previously to the genus by some authors (Fischer and Meyer, 1838; Hohenacker, 1838; Engler, 1883; Marchand, 1869). He considers them as *P. atlantica* subsp. *latifolia*, while *P. mutica* has been judged as the variety of *P. terebinthus* by Nadkarni (1908). Rechinger (1963) classifies three subspecies for *P. atlantica* in Iran: *P. atlantica* subsp. *kurdica* and the two subspecies which were not admitted by Zohary (1952) (subsp. *mutica* and subsp. *cabulica*). Yaltirik (1967a, 1967b), describing *Pistacia* species in Turkey, elevates *P. atlantica* subsp. *kurdica* from the subspecies to the species rank. He proposes a key based on the presence or not of the rachis wings, fruit shape and leaflet shape (Yaltirik, 1967). Rechinger (1969) does not agree, he proposes to consider all the members of the section *Butmela* as *Pistacia atlantica* subspecies and qualified them as geographical races. He considers *P. cabulica* as *P. atlantica* subsp. *cabulica*, *P. mutica* as *P. atlantica* subsp. *mutica*, and *P. eurycarpa* as *P. atlantica* subsp. *kurdica*. Al Yafi (1978) describes four subspecies for *P. atlantica*. He retained Rechinger's subdivision adding *P. atlantica* subsp. *atlantica* which represents the species in North Africa. He proposes his key, based primarily on the presence of hairs on the leaflets, the rachis shape, the leaflet shape and the apex leaflet shape. Nevertheless, he separates again in his thesis (Al Yafi, 1979) *P. atlantica* subsp. *kurdica* and propose to consider it again, as a distinct species, he calls it *P. kurdica* (ZOH) ALYAFI comp. nov. = *P. eurycarpa* YALT = *P. atlantica* subsp. *kurdica* (ZOH) RECHINGER. He states that this taxon is different from *P. atlantica* complex. The name he gave does not have much consideration, and the taxon retains the name *P. eurycarpa* or *P. atlantica* subsp. *kurdica*.

The last key proposed for the three subspecies of *P. atlantica* and for *P. kurdica* (*sensu* Al Yafi) = *P. eurycarpa* (*sensu* Yaltirik) is established by Al Yafi (1979) and is summarized as follows:

***P. atlantica* subsp. *atlantica*:**

- leaves deciduous, imparipinnate, terminal leaflet sessile, leaflets oblong-lanceolate, hairy (under abinocular loupe) with ciliated midrib and ciliated ribs, 3-5 Paired; - rachis widely winged, wings exist along all of the rachis.

***P. atlantica* subsp. *cabulica*:**

- leaves deciduous, imparipinnate, terminal leaflet sessile, leaflets oblong-lanceolate, with ciliated midrib, ribs and veins, 3-5 Paired; - rachis winged, wings exist along all of the rachis.

***P. atlantica* subsp. *mutica*:**

- leaves deciduous, imparipinnate, terminal leaflet sessile, leaflets oblong-ovate with ciliated midrib, ribs but rarely the veins, 2-4 (-5) Paired; rachis winged, wings exist between the two last pairs.

P. atlantica* subsp. *kurdica

- Leaves deciduous, imparipinnate, terminal leaflet subsessile or petiolulated, leaflets oblong-ovate sometimes acuminate; - rachis tightly winged, wings exist between the two last pairs.

Additionally, Behboodi (2004) described leaves and fruits of the three subspecies found in Iran. The Drupes are slightly broader than long in *P. atlantica* subsp. *mutica*; are globose, with equal long and broad in *P. atlantica* subsp. *cabulica*; and are depressed globose, 5-8 mm x 8-10 mm in *P. atlantica* subsp. *kurdica*.

El Zerey-Belaskri and Benhassaini (2016) revised the key determination of the subspecies representing the genus in the Maghreb. *Pistacia atlantica* subsp. *atlantica* is characterized by an important morphological variability and its determination key was updated as follow:

***Pistacia atlantica* Desf.**

Leaves large, imparipinnate, deciduous, leaf rachis winged.

1-Leaves imparipinnate 1.4 – **24.5** cm long, 1.6 – **21.9** cm wide, sometimes **paripinnate by losing the terminal or the preterminal leaflet**. Leaflets (1–) **2–8** (–**9**) pairs lanceolate, oval, elliptic, oblong, rhomboid, **obovate**, (**falciform**); obtuse, acute, acuminate, **mucronated**, **emarginate**, **rounded**, **retuse**, and **attenuate** apex leaflet. **The terminal leaflet** is sessile or **petiolulated** (**0.1 – 3.4 cm long**) subsp. *atlantica*. (El Zerey-Belaskri and Benhassaini, 2016)

Besides, the pollen morphology studied by Behboodi and Ghaffari (2005) does not show a significant difference in the type. Pollen is circular in equatorials, perforate (pentaforate) and foveolate on the surface. However, the authors reveal that *Pistacia atlantica* subsp. *cabulica* is different according to the pollen size and should be considered as a distinct species (*P. cabulica*). *Pistacia atlantica* subsp. *atlantica* showed similarly spheroidal and pantoaperturate pollen (Belhadj et al., 2007a).

4.1.2 Molecular studies

In order to contribute to sort out the taxonomic confusion that still exists within *Pistacia atlantica* complex. Genetic relationships among *Pistacia atlantica* subspecies is attempted towards several molecular techniques (i.e. SAMPL, restriction fragment length polymorphisms (RFLP), randomly amplified polymorphic DNA (RAPD), amplification fragment length polymorphisms (AFLP) and simple sequence repeat (SSR) (Kafkas, 2006; Karimi et al., 2009a ; Arabnezhad et al., 2011; Karimi and Kafkas, 2011; Zalu et al., 2015). Recently, the first molecular characterization of *P. atlantica* in Algeria markers was performed using SSR by El Zerey-Belaskri et al. (2018). Phylogenetic relationship between *Pistacia atlantica* subspecies using amplified fragment length polymorphism (AFLP) and treated by UPGMA analysis separated *P. atlantica* subsp. *mutica* and *cabulica* from *P. atlantica* subsp. *atlantica* and *P. eurycarpa* (Karimi et al., 2009a). These authors propose that *P. atlantica* subsp. *mutica* could be classified as a distinct species as *P. mutica* and the *cabulica* as a subspecies of *P. mutica*. Nevertheless, previous morphological and molecular studies retained *P. mutica* as the subspecies of *P. atlantica* (Zohary, 1952; Kafkas, 2006) within the group of *Eu-Butmella* (Zohary, 1952). Arabnezhad et al. (2011) show that *Pistacia atlantica* and *P. mutica* were the closest species using SSR characterization, therefore *P. mutica* should be considered as a subspecies of *P. atlantica*. Several studies showed that *P. eurycarpa* is synonym for *P. atlantica* subsp. *kurdica*. It is closely related to *P. atlantica* and shows a closer genetic similarity to *P. atlantica* than the other species in the genus, but should be considered distinct from *P. atlantica* (Kafkas and Perl-Treves, 2001; 2002; Karimi et al., 2009a; Karimi and Kafkas, 2011). In addition, the phylogenetic analysis using the SAMPL marker method permits to Karimi and Kafkas (2011) to postulate that *P. atlantica*, *P. atlantica* subsp. *mutica* and *P. atlantica* subsp. *cabulica* are descendants of *P. eurycarpa*.

4. 2 *Pistacia atlantica* botanical review

Pistacia atlantica is called in arabic ‘Al bottm, or ‘El buttum al atlassi’ to distinguish it to *Pistacia terebinthus* or *Pistacia palestina* which are also called sometimes El buttum. Themorphological characteristics are an unavoidable tool for the classification and the organism taxonomy. They serve also to recognize the hybrids or the contaminations (in the case of the microorganisms). When De Candolle (1868) conceived the notion of ‘the characteristic leaf’, he means that the species is not characterized only by the reproductive traits in flower and fruit on which the Linneaus system was based; but also by vegetative traits. Indeed, in the genus *Pistacia*, the diagnostic traits used by Zohary (1952, 1972) to distinguish between the various species are mainly leaf characteristics and nut morphology since *Pistacia* is characterized by its homeochlamydic perianth (Mabberley, 1997) and reduced flower structure (e.g. naked flowers) (Pell, 2004).

Pistacia atlantica trees are strong and vigorous, reaching 15–20 m in height; however, intermediate trees are also observed. The trunk of adult trees can exceed 1 m in diameter and 6 m in circumference (according to our field work, data not shown), with a striated dark grey bark (Fig. 3) (Desfontaines, 1799; Battandier and Trabut, 1888; Monjauze, 1980; Quezel and Santa, 1963). El Zerey-Belaskri (2016) noted that the bark is white-beige in the steppic and Southern populations of Algeria. The trunk is mostly single (Quezel and Santa, 1963) but can be branched from the base. *Pistacia atlantica* is a hardwood species. This species has a strong root system which allowed it to occupy arid lands. Limane et al. (2014) described three root architecture types for *Pistacia atlantica* subsp. *atlantica* in Algeria. Young pistachio plants produce an initial orthogeotropic root which subsequently sends out several secondary ramifications. It may evolve in developing a shallow root network in sandy soil. In loamy or calcareous soils, the root system develops extensive deep roots which are developed to mine deeper water reserves. The deep roots protected trees against hydrous and wind erosions, very common phenomena in areas where the pistachio grows (Fig. 4). El Zerey-Belaskri (2016) reported the presence of a tree (in the region of Sidi Bel Abbes, Northwest Algeria) with 30 m root length; et al *Pistacia atlantica* root system is known as the most resistant to asphyxia root as the other species of the genus (Behboodi, 2005).

Atlas pistachio trees are characterized by dense foliage. The leaves are more or less coriaceous, deciduous, composed of one to eight leaflet pair and a terminal leaflet (imparipinnate) (El Zerey-Belaskri and Benhassaini, 2016). The character of pinnate

compound leaves is a synapomorphy for the Sapindales order. The leaves are symmetric with opposite leaflets. However, asymmetric insertion on the rachis is very often observed (Inbar and Kark, 2007; El Zerey-Belaskri, 2016). According to Graham et al. (1993) and Inbar and Kark (2007), these phenomena may be considered as an indicator of developmental instability. Inbar and Kark (2007) did not record any correlation between the phenomena and the environmental conditions or biotic stress. By losing the terminal or the preterminal leaflet, paripinnate leaves are observed (El Zerey-Belaskri and Benhassaini, 2016).

The leaflets are in variable shapes and many descriptions were interested in their morphological variability (Engler, 1883; Zohary 1952; Quezel and Santa, 1963; Monjauze, 1968; Al Yafi, 1978; Kafkaset al., 2002; Belhadj et al., 2008; El Zerey-Belaskri and Benhassaini, 2016). In Algeria, *Pistacia atlantica* subsp. *atlantica* leaf morphology shows significant inter and intra-populational variability (El Zerey-Belaskri, 2016; El Zerey-Belaskri and Benhassaini, 2016). The morphological leaf variability is observed on several characters and divergences in leaf and leaflet sizes and shapes, in leaflet number, and in leaflet insertion on the rachis; imparipinnate and paripinnate leaves, petiolulated and sessile terminal leaflets are also observed. The petiole is flattened and the rachis is winged. The winged rachis is present in this species but differs from a subspecies to another (Al Yafi, 1978). Trees lose leaves in December and begin dormant from December through February.

In addition to the morphological variability, the leaves show a prominent chemical variability regarding the leaf essential oil and constitute a valuable source of potent natural compounds such as, '**-pinene**', '**Terpinen-4-ol**', '**p-cymene**' (Barrero et al., 2005; Tzakou, 2007; Gourine et al., 2009; 2010; Ait Said et al., 2011; El Zerey-Belaskri et al., 2017). Indeed, certain distinct populations in the North and in the South of Algeria are primarily distinguished by such compounds as **Germacrene D**, **E-caryophyllen** (El Zerey-Belaskri et al., 2017); and **-3-carene** (Gourine et al., 2010).

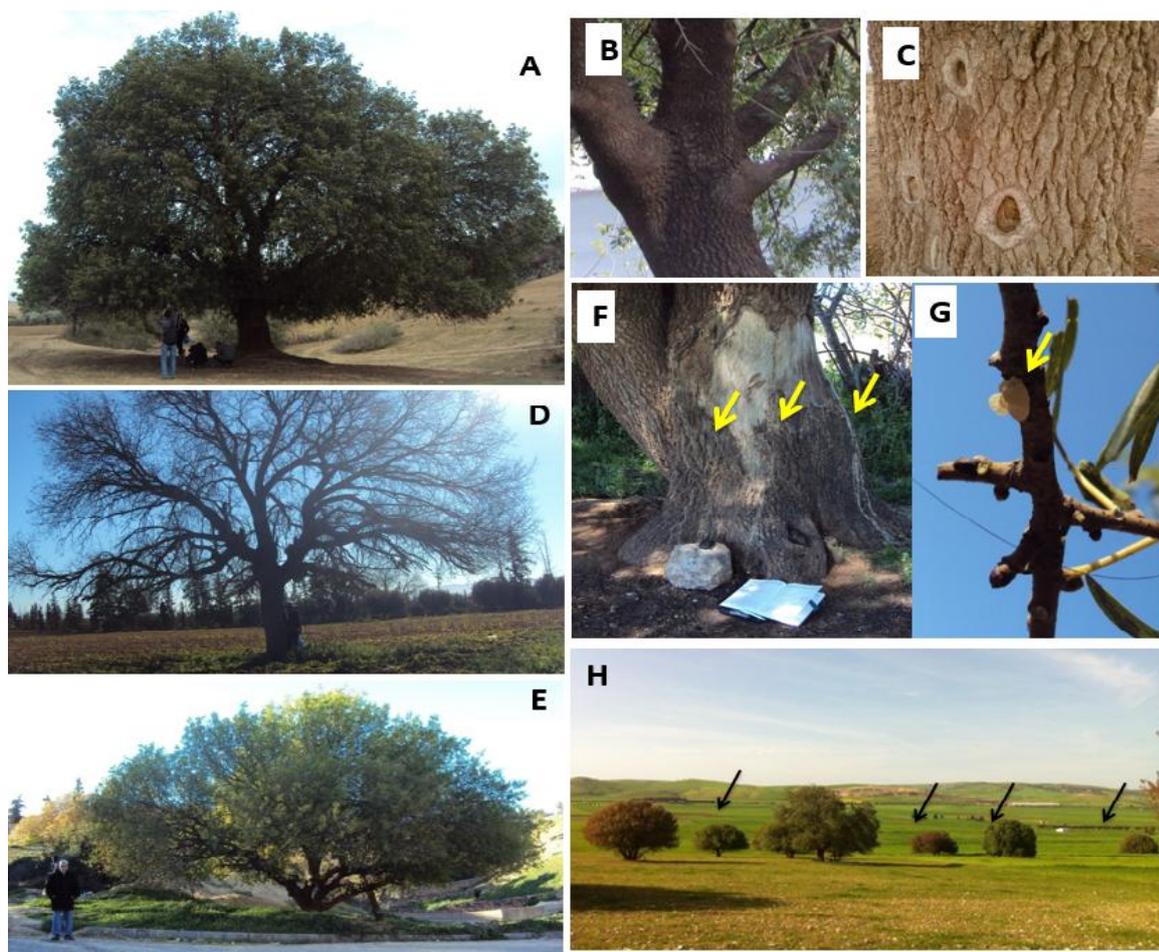


Fig.3 *Pistacia atlantica* Desf. subsp. *atlantica*: (A, D, E) the habit; (D) tree become bare during winter; (A,D) Single trunk; (E) Branched form base; (B) dark grey bark; (C) white-beige bark; (F, G) resin secretion (yellow arrows); (H) hemispherical foliage (black arrows). Photos: A. El Zerey-Belaskri

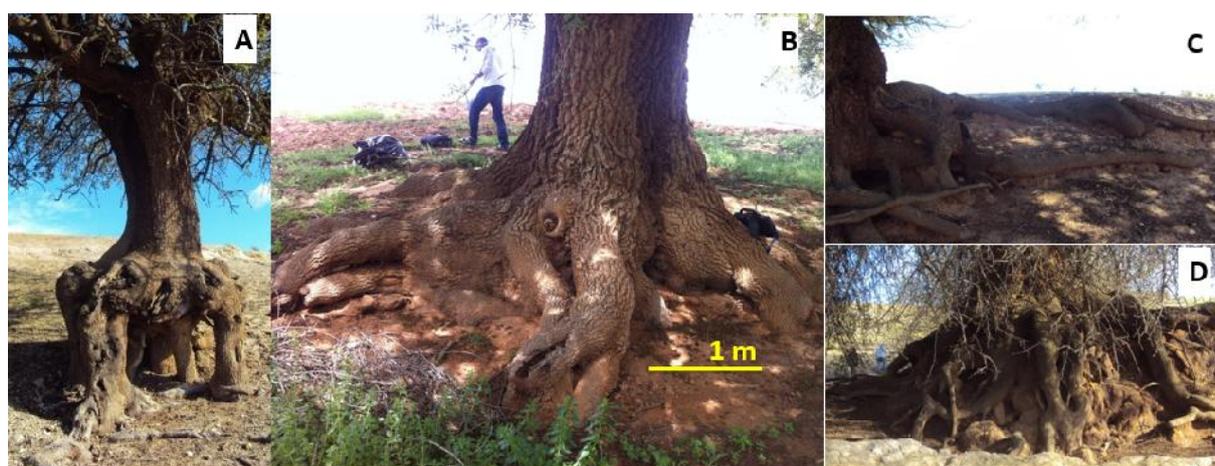


Fig. 4 *Pistacia atlantica* root architecture: (A, D: deep roots); (B, C vigorous lateral roots) (Nb. Root denudation is due to soil erosion) Photos: A. El Zerey-Belaskri

In Anacardiaceae family, the flowers are generally not highly conspicuous but are distinctive in having an intrastaminal nectariferous disc. The flowers are almost always unisexual in Anacardiaceae and the genus *Pistacia* is characterized by its dioecious reproductive system (Mabberley, 1997). Some cases of exceptional sex types were reported in the literature; Ozbek and Ayfer (1958) observed two hermaphrodite trees in Turkey. They reported that these trees were either seedlings of *P. vera*, or hybrids between *P. vera* and *P. terebinthus*. *Pistacia atlantica* is dioecious (Desfontaines, 1799) which showed an exceptional monoecious and/or hermaphrodite trees (Crane, 1974; Kafkas et al., 2001; sfendiyaro lu, 2007; Yaaquobi et al., 2009). This exceptional trait may have arisen as a somatic mutation and may be expressed as a result of an interaction with an unknown biotic/abiotic environmental factor (Kafkas et al., 2001). *Pistacia* is distinguished from other Anacardiaceae members by its reduced flower structure, plumose styles, unusual pollen morphology (Pell, 2004; Perveen and Qaiser, 2010), the absence of nectariferous disc and the petals. The two last characters explain the strict anemophilous pollination of the genus. Nevertheless, the bees may visit the male flowers to feed on pollen (Brichet, 1923). In *Pistacia atlantica* flowers are unisexual, actinomorphic and apetalous. The haplostemonous male flowers in the genus *Pistacia* supported its position within the tribe *Rhoeae* (Engler, 1876; Mitchell and Mori, 1987).

Flowering occurs before vegetative development and males tend to flower before females (Protandry) (Fig. 6 B, B', C, C'). Males invest more resources in flowering early in the season before leaf production (Delph, 1999). So, resources allocated to the development of vegetative growth, including photosynthetic tissues (leaf) may be limited or unsteady (Inbar and Kark, 2007). Inversely, El Zerey-Belaskri (2016) reported that unlike in flower development, female trees develop leaf buds before males (Fig. 6 D, D', E, E', F, F', G, G'). Briefly, trees begin to bloom with the arrival of warmer weather in March; the male pollinates the females via the April winds (Zohary, 1952). The male flowers are clustered in a terminal racemous-thyrsoid disposition (Fig. 6 D, D'), joined at the base and supporting yellow round-shaped pollen sacs. The apetalous female flowers are gathered in short panicles (Fig. 6 E, E') (Desfontaines, 1799). The perianths of the female flowers are highly variable. Three types are reported by El-Oqlah (2001): a perianth with a single bract and three sepals, a perianth with a single bract and 5 sepals, and the third type is composed of two whorls, an outer with 3 to 5 lanceolate sepals with a hairy apex, and an inner with 3 to 5 sepals. This feature is an exception in the genus *Pistacia* (El-Oqlah, 2001).

The perigynous flowers carry tricarpellous and unilocular ovaries. According to Wannan and Quinn (1991), these features characterize a particular clade in Anacardiaceae which correspond to Anacardioideae defined by the molecular studies of Terrazas (1994) and Pell (2004). *Pistacia atlantica* female flowers have single-ovule ovaries. The fruit is a syncarpous drupe, morphologically variable (Zohary, 1952; Belhadj et al., 2008, El Zerey-Belaskri, 2016), with thin and oleaginous exocarp. It is small in size (0,8/0,7 cm) (El Zerey-Belaskri, 2016), large-oval drupes, red turning to dark green when mature (August to September) . Its single seed is ovate and yellow. An average of 37 fruits per infructescence was recorded in adult individuals (Anwar and Rabbani, 1996).

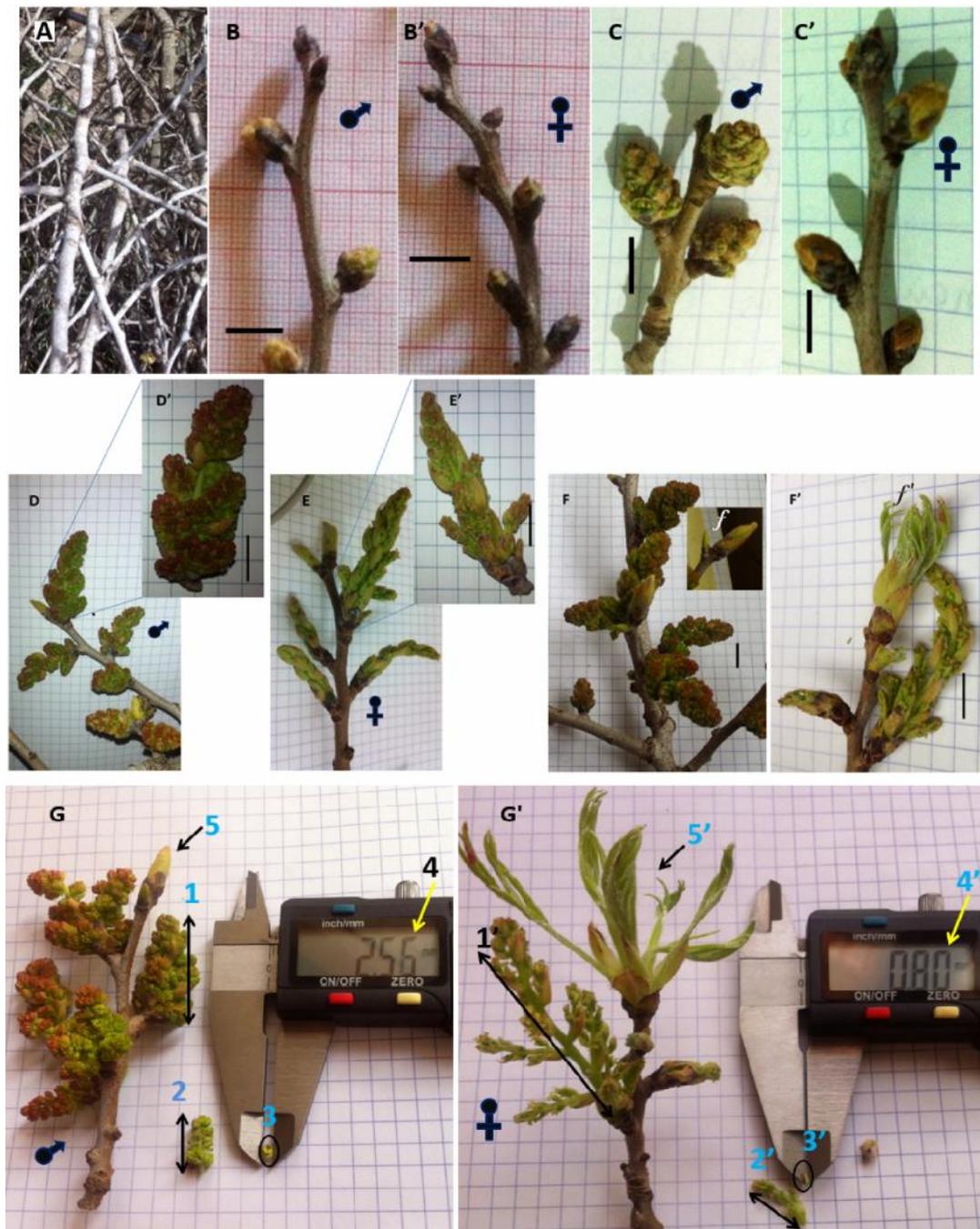


Fig. 5 Major *Pistaciaatlantica*subsp. *atlantica* phenological stages in male and female trees (from dormancy to first foliation): **A**:dormancy (from late December to late February or early March, depending on the weather); **B&B'**: swollen floral bud (early March); **C&C'**: Tight cluster (around the second week in March); **D,D'**, **E, E'**: first bloom (around the third week in March); **F&F'**: bloom (late in March), **f&f'**: show that female trees develop leaf buds before male trees; **G**: male inflorescences (1:male racemous-tyrse, 2: male grape, 3: male flower, 4: male flower size, 5: leaf bud); **G'**: female inflorescence (1':femalepanicule, 2': female grape, 3': female flower, 4': female flower size, 5': first leafing) **NB**: Bars=1cm. Stages and timing were observed from December to March: 2013- 2015. All the photos were taken in 2015, in a natural population in the region of Sidi Bel Abbes. PhotosA. El Zerey-Belaskri

4.3 *Pistacia atlantica* geographic distribution and ecology

Pistacia atlantica is one of the Irano-Touranian taxa which is largely distributed in the Mediterranean region (Zohary 1952). The Mediterranean and the Irano-Turanian regions have many common taxa because they belong to the same climate type and are in contact since ancient geological times (Eig, 1932). Atlas pistachio occupies a wide variety of soils. It shows no soil preference and thrives well in dry and poor soils, in clay or silty soils (Boudy, 1952; Limane, 2014). It has the capacity to colonize the rocky soils where roots insinuate and develop inside cracks and where it can overcome many other species in a growing competition (Monjauze, 1968, 1980).

Monjauze (1980) describes it as the most ubiquitous tree in North Africa and the Middle East. In Europe, the species grows in Greece (in Attica region and in the islands of Rhodos and Chios) (Rouskas, 1996), in Serbia (Al-Saghir, 2006) and in Ukraine (Krym) (USDA/ARS/GRIN, Online Database). In Asia, *Pistacia atlantica* is found from Northern and Western Pakistan, to central and South Afghanistan, South and West Iran, the Southeast Caucasus, North Iraq, South Turkey, Syria, Lebanon, Jordan to Palestine.

In North Africa, it occurs in isolated stands in Egypt and Lybia but builds massive stands in Tunisia, Algeria and Morocco (Desfontaines, 1779; Zohary, 1952; Quezel and Santa, 1963; Monjauze, 1968; Browicz, 1988). It reappears in Canary Islands (Ceballos and Ortuño, 1976), western limit of its wide distribution area. It is believed that *P. atlantica* is originated of Persian region (Iran) from where it has expanded to Southwest of Europe, to North Africa and the Canary Islands Zohary (1952). In these different geographic locations, it occurs with its different subspecies described above (Monjauze, 1968; Behboodi, 2004).

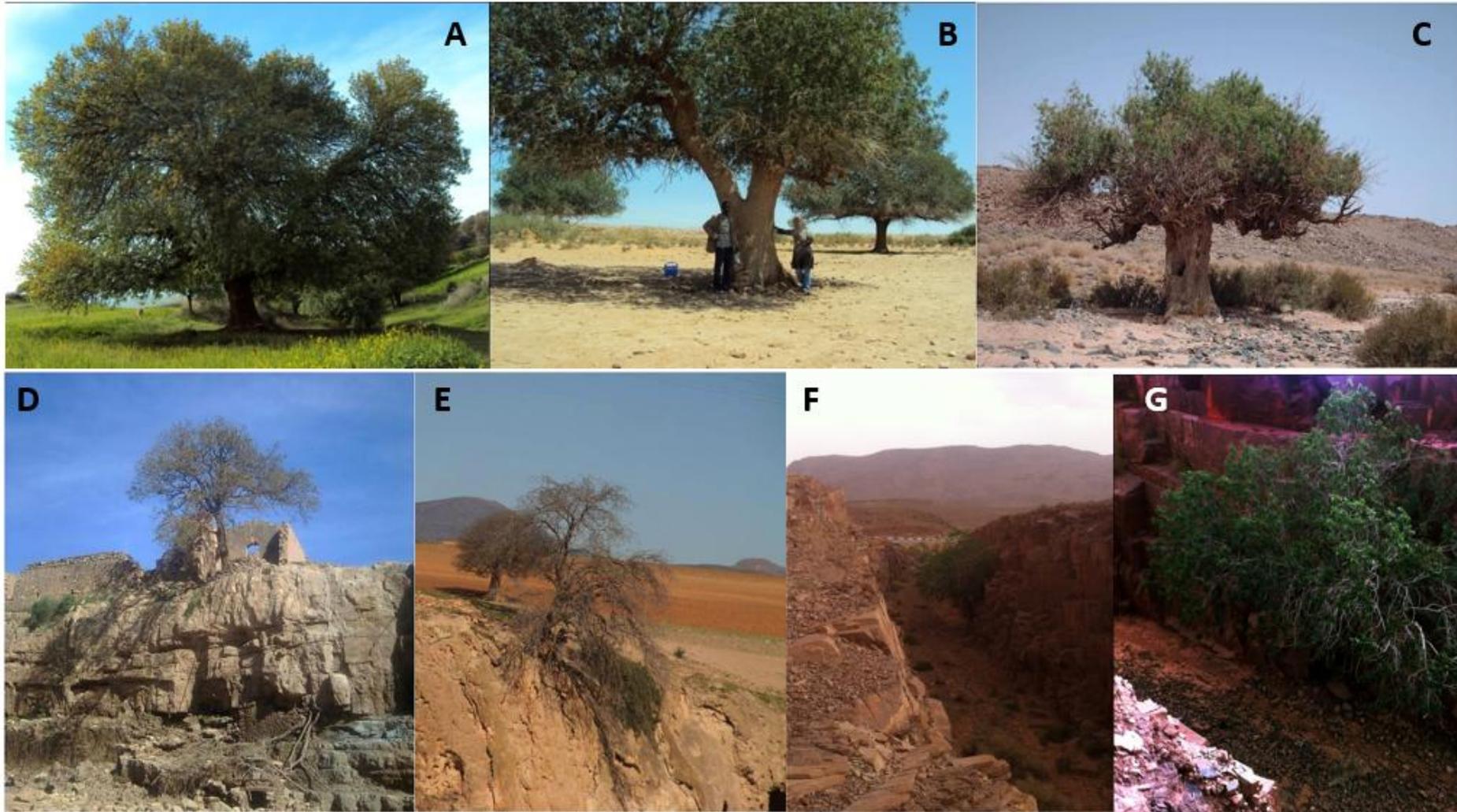


Fig. 7 *Pistacia atlantica* Desf. *atlantica* in various ecological conditions in Algeria : (A) in the plain, in the region of Tallout, Tlemcen (April 2013); (B) in the steppe, in the region of El Abiod Sidi Chikh, El Bayadh (March 2014); (C) in a rocky desert (Hoggar Mountains; (D, E) in rocky soils in Northwest Algeria, Chigguer, Saida respectively (December 2013); (F) along a valley in the Saharian Atlas (Bechar, July 2014) (G) in a rocky soils Bechar (South Algeria, July 2014). Photos (A, B, D, E, F, G) A. El Zerey-Belaskri, (C) offered to the author by Y. Chebbouti.

Pistacia atlantica subsp. *cabulica* mostly grows in regions with less altitude, but it is found until 2500 m. It is distributed in regions which have less than 100 mm rain yearly and is spread to the regions until 200 mm. This subspecies is the most resistant to the lack of water (Behboodi, 2005). This subspecies is found in Afghanistan, Pakistan, and Iran (Rechinger, 1969; Behboodi, 2004).

Pistacia atlantica subsp. *mutica* occurs in high altitude, between 900-2800 m. It grows in regions that have 200-400 mm of yearly rain; it is found in Armenia, Crimea, Turkey, Iran and the Caucasus (Brichet, 1931; Rechinger, 1969; Behboodi, 2004, 2005). *Pistacia atlantica* subsp. *kurdica* (= *P. eurycarpa*) is also found in high altitude (900-2800 m) and is distributed in regions with 500-600 mm of rain per year. It occurs in Iran, Iraq, Syria, Turkey and Palestine (Rechinger, 1969; Behboodi, 2004, 2005).

Pistacia atlantica subsp. *atlantica* is native to the Maghreb countries (Bowicz, 1988). It is possible that this was the reason which led Quezel and Santa (1963) and Ozenda (1983) to describe *P. atlantica* as endemic to North Africa. However, the subspecies is cited in Syria, Lebanon and Turkey (Karimi and Kafkas, 2011). This subspecies is found in limited sites in Egypt and Libya probably because of the latitude, but it occurs in more large areas in Tunisia, Algeria and Morocco. *P. atlantica* grows at altitudes ranging from 100 m (Kalaa, Tunisia) to very high elevations (2000 m, in Algeria) (Boudy, 1952; Monjauze, 1968). It is xerophilous tree, known for its exceptional drought plasticity (Fig. 7) which could be its main trait (Monjauze, 1980). It builds up park-forests and often grows as a dominant constituent of steppe-forest formations.

5. Conclusion

Based on several morphological and molecular studies carried out on *Pistacia* intra/inter genetic relationships (examined above), the IPNI (2010) retained 11 species for the genus. This list was updated from that reported by Zohary (1952, 1972) in his first *Pistacia* monographs. However, the taxonomic status within the genus remains discussable and still shows a permanent evolution. Under different ecological conditions in its large geographical distribution area, *Pistacia atlantica* is characterized by remarkable morphological variability which is a relevant key for the conservation of pistachio germplasm. The different studies and investigations regarding Atlas pistachio variability (at morphological, chemical and genetic levels) could be combined and exploited to develop a mapping based on the macro/micro-morphological, chemical and genetic characterization and also a mapping of valuation fields

and pathways of *P. atlantica*. This mapping will avoid any irrational exploitation or any genetic pollution in the case of *in-situ* and *ex-situ* conservation programs. In this way, we believe that it is very important to pay attention to seed origins in 'ecological restoration and biological conservation purposes and programs'. It is wise for example that seeds from every population or at least from every area should be used to produce seedlings for the restoration of the same population. It would be important to protect the populations especially those characterized by their chemical, genetic or morphological features. Several studies were undertaken aiming to understand the origin of *Pistacia* diversity and to answer many previous questions about the morphological variability in many regions in its vast distribution area. Nevertheless, all these investigations are continuously opening up new prospects for deep and detailed characterization in order to understand the structure of *Pistacia atlantica* natural populations and its evolutionary history.

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