Adv. Hort. Sci., 2012 26(3-4): 163-175

Oleiculture in progress

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Kew words: aging, branching, chilling requirement, cold resistance, flower buds, planting density, triglycerides.

Abstract: The present work evaluates the limits and possibilities of development with regard to the most recent olive-growing techniques in light of up-to-date knowledge of species characteristics. After a brief introduction regarding the productive capacity of olive, the new taxonomic position of the cultivated species and a reorganization of the genus *Olea* is presented in the first part of the work. Examination follows of the assumed stages of domestication, spread (from the Bronze Age until decline in the 6-10th centuries A.D.) and then globalization of the species from the 19th century until the present. The second part addresses the spread of olive to the different continents, environmental limitations to its cultivation and the growth model that distinguishes it from most of the other cultivated woody species. The various problems that arise when olive is cultivated outside its areal of origin are considered, from induction processes to effective chilling requirements, as well as the effects of climatic environment on plant growth and product quality following shifts in areal. The paper concludes with a brief analysis of open questions relative to new models of cultivation.

1. Introduction

Cultivated olive (*Olea europaea* subsp. *europaea* var. *europaea*) (Green, 2002) ranks 21st among agricultural species worldwide and first among woody fruit species in terms of surface area (9.5 million ha), producing more than 3 000 000 t of virgin olive oil (FAO, 2010) and more than 2 200 000 t of table olives per year (IOOC, 2010).

Virgin olive oil, which makes up slightly more than 2% of total vegetal oil production, accounts for a return in the agricultural sector of more than 22 billion dollars, while the figure for palm oil (30% of vegetal oil production) amounts to a little more than 31 billion dollars (FAO, 2010). Olive cultivation worldwide has grown over the past 20 years by more than 20% in terms of surface area with increases noted on all continents. There has also been a doubling in production, which is more than proportional to the increase in surface area (FAO, 2010). These increases have been due to improvements in cultivation technique in traditional plantings as well as entry into production of new, more rational plantings. The species is in general very efficient in exploiting environmental resources and can produce as much as 2 t ha^{-1} of healthy oil food.

Little more than 50 years have passed since olive first expanded beyond its traditional cultivation areas, and the species has shown to be flexible and adaptable in various agronomic, climatic and environmental situations, able to add value to extensive areas and to face the climate changes currently taking place.

Received for publication 28 January 2013
Accepted for publication 15 February 2013

2. Taxonomy

Cultivated olive is an evergreen bush that can be, with suitable intervention, grown as a tree and it is considered typical of Mediterranean flora. The taxonomic position of the species *Olea europaea* L. has been reviewed (Green, 2002), also in light of the data that has emerged from new technologies of molecular identification (Besnard *et al*., 2002).

The *Olea* genus is divided into three subgenera and in the subgenus *Olea*, sez. *Olea*, the species *Olea europaea* is grouped as a "complex" with potentially infertile forms, compatible for grafting, and characterized by the presence of flavonoid glucosides in plant tissues and fruit.

The *Olea europaea* complex is further divided into six subspecies: *cerasiformis* (Island of Madeira), *cuspidata* (from the south to northeast of Africa and from southwest Asia to the arid zones of the Yunnan and Sichuan in China), *europaea* (Mediterranean basin as far as Mesopotamia), *guanchica* (Canary Islands), *laperrinei* (Hoggar high plain in the south of Algeria as far as al Jebel Marra in the western Sudan), and *maroccana* (southern slope of the Atlas mountains in Morocco). These subspecies can be considered "geographic entities" with notable molecular differences (for example *cerasiformis and maroccana* are polyploid) (Besnard *et al*., 2007 a) but their morphologic characteristics are so similar that in certain cases descriptions can overlap. This fact justifies past imprecision in classifications.

Many entities which in the past were considered to be separate species, including progenitors of cultivated olive such as *O. crysophylla* and *O. ferruginea* (Simmonds, 1976), have been placed within the subspecies *O. europaea cuspidata*.

Based on this classification, the areal of the *Olea europaea* complex occupies three continents: starting from South Africa it crosses the central part of the continent and the Horn of Africa, from Egypt and the Red Sea it reaches the Mediterranean and toward the west into the islands of Macaronesia (Island of Madeira and the Canary Islands), while in the east it passes through Palestine, Syria, Mesopotamia and western and eastern zones of the Himalaya chain as far as southwestern China.

3. Origin and domestication of the species

Due to a scarcity of fossil evidence, it is difficult to determine the geologic period during which this complex *taxa* became defined and began to evolve. It is believed that both a floristic element of African paleotropical origin and the long evolutionary history of this group spanned a large part of the Tertiary (Besnard *et al*., 2009). It seems that the genus *Olea* had its origins in the Oligocene and that numerous *taxa* diversified thanks to catastrophic climatic and tectonic events which were characteristic during the Tertiary (from the great glacial period of the Oligocene to the raising of mountains in eastern Africa and desertification of the Sahara).

A study on the phylogenesis of the *Olea* genus, conducted by Besnard and coworkers (Besnard *et al*., 2007 b) using plastidial DNA and nuclear ribosomal DNA as biological clocks, positions the principal phylogenetic nodes for determining articulations of the genus from the Oligocene (c. 59.2 mya) until the Pliocene (c. 4.4 mya), by which time the main *taxa* of the genus had clearly separated. The desertification of continental Africa seems to be correlated to subsequent differentiation of *taxa* adapted to arid conditions. The new dry environments may have favored establishment of foliar morphotypes in *Olea*. Recurrent segregation and hybridization events could very well have been caused by geographic barriers (e.g. the Sahara) and land bridges.

Probably until the end of the last ice age (15 000-12 000 B.C.) the distribution of olive was prevalently in the area of Africa where desertification led to isolation of Saharan populations (subsp. *laperrinei*). Only later were the southern coasts of the western Mediterranean colonized through the spread of glacial refugia. Thus, spontaneous olive in the western Mediterranean would be of African origin, redistributed as far as the coasts of Spain, France and the Tyrrhenian portion of Italy after the last glaciations (Besnard *et al*., 2001).

The subspecies *O. europaea europaea* is divided into two botanical varieties: *europaea*, which corresponds to the old denomination *Olea sativa* (Weston) and includes the cultivars having seedlings called olivasters; and *silvestris* (Mill.) which corresponds to the old presumed species *Olea oleaster* (Hoffman and Link), spontaneous olive or oleasters.

The wild oleasters forms represent the original post-glacial Mediterranean population. In the area between ancient Palestine (Zohary, 1994; Zohary and Spiegel Roy, 1975) and the Caucasus, the earliest plants adapted to the needs of proto-cultivators (around the 5th millennium B.C.) were individuated, utilized and multiplied. Considering the ease of agamic reproduction and longevity of the plant, it is possible that few generations of crosses divide contemporary cultivars from these not-so-distant progenitors.

As colonizers advanced westward, carrying with them plant material and expanding cultivation, they individuated and utilized autochthonous material, progressively diversifying the genetic base of their cultivars and at the same time enriching the local forms.

Generally speaking, significant molecular differences exist between the oleasters of eastern and western zones of the Mediterranean (Breton *et al*., 2006 a) and it is possible to identify separate data groups with a separation line that passes through the Adriatic Sea and the Libyan desert (Breton *et al*., 2006 b). From the cited work, the cultivated genotypes seem rather dispersed which can point to a mixing among the various markers, suggesting repeated attempts at domestication and subsequent crossing among cultivars of different origins. Evidence of these events are illustrated by Hannachi and coworkers (Hannachi *et al*., 2010): comparing plastidial DNA of traditional Tunisian cultivars and wild Tunisian forms, they demonstrated that seven of the 15 cultivars currently under cultivation in that country are of oriental origin, while the others are linked to wild material of Maghrebian origin.

Even if the center of domestication for olive was in the eastern Mediterranean, pre-domestication episodes seem to have occurred more or less at the same time, starting from the 5th millennium B.C., in various areas around the basin, for example on the island of Crete and southern Spain. In these areas “stratifications” have been found with cultivated olive seeds overlaying oleaster seeds, as well as the contrary with “imported” seeds from cultivated forms supplanted by autochthonous forms (Terral *et al*., 2004).

Initially olive was used for different purposes compared to its modern use: it was employed for shade, to produce forage and firewood, and to make tools such as poles and staffs; it took thousands of years of cohabitation to arrive at use of the fruit and oil. When cultivation advanced beyond the phase of simply collecting spontaneous fruits, the proto-farmers decided it was more practical, in a preliminary form of cultivation, to group together the best examples from spontaneous forms through agamic propagation by part of stump. This multiplication technique remained in use until the 1970s in many traditional olive-growing countries of the southern Mediterranean.

4. The spread of cultivation

In the beginning, direct use of the fruits must have been limited since the drupes are very bitter, even when extremely ripe, due to the presence of elevated quantities of oleuropein and other phenolic glucosides, and the technology required to remove the bitterness and for brining was too complex for the means available at the time. However, the oil could be extracted through milling using implements similar to those used for grains, making it available for medicinal use, as fuel, for illumination (both sacred and not) and as an unguent.

The use of olive oil in the diet came later in this plant's history, around the first half of the 2nd millennium B.C., when use of this product spread via sea routes first from the eastern Mediterranean and Aegean Sea toward Greece, then thanks to the Phoenicians along the coast of Africa toward the west as far as (and beyond) the Pillars of Hercules.

It is probable that with this progression, attempts at domestication by the inhabitants of the various zones brought advantages. It should be no surprise that ample deposits of Knossos oil have been found, which testify to the presence of active olive oil commerce in the Minoan period (second half of the 2nd millennium B.C.), nor is transportation of oil from Spain toward Carthage a surprise as cultivation on the Iberian peninsula probably dates back farther than evidence and documentation demonstrate.

At the beginning of the 1st millennium B.C. olive cultivation and oil use had reached the various coasts of the Mediterranean and the type of "domestication" of the plant is revealed through differentiation: the Greeks, as far back as the oldest writings, distinguished the oleaster as κότινος for wood usage from ελαία for oil production.

According to Pliny, the Romans didn't know olive cultivation until the time of Tarquinio Prisco (6th century B.C.) but in the 1st century A.D. oil from the Italian peninsula was exported to the provinces of the Empire. In Rome, oil was principally used for external treatment of the body. As the saying went, "wine on the inside, oil on the outside" (*intus vini fori olei*)[1]

Between the 2nd and 4th centuries the spread of this plant reached its greatest development in the entire Mediterranean region. Oil was distributed free of charge to the plebs of Rome as a food source and sent to the legions in Germany. The trade surrounding oil was so important that remains from the jars and amphorae in the port of Rome of the time left a hill which is today one of the recognized neighborhoods of the city (Testaccio).

5. Globalization of cultivation

With the fall of the Western Roman Empire in 476 AD and loss of control of the sea routes, trade and use of olive in the western Mediterranean declined rapidly. Evidence of introduction of oil from northern Africa in the 6th century can be found (Brugnoli and Varanini, 2005) but from the 7th century sea transport of oil toward Rome ceased, at least in an organized way, to exist. At the same time a period of instability in North Africa began, marking a generalized abandonment of olive cultivation in the region; it did not pick up again until after the Arab conquest around the 10th century.

In Europe, olive oil acquired new importance through the Christian religion, and for which substitutes were not possible (e.g. for illumination of altars, anointing of the sick, use of plant oils during Lent or other periods of abstinence from foods of animal origin). For this reason, cultivation was undertaken in some areas considered marginal in terms of climate for the cultivation of olive (north-central Italy until the Alpine valleys) as a way to at least guarantee the needs for churches and monasteries.

Olive growing zones along the coasts receded with the fall of commerce and only the oldest cultivation areas remained important: Palestine, Syria, and the island of Crete provided oil for Venice and Constantinople while Andalusia furnished Muslim areas.

The olive oil trade was revived in the 11th and 12th centuries thanks to merchants from Genoa and Venice. They supplied monasteries, cities in Italy, France and Constantinople with this precious product needed not only as a food source but also for religious and liturgical purposes, illumination, and soap and wool production.

An intense freeze in 1009 killed off the remains of ancient olive growing on the Italian peninsula along the entire Adriatic and in particular in Puglia. Subsequently this region experienced a notable increase in olive cultivation with new plantings, at the expense of grain cultivation, thanks to the development of trade by the Venetians. In this period Apulian markets were open to traffic from Venice, Genoa and Byzantium, thus progressively establishing this area as an important zone for olive cultivation (Iorio, 2005). Even today Puglia accounts for the most extensive and productive portion of Italian olive production, with more than 20 million trees of 300-500 years of age.

After about 1300, olive oil (for illumination and soap and wool production) became one of the most important products necessary for industrial development in northern Italian cities. As it was not possible to rely exclusively on commercial trade, it became necessary for the economies of many zones to provide incentives for cultivation, also in areas with extreme soil and environmental conditions.

The 15th century represents a turning point not only in the history of olive but also for humanity. In 1453 Constantinople fell, the last remnant of a civilization born with the cultivation of olive, while in 1492 two important events occurred: the fall of Granada, the last vestige of Muslim dominion in Spain, and the landing of Colombo on San Salvador. The interest of Europe shifted westward and with it went the olive, a colonizing plant *par excellence*. Olive was introduced in Spanish colonies, first in Cuba around 1520 and then in California. The original plant material left the port of Seville as seeds or seedlings and so

[1] Plinio, Storia Naturale, XIV, 150.

genetically the material can be considered as Andalusian in origin. The Spanish colonists carried olive with them as they travelled southward from California along the Pacific, introducing it in Peru and from there crossing to Argentina. An olive plant considered to be more than 400 years old exists in the province of La Rioja in Argentina, which would place its establishment at the time of the first European settlements in that region when the capital, Ciudad de Todos los Santos de le Nueva Rioja, was founded (1591) (Fig. 1). During its trip from California to Argentina, the genetic material of olive underwent further selection with identification of cultivars such as 'Mission' (California) and 'Arauco' (Argentina), the 400-year-old tree belonging to this latter.

Fig. 1 - Old picture (dated around 1950) of the oldest 'Arauco' plant in Argentina.

With the spread of colonialism and the need to transfer plant productions able to satisfy industrial and dietary requirements in the colonies, also olive began to be valued, utilized and cultivated in various areas considered to be suitable.

In 1661 Dutch merchants carried olive to South Africa where spontaneous forms of *Olea europaea cuspidata* were already present. Between the end of the 18th and beginning of the 19th centuries cultivated olive, together with *cuspidata*, landed in southern Australia where the two subspecies found a favorable environment, giving rise to a vast phenomenon of spontaneity (Breton *et al*., 2008). The first documented introduction dates back to 1800 when olive officially arrived in Sydney (Spennemann, 1999). From then until before the Second World War, olive from various provenances was introduced (from Spain, Italy, Greece and later Israel). Starting in 1956 there was interest in olive cultivation in China as well, where the plant was known but its cultivation was difficult due to intense summer rainfall.

Currently, the cultivation area of olive is spread in both hemispheres between 45° and 30° of latitude with extension toward the warm-temperate zones of our planet. The agronomic success of this species is based on two fundamental characteristics that distinguish olive from all other cultivated fruit species:

Its particular growth model and flower formation make it easy to manage and the reliability of its production have been determinant for its cultivation since Neolithic times.

It is adaptable to highly variable climatic conditions and its localities of origin for domestication are characterized by different conditions.

6. Environmental limitations

The limits for cultivation of olive are attributable to environmental factors and their annual cycles. Beyond the degree of latitude (45°) for cultivation for this species, plants are potentially exposed to damage from cold temperatures that can compromise production or even the life of the plant, depending on intensity and timing of the event.

Cultivated olive is only moderately tolerant of low temperatures and even if it is suitably prepared for winter cold (acclimatization), it can resist only a few degrees below zero due to a protection mechanism (supercooling) that keeps water in cells in the liquid state down to several degrees below the freezing point (Table 1). The most resistant tissues are the bud meristems (in 'Ascolana tenera' the recorded lethal temperature is -19.3°C) (Fiorino and Mancuso, 2000), so that vegetation severely damaged by

Table 1 - Lethal temperature (°C) as evaluated by differential thermal analysis for various organs in two acclimatized olive cultivars having different resistance to cold: 'Ascolana tenera', very resistant; 'Coratina', poorly resistant

Part of plant	Lethal temperature (°C)	
	'Ascolana tenera'	'Coratina'
Leaves	-14.5 ± 0.2	-11.8 ± 0.2
Shoots	-18.6 ± 0.6	-12.6 ± 0.4
Buds	-19.3 ± 0.6	-13.5 ± 0.4
Roots	-9.1 ± 0.3	-8.6 ± 0.3

From Fiorino and Mancuso, 2000.

intense winter freeze can copiously resprout in the following spring from latent and adventitious buds, in particular on the stump. Differences exist among the cultivars: comparing 21 prevalently Italian cultivars for their resistance to cold, employing three different evaluation methods in leaves and sprouts, the authors (Azzarello *et al.*, 2009) were able to divide the material into three groups in relation to lethal temperature.

With regard to phylogenesis, and considering knowledge of other subspecies such as *Olea europaea* subsp. *cuspidata* which is poorly resistant to cold stress, it is possible that the varieties cultivated today have reached their maximum result possible through genetic pressure applied by humans in terms of advancement toward colder regions.

Furthermore, due to its tropical origin, the species is characterized by a relatively high critical temperature (10-12°C) (Mancuso, 2000), thus pushing cultivation toward northern limits would result in a growing season that is too short. The highest latitude areas with olive cultivation are the alpine lakes in Italy, Istria (Slovenia, Croatia), and the olive-growing area of Odessa (Crimea, Ukraine).

The factors which limit expansion toward the Equator are less evident. Olive is a species that can support high temperature: the lethal temperature for leaf tissues varies from 46 to 50°C depending on the cultivar and can reach 52°C in sprouts (Mancuso and Azzarello, 2002). The greatest limiting factor seems to be the need by flower buds for a period of low temperature in order to pass from an "inductive" phase to that of tissue differentiation and development of the inflorescence. This rest phase is generally divided into two periods with very different thermal needs. In the first phase low temperatures (6-9°C) are needed to remove inhibition for subsequent growth, and in the second warmer temperatures (above 8.5°C) are required to accelerate evolution of the phenomenon. The currently used reference model for olive (De Melo-Abreu *et al.*, 2004) is based on that of Richardson to study periods of rest in peach (Richardson *et al.*, 1974). This model considers the period from 1 October to 31 January useful for overcoming chilling need, with 7.3°C being the optimal temperature. Temperatures from 0 to 18.5°C can also be considered acceptable with a weighted effect of their distance from the optimal temperature, similar to the Richardson model. The authors terminate calculation of the chilling units on 1 February, as they consider that for their study area (Cordoba and Mas Bové Reus Terragona in Spain, Elvas and Santarém in Portugal) by that date the needs of olive for cold should already be satisfied. The authors underline that temperature is not the only factor toward which olive is sensitive and thus the data needed for this calculation should be verified every time there is a change in cultivation zone or variety.

Interest in the effect of low temperatures for normal development of flower buds is relatively recent: only in the 1950s was it proposed that the amount of flowering is in some way linked to the duration of low winter temperatures (Hartmann, 1953; Hartmann and Porlingis, 1957). In the beginning researchers (Hackett and Hartmann, 1964) believed that the role of low temperature was more incisive and able, together with other environmental factors, to influence flowering processes from the first phases of induction, but later it was demonstrated (Rallo and Martin, 1991) that its role is limited to development subsequent to the induction phase.

There are however ample areas of research that have only barely been considered. For example, in 1975 it was noted in a study (Hartmann and Whisler, 1975) that: 1) by applying a suitable period of cold, flowering can be stimulated in any time of the year (this somehow confirms the theory of "aging" of apical meristems that when mature produce buds able to directly develop flowers) (Fiorino and Marone, 2010); 2) there are ample differences between cultivars in regard to their response to various quantities (constant or variable) of low temperatures (varietal differences represent the weak point of all experimentation in this field); and 3) thermal thresholds of response seem extremely various among cultivars themselves as evidenced by the behavior of local cv. Mission which can, by flowering continuously throughout the cool summer typical of the California coast, lead progressively to a modest number of inflorescences.

In 1983 a work was published (Denney and McEachern, 1983) aimed at improving understanding of responses of this species to various environments. The results were obtained by elaborating temperature data (October-May) from 15 olive-growing stations to determine the effect of the "cold", measured as the capacity of the olive plant to flower in the subsequent spring, when two conditions have been met:

1) active growth has concluded;
2) daily temperature trend does not exceed an average of 12.5°C.

The greatest interest with regard to this study concerns the concept of "effective chilling" which indicates, for regular flowering to occur, the number of days when the average temperature must not drop above 12.5°C. In order to satisfy the thermal needs of olive, 70-80 days of "effective chilling" are necessary, thus setting geographic limits for the species.

A comparative analysis of the thermal conditions of some geographical zones at the warmer limits for cultivation (Ico, Peru and Caborca, Mexico) and where olive growing is undergoing development (Gran Chaco, Argentina) (Ayerza and Sibbett, 2001) points out that often in "new", "warm" olive-growing areas the number of days for wintering are fewer than those considered necessary (70-80 days). For example, at Ico (Peru) the possibility for wintering does not exist as average daily temperatures are never below 12.5°C, although there are cultivars that produce well enough in the area to allow commercial plantings. The area is characterized by a lack of rainfall despite frequently cloudy skies, making it possible to control growth through drastic reductions in irrigation water which oblige the plant to reduce or interrupt vegetative growth, despite year round temperatures that are relatively high. The authors of the study admit that the reasons for this behavior are not clear and hypothesize that in the autumn-winter period, as the sky is almost constantly overcast, the thermal lows needed for the buds are attained, although perhaps they wouldn't be in sunny areas.

Sensitivity to different thermal thresholds or chilling needs to bring about flowering is appearing in new plantings, in areas considered to be homogeneous with consistent seasonality, but where there are specific zones with cold periods of different duration and intensity. For instance, this can be the case in the Mediterranean basin where notable differences are recorded for Florence (central Italy), Seville (southern Spain) and Cairo (Egypt).

The millennia-long history of olive has made it possible to identify local cultivars perfectly suited to specific environments, thus creating varietal standards able to adapt themselves to the thermal trends of that particular area. In recent olive-growing, cultivars famous in a specific territory have often simply been used elsewhere, although this has led to unsuccessful attempts generally due to a lack of adaptability to the relative high winter temperatures of the new environment. Examples of this are the negative results obtained from the transfer of 'Frantoio' (cultivar from Tuscany) to southern coasts of the Mediterranean or warm areas of the planet.

This sensitivity of the plant to specific thermal requirements for flowering confirms the fundamental role of temperature in all aspects of the life of olive, from the progression of phenological phases to the biochemistry of the oil.

There are notable differences among Mediterranean germplasm with regard to the effective chilling requirements of autochthonous material which do not necessarily depend on where the material was selected. Thus, two varieties selected in similar environments and at approximately the same latitude, for example 'Arbequina' and 'Frantoio', have demonstrated opposing behaviors when cultivated in warm areas: the former flowers copiously and early, while the latter rarely flowers much and often not at all.

In olive, the effect of low temperature is more complex than in temperate species which are often referred to: for some varieties the "chill" that results from diurnal temperature variation is sufficient to permit normal flowering (e.g. in 'Arbequina') and the thermal threshold of chilling must be rather elevated since nocturnal temperatures of less than +2 to -1°C markedly diminish flowering under controlled conditions (Malik and Bradford, 2009).

7. Current trends

Over the course of the millennia of expansion (4th-2nd millennia B.C.) and cultivation (1st millennium B.C. - 2nd millennium A.D.) the techniques for growing olive remained essentially unchanged, just as the needs of agriculture to have long-living, hardy, easily managed plants able to produce oil for nutrition, illumination, industries (textile and mechanical) and other purposes did not change over time. It was only in the 19th century that olive-growing began to gain advantage from technological development, in particular with regard to oil extraction, while agronomic techniques remained anchored in acquisitions and requirements from the past. Research pertaining to olive-growing was only blandly affected by the innovative spirit that invested agriculture and in the first half of the 20th century knowledge based on millennia-old, empirical observations persisted or models and concepts were adapted that pertained to other cultivated woody species, for example fruit-bearing species from temperate zones.

At the turn from the 19th to 20th centuries, in Europe olive oil was considered a strategic food but it was only in the middle of the 20th century that the true importance of this product for human nutrition was understood in terms of its nutritional, organoleptic and functional profile. With economic and geographic expansion of olive cultivation in the second half of the last century came awareness of the peculiarity, potentiality and lack of scientific knowledge about this ancient species.

Olive possesses all the fundamental requisites to become a modern crop: good productivity (more than 2 t ha^{-1} per year of oil), very early entry into production for plantings that are well positioned in terms of water and nutritional availability (on average the third year after planting), good adaptability to diversified environments and availability of light, soil and other resources, good availability of plant material that can be obtained using new techniques (mist-propagation and micropropagation), and great flexibility of plant material for adaptation to various breeding systems, all depending on the various destinations of the product (for oil or the table) and in relation to the needs of the market.

8. Architecture of the plant

Olive owes its agronomic success to the longevity of plantings, simplicity of its constitution and reconstruction of the canopy, and predisposition for flowering.

In nature, the plant grows as a bush with a stump rich in vegetative meristems able to produce suckers that can form trunk-like structures able to survive for hundreds of years; it can grow to have canopy heights and diameters of 10-12 m.

The olive model is not greatly described in literature. Each vegetative meristem on the stump (or positioned plantlet) can give rise to a sprout with acrotonous, orthotropous attitude and continuous growth that will form the vegetative axis. Early on, this sprout is poorly lignified, slender in relation to its height and tends to curve if not supported. At its point of curvature (the new tip of the branch), another vegetative meristem grows and repeats the cycle, while the distal portion of the original branch continues his growth in a lateral direction.

With lignification and subsequent radial growth, the insertion angle of the two consecutive, opposing sections attenuates and the structure takes on the form of a single trunk resulting from fusion of the segments (Fiorino *et al.*, 2012).

The originally-vegetative apical meristems, over time and with growth, mature, change in function, lose their orthotropous characteristics, become plagiotropous and take on reproductive functions (“aging”) (Fiorino and Marone, 2010) with subsequent formation of fruit-producing vegetation.

This particular type of growth and shift to production makes olive a very flexible plant as it can be grown either with a central axis and short branchlets arranged at various heights or with varying vase-like forms, obtained via subsequent vegetative axes, having or not a central trunk. Having these characteristics, the parts of the canopy destined to support the vegetation are semi-permanent structures that periodically need to regenerate the growth-aging-flowering cycle typical of olive branches. This growing habitus simplifies pruning principles and operations.

9. Induction and differentiation

Growth and lengthening of the branch in subsequent years is almost completely delegated to apical meristem activity, creating a continuous linear structure (branch-limb) with persistent (three years), opposite leaves and lateral flowering that allows further apical growth. The branch-limb complex is made up of a succession of nodes generated by an evolving meristem (vegetative vs. reproductive) that will determine bud functions. The growth-aging process continues until a progressive weakening leads to the loss of the apical meristem or until itself transforms into a flower (Fig. 2).

Fig. 2 - Terminal bud transformed in floral grape in cv. Koroneiki (Photo E. Marone).

Two types of buds coexist at each node. The main, most evident ones that can remain on the plant for no more than two vegetative cycles, and at least two accessory buds positioned above the main one (Fig. 3). These accessory buds are poorly visible and often covered after their formation by cortical tissues (and therefore also called hidden buds) of the growing branch to the point of not even being considered (Lavee, 2007), and are destined to become latent and able to burst many years after their formation.

Fig. 3 - Node showing the two main buds producing floral grapes and in upper position the two accessory buds (Photo E. Marone).

The evolutionary phases of a flower meristem are not distinguishable to the naked eye before the burst of the buds (Barone and Di Marco, 2003; Andreini *et al*., 2008) and sometimes, even under morpho-anatomical analysis, some early manifestations of differentiation are ambiguous and difficult to interpret (Troncoso, 1966).

Histological and histochemical indications point out that: a) there are histochemical differences in the formation and development of lateral buds in different genotypes (e.g. ‘Leccino’ and ‘Puntino’); b) there are differences in zeatin levels in buds of the same cultivar (e.g. ‘Leccino’) taken from plants with different fruit loads and these hormone level differences start early, from the month of July (Andreini *et al*., 2008); c) there are differences in development (timing and forming structures) among homologous buds removed from rising branches or identified in peripheral parts of the canopy and these also start early, from the month of July (Fabbri and Alerci, 1999).

It was believed (Lavee, 2007) that in growing sprouts the principal buds of originally mixed function could shift toward flower formation only when a specific sequence of events occurred, which are successive (preinduction-confirmation), temporally separated and controlled by endogenous and exogenous factors.

More recent research has indicated the primary role of apical growth in the formation of fruit-bearing vegetation and in the evolution that is determined by growth. In order to reach adequate levels of aging, in relation to the cultivar, buds with defined function - flowers for the principal buds, vegetative for the accessory buds - form along the lengthening sprouts (Fiorino and Marone, 2010; Marone *et al*., 2013).

In this way, and possible due to an adequate intensification of cultivation, the amount of annual growth of mature branch-limbs increases leading directly to an increase in the number of flower clusters and thus fruit load on the branch. The fruits, due to their weight, pull the vegetation downward forming fruit-bearing cascades that are particularly suitable for mechanical harvesting by horizontal shakers (Fiorino *et al*., 2010).

10. Adaptability

Due to olive's adaptability to xeric environments, currently expansion of cultivation takes place with success mainly in warm-temperate dry zones below 30-35° latitude in both hemispheres: these areas, where land is available, are characterized by short winters, early-spring temperature rise and hot, sunny summers, all factors which affect the quantity of growth, progression of phenological phases and oil characteristics as particularly influenced by temperature, according to results presented in the literature.

In a study carried out at one location (Montepaldi, Tuscany, 43° 40' N Lat., 11° 09' E Long., 266 m a.s.l.) to evaluate the behavior of cultivars selected over time from areas having different climatic conditions (Mancuso *et al*., 2002), analysis of the relationship between variations in annual climatic conditions and development of phenological phases revealed the following roles played by temperature:

a) in the determination and evolution of the various phases together with different behavior of cultivars coming from different areas. Cultivars 'Coratina' and 'Carolea', selected from southern Italy where spring temperatures are warmer, have more accelerated bud burst and phenological phases up until fruit set compared to cultivars ('Moraiolo' and 'Leccino') selected in the cool, test area; and
b) in the appearance of phenological phases in relation to average increase in temperature and duration of insulation. From a data pool pertaining to five cultivars (the four previously mentioned plus 'Picholine Languedoc') it was found that an increase of 0.5°C leads to an anticipation of flower bud burst by more than three days, with notable effects from the time of pit hardening. In addition, an increase in average insulation seems to increase the speed with which these phenological phases progress.

The influence of spring temperatures on the date of flowering in different cultivars was confirmed by De Melo-Abreu and coworkers (De Melo-Abreu *et al*., 2004). More recently, Orlandi *et al.* (2012) found that pollen release was generally determined by meteorological factors in the period before flowering, with effects on both pollen amounts and timing of flowering (early or delayed).

The role of temperature in oil composition is more extensive. Independently in each cultivar, temperature trend during fruit growth and maturation influences the ratio among fatty acids of the triglycerides in the oil (Fiorino and Ottanelli, 2003; Marone *et al*., 2003) with a reduction of the percentage normally expected for oleic acid in years characterized by prolonged periods of elevated temperature. With increased average seasonal temperatures (expressed as thermal sums, GDH, with 10°C threshold) (software for the calculation of GDH with variable thresholds was elaborated by Marone, 2003), the percentage of oleic acid content drops and is substituted by increases in palmitic and linoleic acid percentages.

Employing a collection of Italian germplasm, with plants grown in the same environment (Mirto, Calabria) and with adequate agronomic techniques, and through analysis of the variations between levels and ratios of the three principal fatty acids (palmitic, oleic, linoleic) and the thermal sums values of GDH for the relative years, it was possible to measure the existing regression between thermal sums and levels of oleic acid percentages in the oils obtained from the cultivated accessions (Fig. 4) (Lombardo *et al*., 2008).

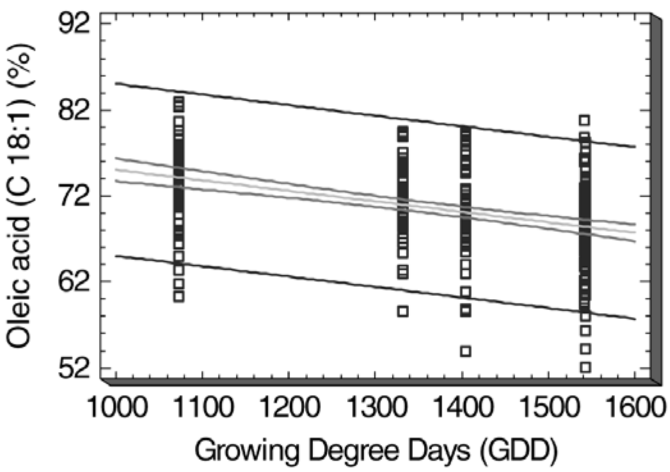

Fig. 4 - Regression between the % content of oleic acid in the TAGs of different cultivars and GDD (population 188 cultivars in total with at least two analytical data in the five years; p≤ 0.01 and r=0.473). On the left, the coolest year (2005), on the right, 2003 (the warmest, practically superposed with 2001) (From: Lombardo *et al*., 2008).

Each cultivar constantly adapts its triglycerides composition, modifying equilibriums and increasing palmitic or linoleic acid (Lombardo *et al*., 2008). The graph shown in figure 5 illustrates the division of a population of cultivars into three clusters separating samples with different characteristics. The first, the most numerous, groups the cultivars that compensate for the reduction in percentage of oleic acid with linoleic acid and subordinately palmitic acid (cv. Canino, Nera di Gonnos, Tonda di Cagliari and Moraiolo). The second group reacts in the opposite manner (cv. Raja sabina and Moraiolo T. Corsini), while only 5% of the tested population is composed of stable triglycerides (cv. Nocellara messinese). The intensity of the response to temperature changes can be such that the oil from some cultivars approaches or exceeds the limits established by law in some countries with regard to triglyceride composition.

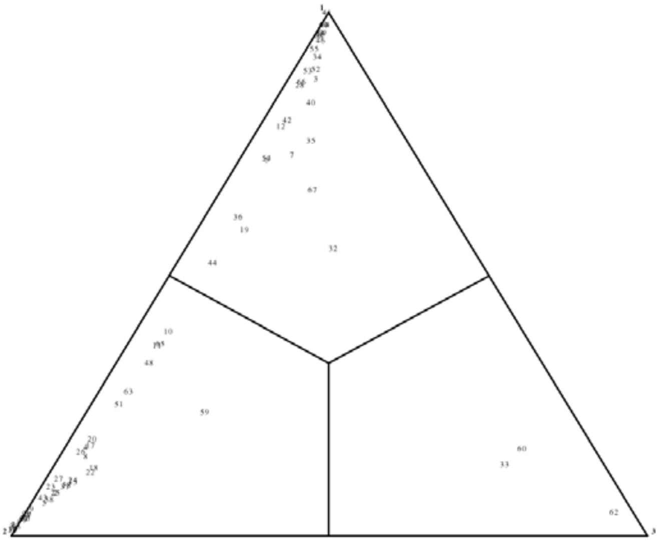

Fig. 5 - Fuzzy clustering in a ternary plot (fuzziness f= 2.25), utilizing the absolute value's differences for the two compared years between 69 cultivars for saturated, monounsaturated and polyunsaturated FAs (From: Lombardo *et al*., 2008).

Working in the province of Rome, Italy (41° 53' N Lat., 12° 14' E Long., 30 m a.s.l.) on 'Arbequina' and 'Arbosana' plants grown as hedges under superintensive cultivation, the acidic composition of the oil was well balanced and characterized by elevated amounts of oleic acid and low or very low levels of linoleic acid in both cultivars (Marone *et al*., 2009). However, when the same varieties were grown in warm, dry valleys in the northwest of Argentina, with a prolonged growing period and high temperatures during the growing season, the acidic composition was modified: there was a drop in oleic acid and a rapid rise in level of linoleic acid (Rondanini *et al*., 2011).

Due to this sensitivity to high temperatures during fruit growth and maturation, the need to review the limits for some parameters in the oil, as prescribed by international laws intended to verify the genuineness of the product, becomes necessary with the extension of olive growing in warm areas or the marketing of local products that had previously been destined for self-consumption. Unadulterated productions can, for example, present not only variations in the ratios among triglycerides (often the amount of linoleic acid exceeds the allowed limit of 1%), but also alterations with regard to the phytosterols, with increases in particular in campesterol levels beyond established limits and which could indicate an addition of seed oils to the olive oil.

There have been few observations of the result of transfer of cultivars from warm to cooler zones. In this case, an opposite phenomenon has been noted with an increase in oleic acid percentage (Fiorino and Marone, unpublished data); it is possible that special characteristics of some productions from cool olive cultivation zones derives precisely from the specific interactions between some cultivars and the various climatic zones.

11. Open questions

New plantings require the transformation of current cultivation techniques, which are still tied to millennia-old traditions. This shift calls for not only radical cultural changes, but also notable investment for establishment of new or modification of existing plantings as well as for machinery. The objective of new plantings is to produce oil, with a lengthening of the production chain from the fruit to the finished product - extra virgin olive oil - which remains unique among other vegetal oils on the market for the presence of complex antioxidants (i.e. polyphenols) that derive directly from this plant's origins.

For researchers and technicians who direct their efforts toward globalization of cultivation, the weak point remains the modest amount of basic knowledge available in order to respond to questions that arise regarding varietal adaptability to different environments, regularity of production and canopy management.

In particular, with regard to the spread of new intensive or superintensive olive-growing models (terms linked to the elevated number of plants per hectare), there are a series of questions: What is the productive lifespan of orchards? What are the characteristics of the product? What is the varietal platform?

The reduced productive lifespan of orchards represents the greatest difficulty to overcome for the spread of this model in countries where olive-growing is deeply rooted in culture and history. Today, plantings last only a few years: about 10 for peach, 15 for apple and pear, perhaps 20 or a bit more for olive, with plants having performed their economic duty in this period of time.

As for the characteristics of the product, research has pointed out that it depends more on cultivar/environment interaction than on the growth system. Initial data seem to confirm that, in any case, the chemical and sensory characteristics of the oil do not change in intensive or superintensive plantings (Marone *et al*., 2009).

The varietal platform suitable for superintensive plantings is made up of few cultivars typical of specific areas ('Arbequina' and 'Arbosana', Spain; 'Koroneiki', Greece). Growth and productivity characteristics are known for the new planting models (Rallo, 2006; Tous *et al*., 2003) as well as the characteristics of the product (Marone *et al*., 2009). Novelties, such as Tosca 07® and Chiquitita® (Redacción Olint, 2007; Rallo *et al*., 2008), have been more recently introduced in new plantings and still need to be better defined agronomically.

The longevity and vitality of olive, and the marginality of its cultivation and production have penalized genetic improvement of this plant: it was undertaken unconsciously in the past but has been more targeted in the last century.

The ideotypes must combine different characteristics (Fiorino, 1999). In addition to growth habit, fructification, and resistance to biotic and abiotic stress, they have to respond to precise composite characteristics for oil which indicate the nutritional value for humans and are by now used internationally for marketing of the product.

Despite the existence of a broad genetic base, with a total of more than 1200 cultivars in germplasm collections (Bartolini, 2008), there is little reliable information available about genetic determination of traits and their heredity (Bellini *et al*., 2003) and this lack makes it difficult to choose the genetic material to use for crossing programs. A recent review (Rugini *et al*., 2011) about the major needs for genetic improvement of olive, indicated systems and aim to achieve different goals in this species, but at present it often ends up being based simply on the phenotypic behavior of parental lines. Also variability in the triglyceride and unsaponifiable fraction in descendents from crosses with the same parents was wide (Tables 2-4) and sometimes with percentages of some fatty acids outside normal values (Fiorino, 2001). The Table 2 reports the values for fatty acids, polyphenols and tocopherols in oils obtained from eight genotypes of open-pollinated 'Arbequina' grown in the same environment. The lineage is characterized by great variability in acidic composition, above all for linoleic acid contents.

It has only been in the past ten years that indications regarding the technological characteristics of the various germplasm collections are present in terms of the qualitative and organoleptic characteristics of the oil (Rotundo and Marone, 2002). Furthermore, characterization of the oils produced by single cultivars in specific environments has begun in this past decade as well (Cimato *et al.*, 2004; Di Vaio, 2012).

New plantings call for control of canopy dimensions, and as most varieties selected over the millennia are very vigorous, new input has come from selection of clonal rootstocks able to influence growth and vigor in olive. By using rootstocks from specific varieties ('Tosca 07® and 'Leccino dwarf') vigor and architecture have been modified in plants of 'Cerasuola' highly vigorous and 'Bianco-

Table 3 - Values for the most important fatty acids in oil from crosses of 'Arbequina'

Fatty acids (%)	Genotypes		
	127*	129*	B28**
C 16:0	13.7	11.7	19.6
C 16:1	0.9	0.8	2.4
C 18:0	2.1	2.3	2.1
C 18:1	66.1	76.6	50.2
C 18:2	14.7	6.3	23.3
C 18:3	1.0	0.8	1.2

* no. 127 and no. 129 = 'Arbequina' x 'Aggezi Shami'.
** B28 = 'Arbequina' x 'Picholine Languedoc'.
From Fiorino, 2001.

Table 2 - Oil characteristics of genotypes obtained from open-pollinated 'Arbequina' (Ghiza, Egypt)

	Genotypes							
Fatty acids (%)	16	52	56	61	67	68	94	105
C 16:0	10.7	14.2	14.2	16.2	19.3	14.9	15.7	18.6
C 16:1	1.0	0.6	1.2	2.2	3.4	2.0	2.1	3.4
C 18:0	2.5	2.1	2.3	2.2	1.8	1.7	2.5	1.7
C 18:1	75.3	66.7	50.7	60.6	42.0	45. 9	61.1	58.5
C 18:2	8.5	14.2	29.3	16.6	31.7	33.3	16.6	15.7
C 18:3	0.7	0.9	1.3	1.2	0.9	1.2	1.0	1.0
Tocopherols (mg/kg)	416	168	219	366	286	347	91	420
Polyphenols (mg/kg)	34	165	67	51	77	91	50	101

From Fiorino, 2001.

Table 4 - Oil characteristics of genotypes obtained from controlled crosses of 'Manzanilla' x 'Picholine Languedoc'

	Genotypes					
Fatty acids (%)	A2	A5	A4	A14	A18	A19
C 16:0	12.0	10.9	13.7	16.6	9.9	16.1
C 16:1	0.9	1.2	1.9	1.9	0.9	2.1
C 18:0	2.5	2.1	2.3	1.9	2.1	2.1
C 18:1	68.6	75.0	64.9	63.9	72.0	58.0
C 18:2	13.7	8.8	15.1	13.7	12.8	19.5
C 18:3	0.8	0.7	0.8	0.9	0.9	1.3
Tocopherols (mg/kg)	173	185	215	177	214	318
Polyphenols (mg/kg)	169	-	286	-	140	305

From Fiorino, 2001.

lilla' low vigorous (Caruso *et al.*, 2012). These results are very promising, even if they must be verified in the field and in different environments.

12. Conclusions

As with other woody fruit trees (e.g. *Citrus* spp.) and prevalently herbaceous species (e.g. corn, soy, sugarcane, manioc), olive is rapidly expanding its territory into new areas, which in turn permits the latent capacities of this species to be expressed to an equal or greater extent compared to that possible in the species' areas of domestication and millennia of cultivation.

Olive seems able to gain added value in some temperate-warm areas of the planet where otherwise unutilized desert zones could offer ample space. In these areas it would be possible to control growth and fructification through the water stress inherent to the climate as well as temporal space during the annual growth cycle to satisfy the modest chilling requirements of some cultivars.

The current geographical limit toward the equator (30° Lat.) does not seem insurmountable and, in particular conditions, the margins for maneuvering with regard to enlarging the areal still seem quite wide. The limits of this development are related to a lack of some background knowledge and uncertainties in interpretation of research data, especially with regard to control mechanisms for flowering, flower formation (inductive phase), and flower development (chilling requirements).

Olive oil has special characteristics that make it not only a food and condiment, but also a product able to protect the human organism from dysfunctions and pathologies, thanks to the presence of a number of components, and thus it plays an important role in a balanced diet.

Olive has a particular capacity to respond to changes in its environment (especially vegetation and fruits with regard to temperature) and greater development in warm cultivation areas is possible but first more knowledge is needed regarding genotype/environment interactions of varieties suitable for cultivation in these zones to maintain olive oil as a preferred source of vegetal fats.

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