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Horticultural management of Italian Pistachio orchard systems: current limitations and future prospective

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Gestione della coltura del Pistacchio: limiti attuali e prospettive future

Riassunto. La produzione mondiale di pistacchio è aumentata fortemente negli ultimi anni grazie alla capacità di questa specie di crescere in condizioni limitanti e per l'elevato prezzo che il prodotto riesce a spuntare sul mercato. In Italia, le superfici interessate alla coltivazioni del pistacchio, rispetto ai grandi paesi produttori come la California e l'Iran, risultano essere molto esigue e la redditività economica limitata principalmente da: una bassa produttività per unità di superficie, una spiccata alternanza di produzione e un lungo periodo improduttivo. Questo sistema agricolo "tradizionale" sopravvive, in un mercato globale altamente competitivo, grazie alle peculiari caratteristiche organolettiche dei pistacchi siciliani che si distinguono per l'intenso colore verde dei cotiledoni molto apprezzato dalle industrie di trasformazione e dai consumatori. Per migliorare la redditività di questi sistemi produttivi si rende necessario attuare un programma di innovazione del comparto, con particolare riguardo alle pratiche di gestione colturale attualmente in uso. Ad esempio, la riconversione degli impianti da asciutto ad irriguo e l'adozione di tecniche di fertilizzazione razionali consentirebbe, da un lato, di aumentare le rese unitarie, dall'altro, di mitigare il fenomeno dell'alternanza di produzione. Considerando, inoltre, la scarsa disponibilità di risorse idriche nelle aree in cui viene coltivato il pistacchio, al fine di massimizzare l'efficienza dell'uso dell'acqua, l'irrigazione dovrebbe essere gestita con precisione possibilmente implementando protocolli di gestione basati sul monitoraggio diretto o indiretto dello stato idrico delle piante. Portinnesti ibridi di P. Atlantica x P. integerrima dovrebbero essere utilizzati nei nuovi impianti con l'obiettivo di incrementare le rese, la resistenza al Veriticullum e ridurre il periodo improduttivo. Infine, dovrebbero essere implementate le più moderne tecniche di lavorazione post-raccolta per ridurre i rischi di contaminazioni da aflatossine mantenendo, allo stesso tempo, le proprietà organolettiche e nutrizionali del prodotto. In questo articolo si è cercato di mettere in evidenza i passi necessari per l'avvio di un processo di innovazione della gestione colturale e gli effetti sulla sostenibilità economica delle aziende pistacchicole siciliane.

Parole chiave: *Pistacia vera* L., irrigazione, alternanza di produzione, Pistacchio di Bronte, qualità dei frutti.

Introduction

The agricultural framework has deeply changed in the last 30 years to meet the higher request for food associated with population increase. Mechanization and intensification of agricultural systems allowed higher production per surface unit, but also led to the development of agricultural systems less self-sufficient, that strongly relives upon the external input of water, fertilizers and pesticides. This "intense" agricultural model was rapidly adopted in countries where agricultural industries were new leaving back "traditional" agricultural realities based on more resilient but less productive growing systems.

Today agriculture is challenged by climate change: upcoming regulations are limiting the use of fertilizers and pesticides and water scarcity is affecting several areas of the world. In such a contet, the attention toward crops and systems that are more resilient is increasing.

New agricultural policies tend to connect the productive aspect of agriculture with its capability to supply services of an environmental and social nature.

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This multifunctional vision of agriculture is promoting the rediscovering of minor crops of local interest for peculiar quality traits of their products, often associated with the territory of production. These crops may play an important role in valorizing marginal areas of the world and increasing the sustainability of traditional agricultural territories. The history of the Sicilian pistachio (*Pistacia vera* L.) industry is a perfect example of these changes. Based on the "Historia Naturalis" by Plinio, the first pistachio trees were introduced in Italy by the Roman governor Lucio Vitellio during the 30 A.D. During the Arabic domination (827-1060 A.D.), the cultivation of pistachio expanded on the shallow and calcareous soils located in the inland of Sicily (Minà Palumbo, 1882). Today Sicily is the only Italian region where this species is cultivated (Greco, 2001). The Sicilian pistachio industry reached its maximum expansion at the beginning of the XX century with more than 15,000 ha and then progressively declined (Greco, 2001). Today most of the Pistachios produced in Sicily are grown in the Etna areas, onto approximately 4,500 hectares. Due to the ability to survive and produce modest crops with little or no irrigation (Goldhamer, 1995), it is traditionally cultivated on marginal soils and under rainfed conditions. Recently, interest in pistachio cultivation has grown, leading to the plantation of more intensive and modern orchard systems. However, sicilian pistachio growers struggle to increase productive performance of these orchards, whose average yield is half of that achieved in other areas of the world.

In this review, we analyze this peculiar agricultural reality, how it survived to a competitive international market thanks to the unique organoleptic profile of its product and we highlight the main horticultural innovations that should be implemented to increase the competitiveness of this industry.

Environmental biology and adaptability

Pistachio, being original of desert areas, is a very rustic crop, tolerant to drought and high temperatures (Spiegel-Roy *et al.,* 1977; Behboudian *et al.,* 1986; Rieger, 1995). The environmental conditions for pistachio production must be characterized by long, hot and dry summers, that allow full fruit ripening and development, followed by moderately cold winters. It can survive to temperatures as low as -20 °C and in summer it tolerates up to 50 °C if air humidity is low (Khalife, 1959). The chill requirement can vary between 36 and 69 chill portions, depending on the cultivar (Pope *et al.,* 2014; Elloumi *et al.,* 2013; Zhang and Taylor 2011; Benmoussa *et al.,* 2017). Spring rains and dry winds during bloom may affect pollination while high air humidity during the growing season, and particularly during fruit growth, favor the development of fungal diseases in fruits and shoots.

In the last years, due to the increased variability in climatic patterns, different cases of lack of chill during winter have been observed in Sicily as well as in California with consequent delays in leaf out and flowering and yield reductions. Pistachio adapts to different types of soils but it requires a good drainage. It is one of the most salt tolerant fruit crops (Walker *et al.*, 1987), with the capability to maintain full productivity in soil with electrical conductivity (ECe) as high as 8 dS/m after six years of saline irrigation (Sanden *et al.,* 2004) However, under longer term condition (30 years) pistachio sensitivity to salinity may be higher particularly under sodic conditions (Marino *et al.,* 2019a).

Several studies highlighted the high adaptability of pistachio to saline soils typical of the original area of expansion, in the area of Kerman, where soil ECe normally ranges between 3.7 and 5.6 dS/m (Saadatmand *et al.,* 2008). Sepaskhah and Karimi-Goghari (2005) showed the capability of this species to take advantage of shallow perch water tables with high concentration of salt in adverse climatic conditions of the central desert of Iran. Thanks to this documented resistance to salinity, pistachio production has expanded in the last 15 years in areas of the world affected by salinity and sodicity, such as the west side of the Central Valley in California (Goldhamer, 2005).

In the area of the world where pistachio differentiated, it survives exploiting the small amount of natural rainfall, ranging between 250 and 400 mm (Whitehouse, 1957). Experimental trials in the Negev desert (Israel) demonstrated that pistachio is able to differentiate flower buds and bear yield despite the extremely unfavorable conditions: 54-163 mm of rain during the two years of trial paired with extremely high environmental evaporative demand (2,600 mm) (Spiegel Roy *et al.,* 1977). Studies on the cultivar "Kerman" grafted onto *P. atlantica* highlighted some photosynthetic activity in the leaf of trees with a stem water potential as low as -5 and -6 MPa, demonstrating a response to water stress characteristic of some of the most tolerant fruits tree crops and most of the xerophytes (Behboudian *et al.,* 1986; Di Vaio *et al.,* 2012).

The alternate bearing

Alternate bearing is common to several tree crops and it has been correlated with the low differentiation

of flower buds during the bearing year (Monselise and Goldschmidt, 1982). In the case of pistachio, the alternate bearing phenomenon is peculiar, since the flower buds differentiate during the heavy crop years, but they drop (Caruso *et al.,* 1993; Crane and Nelson, 1971) in concomitance with embryo growth (Mahvelati *et al.,* 2017).

As previously reported, pistachio is originally from arid and semi-arid areas with scarce rainfall in summer; under these conditions, trees try to complete all the vegetative and reproductive phases of development in a very short timeframe, between March and May, to take full advantage of soil moisture storage-from winter precipitation and ensure species survival. The remaining part of the season is dominated by endocarp lignification and embryos growth. The bud drop starts exactly at the end of June, after the beginning of the proliferation of the zygote (Porlingis, 1974) and it intensifies in July and August, during the most intense growth of the embryo.

Despite the clear overlapping of bud drop with the growing stages of the nuts, the physiological process that causes buds dehiscence is still under debate. BAsed on the "hormonal" hypothesis some growth regulators are directly involved in bud abscission (Agrawal *et al.,* 1980; Chacko *et al.,* 1972; Crane and Iwakiri, 1987), however, experimental trials failed to characterize a unique and clear correlation between the application of endogenous hormones and bud drop (Crane and Nelson 1972, Takeda and Crane 1980, Vemmos *et al.,* 1994). The "nutritional" hypothesis associates bud abscission with the competition between buds and the growing embryos (the strongest sinks) for energy, metabolites and nitrogen (Crane and Nelson, 1971, 1972; Crane *et al.,* 1973; Crane, 1984; Caruso *et al.,* 1995; Marra *et al.,* 2004; Marra *et al.,* 2009; Rosecrance *et al.,* 1998; Spann *et al.,* 2008). The strong involvement of resource limitation in the fructification cycle in pistachio is supported by the different levels of carbohydrates accumulation observed in non-bearing branches versus bearing branches (Barone *et al.,* 1995; Nzima *et al.,* 1997; Marra *et al.,* 1998; Vemmos 1999).

Marino *et al.,* (2018a) characterized the photosynthetic performance of a branch as a function of crop load, demonstrating that high fruit load precipitated an early leaf senescence and drop (fig. 1) that decreased seasonal carbon gain by 26% in bearing compared to non bearing shoots.

Despite all these scientific evidences alternate bearing and fruiting patterns in pistachio could be more complex than previously suspected (Rosenstock *et al.,* 2010; Martinelli *et al.,* 2018). Stevenson and Shackel (1998) dissociated the alternate bearing from

Fig. 1 - Early leaf yellowing and senescence in bearing branches of a pistachio tree under rainfed conditions.
Fig. 1 - Ingiallimento e senescenza precoci delle foglie in rami carichi di un pistacchio non irrigato.

a simple response to available carbohydrates and suggest considering this phenomenon, with an evolutionary approach, as an ecological adaptative strategy.

In Sicilian pistachio orchards, the severity of alternate bearing is higher with respect to Californian orchards, where the rational management aiming to minimize water stress and control vegetative growth with mechanical pruning (Ferguson *et al.,* 1991), in addition to other genetically controlled factors (Kanber *et al.,*. 1993), allows higher and more constant productions.

Marino *et al.,* (2018c) demonstrated that supplemental irrigation positively affects pistachio branches carbon budget by increasing gas exchanges and delaying late-season leaf drop and senescence (fig. 2), smoothing the alternate bearing of a mature rainfed Sicilian pistachio orchard. Further studies should focus on the interaction between reproductive and vegetative cycles in pistachio at tree level and in a multi-year prospective.

Water relations and irrigation

Despite its drought resistance pistachio production deeply improves with irrigation.

Irrigation affects production quantitatively and qualitatively (Polito and Pinney, 1999; Goldhamer, 2005). In Turkey, in the cultivar "Kirmizi", irrigation increased the yield by 74%, split fruit percentage by 56% and filled nuts percentage by 18% (Ak and Agackesen, 2006). Similar effects were observed in a study conducted in Spain (Gijon *et al.,* 2009). Monastra *et al.* (1995) showed that irrigation increased trunk-cross sectional growth, leaf surface area and number of infructescences per branchlet in the cultivar "Larnaka" grafted onto *P. integerrima*.

Under optimal soil moisture conditions, pistachio transpires very high amount of water, reaching up to 200 l/day for a mature tree (Goldhamer *et al.,* 1985). Crop evapotranspiration requirements (ETc) can be calculated using the crop coefficient (Kc) developed in California by Goldhamer and co-authors (Goldhamer *et al.,* 1985; Goldhamer 2005). These crop coefficients reach values as high as 1.19 in the month of July and August resulting in annual water application of ~ 12,000 mc/ha. In Sicily the calculated seasonal crop water requirements is ~ 6,000 mc/ha. These volumes of water are commonly not available for agricultural purposes in the dry inland territory of Sicily where pistachio is traditionally cultivated. In the modern pistachio plantations, generally, a small reservoir allows the collection of winter rainfall and this water is later distributed during the growing season with a drip irrigation system, as a "supplemental irrigation". Despite this limited amount of water (~ 500-1000 mc/ha) satisfies only a small portion of the potential crop water requirement, it affects positively leaf gas exchanges and productivity, which increased by 30% after three of water application (Marino *et al.,* 2018b).

Several studies highlighted changes in pistachio stomatal behavior and water relations through the sea-

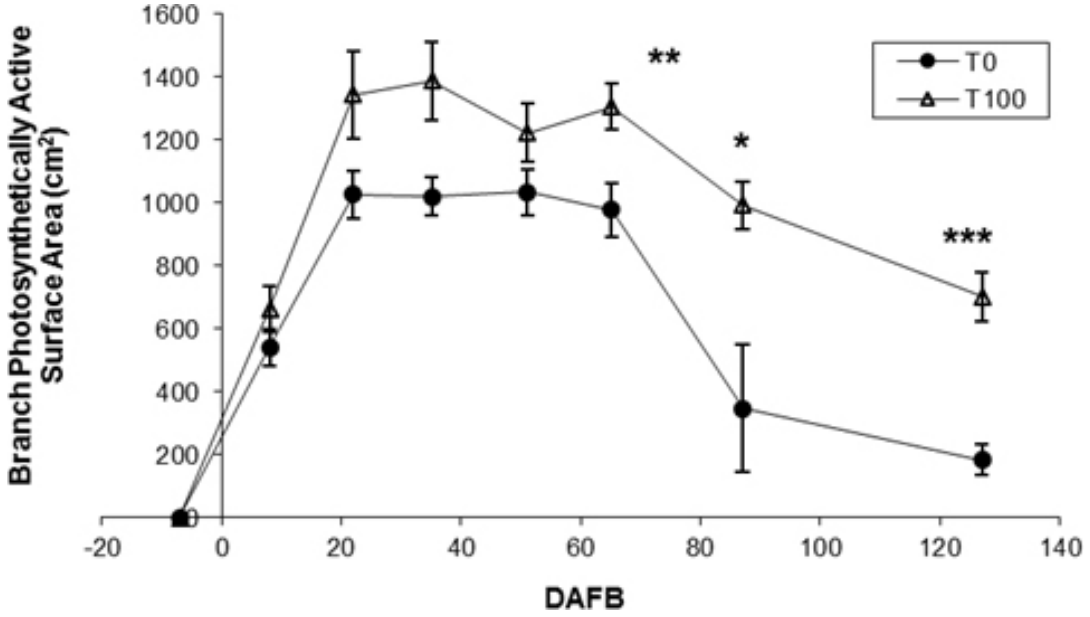

Fig. 2 - Seasonal time course of photosynthetically active leaf area of a bearing branch of rainfed (T0) and irrigated (T100) pistachio trees in the area of Caltanissetta, Sicily (from Marino *et al.,* 2018c.).

Fig. 2 - Andamento stagionale della superficie fogliare fotosinteticamente attiva di un ramo carico in alberi di pistacchio in asciutto (T0) e irrigati (T100) nell'area di Caltanissetta (da Marino et al.*, 2018c.)*

son (Marino *et al.,* 2018a, Gijon *et al.,* 2009) suggesting that the efficiency of irrigation could be further improved taking into consideration the physiological response of pistachio to water stress. Plant water potential is the most used physiological indicator for irrigation management in fruit trees (Klepper, 1968). Memmi *et al.,* (2016a) recently published the first reference stem water potential (Ψ_{STEM}) baseline for pistachio, and reported Ψ_{STEM} values ranging from -0.7 to -1.5 MPa in response to vapor pressure deficit (VPD) changes from 0.5 to 4.5 kPa. Other authors reported that a midday Ψ_{STEM} below -1.5 MPa reduces gas exchanges (fig. 3) (Memmi *et al.,* 2016b; Marino *et al.,* 2018b; Marra *et al.,* 2017).

The availability of new technologies led to the development of more efficient irrigation protocols based on the use of proximate (Guerrero *et al.,* 2006, Testi *et al.,* 2008) or remote (Gonzalez-Dugo *et al.,* 2015) measurements of various plant parameters differently associated with water stress. These methods have been developed in response to climate change and water scarcity with the main aim to optimize (mainly reduce) water applications and increase water productivity with respect to full irrigated orchards. However, these sophisticated sensors are not commonly adopted in commercial orchards because of the high costs of installation, maintenance, and data interpretation associated with the risks of yield reduction under deficit irrigation (Fernandez 2014). In the currently supplementary irrigated pistachio orchards the situation can be analyzed from the opposite perspective: the main benefit of implementing more precise water management protocols would be increasing yields. The positive impact that precise water management can have on orchard productivity may be a key to the adoption of new technologies by local growers. In this sense, we believe a research and extension effort should be done to select the best sensors-indicators, develop simplified irrigation protocols and outreach this information to growers.

Cultivars and rootstocks

As opposite to other species that have a very large germplasm variability in the Sicilian island such as olive, with 27 recognized genotypes and hundreds of clones and accessions (Marino *et al.,* 2019b), few cultivars of pistachio have been identified in this territory: 'Bianca' (synonymous: 'Napoletana'), 'Femminella', 'Natalora', 'Agostana'. Other minor Sicilian cultivars are 'Silvana', 'Cerasola', 'Cappuccia', 'Insolia', 'Ghiandalora', 'Gialla', 'Tardiva' and 'Pignatone', characterized by smaller nuts with an elongated shape and an extremely low percentage of dehiscence. Most of these minor cultivars are no longer grown commercially nor available in nurseries. Therefore, to avoid rapid genetic erosion, as a part of a breeding research program carried out at the University of Palermo, a germplasm collection has been recently established.

Generally, fruits from Sicilian varieties are characterized by a unique organoleptic profile and high con-

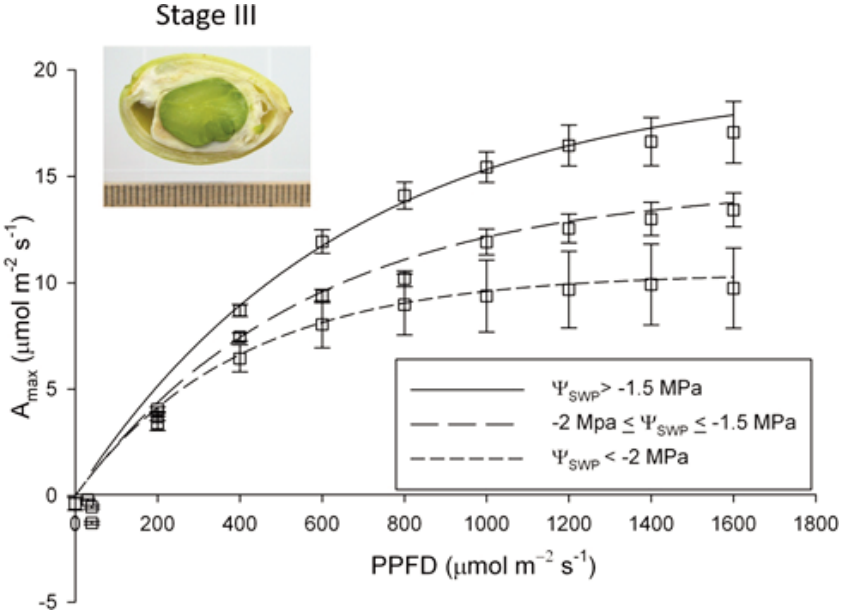

Fig. 3 - Effect of plant water status on photosynthetic light response curve of pistachio leaf during the phenological phase of rapid embryo growth (Marra *et al.,* 2017).

Fig. 3 - Effetto dello stato idrico delle piante sulla curva di risposta fotosintetica alla luce di una foglia di pistacchio durante la fase fenologica di rapida crescita dell'embrione (Marra et al.*, 2017).*

tent of chlorophyll of the cotyledons (fig. 4). The cultivar “Bianca” mainly grown in the area of Bronte closed to the Etna Volcano, has been recently protected with a specific disciplinary of production and it has been assigned the label of PDO (protected designation of origin) “Green Pistachio of Bronte”. The obtainment of the trademark PDO started from a request of the Bronte growers and their need to valorize the unique features of their local product. The request has been approved by the “Ministry of the Agricultural, Food, and Forestry Policies” and published in the Official Journal of the European Union (OJEU) on the 8 October 2001, after previous approval of the production disciplinary, written by an association of growers. Only in 2009, with the OJEU 2009/C 130/09, the final disciplinary of production was published, where the PDO geogreafic boundaries are identified within ‘the municipalities' of Bronte, Adrano and Biancavilla, and all the horticultural management practices for production, harvest and labeling guidelines associated with the PDO are described.

Among the male cultivars belonging to the species *P. vera,* the most used internationally are ‘Peters’ and ‘Chico’ from California, ‘Beta’ and ‘Gamma’ from Greece and ‘Ask’ from Israel. About 10% of male trees are necessary to ensure a good pollination, and male cultivar flowering time has to overlap the female bloom as long as possible. In Sicily, only recently selected *P. vera* genotypes have been used for pollination, while in the past this was ensured by the presence of wild *P. therebintus* males spread in the territory. Eight *P. vera* genotypes (M1; M3; M4; M5; M7; M8; M9 and M10) were selected at the Department of Arboriculture of the University of Palermo and only three of them (M1, M4 and M5) were suggested as the best option for pollination of the Sicilian cultivar “Bianca”. Their blooming period goes from the last week of April until the first week of May with very good overlapping with ‘Bianca’ blooming (Barone *et al.,* 1996). Year to year variability in blooming time, associated with climatic patterns, suggests the need to use more than one male pollinator in the orchard, to ensure a longer period of pollen availability.

Moreover, trials demonstrated that the pollen from *P. vera* has a vitality of ~ 60% while the pollen from *P. therebintus* had a vitality ranging between 30-80%. Germinability was as low as 14% and 12% in *P. vera* and in *P. terebinthus,* respectively (Buffa *et al.,* 2007). Such a low germinability of the pollen plus the lack of bloom overlapping between *P. therebintus* and *P. vera* is a main limiting factor to productivity in Sicilian pistachio traditional systems (Vaknin *et al.,* 2002).

Fig. 4 - Green kernes from the cultivar Bianca that have been recently assigned the trademark of protected designation of origin as “Green Pistachio of Bronte”.

Fig. 4 - Cotiledoni verdi della cultivar Bianca a cui recentemente è stato assegnato il marchio di denominazione di origine protetta come "Pistacchio verde di Bronte".

The *P. terebinthus* is the main rootstock used in Sicilian pistachio orchards, since it is perfectly adapted to marginal soils. In the past, spontaneous plants of terebinth, growing on the rocky, steep volcanic soils of Etna mountain, were grafted with *P. vera* scions to obtain the so-called "natural pistachio plantings" typical of these areas (fig. 5) (Barone *et al.,* 1985).

In addition to these "natural plantings", there is a "new" pistachio orchard model in Sicily (fig. 6) that has been planted more recently with rational design, implementing regular planting densities (6.5 x 5 m) and common cultural practices. In these modern systems, the species *P. terebinthus* is also used as rootstock, due to its rusticity. Unfortunately, the negative aspects of selecting *P. terebinthus* as a rootstock, such as the high susceptibility to *Verticillium dahliae*, slow growth in the nursery, graft incompatibility, recalcitrance to rooting, heterogeneity of the seedlings and extremely long unproductive period, are limiting the spread of the species in new suited areas of Sicily. All these factors affect the international competitiveness of Sicilian pistachio production, which would benefit from the choice of alternative rootstocks.

The hybrid rootstocks UCB1 (*P. atlantica* × *P. integerrima*), developed by the University of California, is the most used rootstocks in California (fig. 7). It has been also adopted worldwide for its tolerance to *Verticillum* and very high vigor that allows a strong decrease of the unproductive period that lets first harvestable crop after only 6-7 years after plantation, against an average of 10 years when the *P. terebinthus* is used as rootstock. However, since *P. terebinthus* has elevated drought tolerance showing a capability to maintain higher leaf area and stomatal control under stress with respect to *P. atlantica* (Gijon *et al.,* 2011) and *P. integerrima* (Memmi *et al.,* 2016b), it is often considered a good choice for marginal conditions (Germana, 1997; Ferguson *et al.,* 2005). As the amount of water available in Sicily will never match full crop water requirement, preliminary trials should be carried out before the introduction of new rootstocks in Sicilian commercial orchards, to characterize their performance under management practices typical of this territory.

Production and quality

The Sicilian production of pistachio represents less than 0.6% of the world production. Yearly production in the modern and more specialized orchards is variable with an average yield per tree ranging from a minimum of 3 kg up to maximum values of 7-

Fig. 5 - "Natural pistachio plantings" where *P. vera* trees grafted onto *P. terebinthus* are growing without a regular spacing in the rocky volcanic soils of the Etna volcano together with other resistant species such as Prickly Pear (*Opuntia ficus-indica* (L.) Mill.).
Fig. 5 - "Piantagioni di pistacchio naturali" con alberi di P. vera *innestati su* P. terebinthus *senza una spaziatura regolare nei suoli vulcanici rocciosi dell'Etna insieme ad altre specie resistenti come il fico d'india (*Opuntia ficus - indica *(L.) Mill.).*

Fig. 6 - Modern 30 year-old pistachio orchard in the inland territory of Sicily, planted with a regular design and managed with rational horticultural practices.

Fig. 6 - Moderno pistacchieto di 30 anni nel territorio interno della Sicilia, piantato con sesti regolari e gestito con pratiche agronomiche razionali.

Fig. 7 - Mature (30-year old) Pistachio orchard in California planted with hybrid rootstocks, characterized by very high canopy cover, fully irrigated and mechanical pruned.

Fig. 7 - Pistacchieto maturo (30 anni) in California realizzato con portainnesti ibridi vigorosi, caratterizzato da elevata copertura del suolo, irrigazione e potato meccanicamente.

10 kg (dried in the shell), corresponding to ~1600 kg/ha. In the "natural pistachio planting" these values decrease to an average of ~800 kg/ha during the bearing years followed by one year with no production. These values are significantly lower with respect to the ~ 3,500 kg/ha recordered in California between 2017 and 2018 (Administrative Committee for Pistachios Processors' Producer Delivery Reports and Acreage Surveys).

Despite the low productivity, in the international market the pistachios from Sicily are generally sold at very high prices, due to the peculiar organoleptic characteristics of these nuts (Woodroof, 1967). Sicilian pistachios are particularly known for the intense green color of the cotyledons which are highly appreciated by the processing industries (Giuffrida *et al.,* 2006); for example, an average price per kilogram of in-shell Sicilian pistachio was 13.20 € in 2019, higher with respect to an average price of 8-9 € paid in the market for the same amount of non-Sicilian pistachios. The Sicilian pistachios are only used for confectionery (ice cream and pastry) and bagged meat industries (fig. 8). The percentage of indehiscence of the endocarp at maturity makes this cultivar not suitable for the snack industry, where nuts with split shells are preferred for the roasting and salting process.

Once harvested and separated from the hulls, the nuts in Sicily are traditionally spread in the ground for 4-5 days and dried under the sun (fig. 9). In countries where the nuts are roasted and salted to be sold as a snack, dryers are used since a long time ago. Recently, the Sicilian transformation facilities increased the level of technologies renovating their working line, and the number of transformation facilities in the territory duplicated with respect to the late '90s. Experimental trials had compared the "natural" and the "artificial" or controlled drying methods, showing that the chemical compositions of the nuts from cv. Bianca was not significantly affected, but the traditionally dried fruits showed more intense oxidative process during the conservation (La Russa *et al.,* 2007). The use of drying machines helped to concentrate operations in a short time window, improved management of harvesting operations and reduced the cost of harvesting and the risk of pathogens. However, the temperature was maintained continuously at values lower than 55 °C to avoid chlorophyll degradations (Giovannini and Condorelli, 1958).

Conclusion

The unicity of the pistachio industry in Italy (Sicily) is clearly associated with the high organoleptic quality of the nuts of the autochthonous cultivar "Bianca" and probably also with the peculiar management practices that distinguish this area from the most specialized producer countries. The high attention to its organoleptic qualities, and particularly the green color of the cotyledons and to the amount of volatile compounds, is linked to the main commercial use of this product as an ingredient for confectionery uses, which is in contrast to the snacks industry that dominates the market. The highest prices achieved by these nuts make the Sicilian pistachio production economically sustainable for growers. Surely, the establishment of a certified trademark that ensures and val-

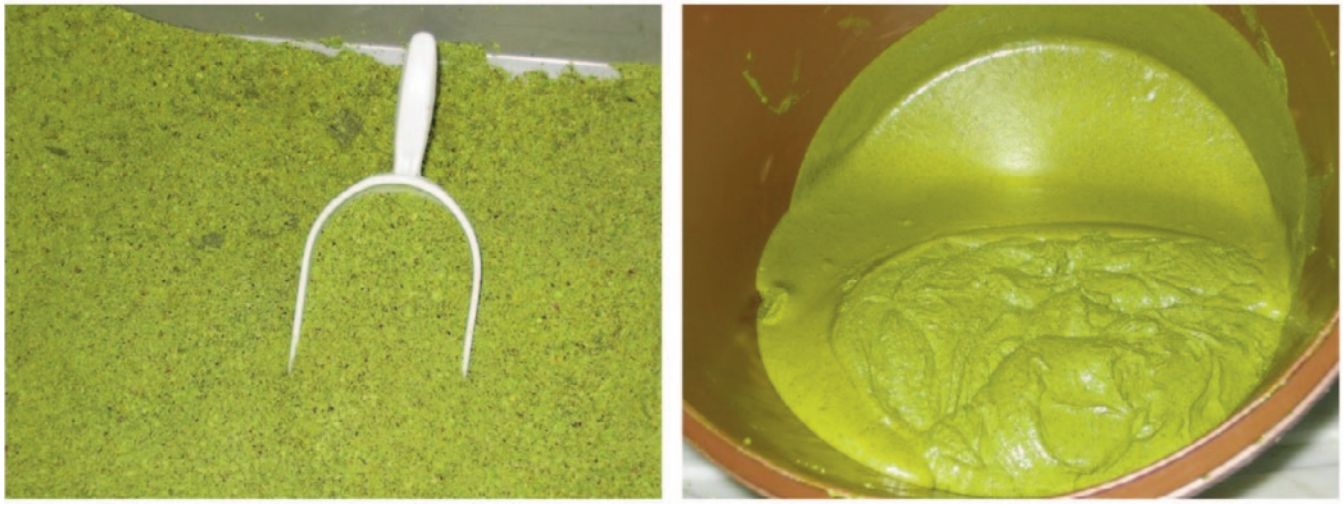

Fig. 8 - Two typical uses of the pistachio nuts in Sicily: the grindle kernels are generally transformed in pesto (on the left) and in cream (on the right) used to make pastries.

Fig. 8 - Due usi tipici del pistacchio in Sicilia: il nocciolo di pistacchio macinato viene generalmente trasformato in pesto (a sinistra) e in crema di pistacchio (a destra) usata per fare dolci.

Fig. 9 - Method traditionally used for drying the pistachio nuts in Sicily (on the left): after removing the hull, the in-shell pistachios are placed on tarps under the sun for 4-5 days. Recently this methodology has been partially substituted by the use of professional dryers (on the right).

Fig. 9 - Metodo usato tradizionalmente per essiccare i pistacchi in Sicilia (a sinistra): dopo aver rimosso il mallo i pistacchi vengono posti su teloni sotto al sole per 4-5 giorni. Recentemente questa metodologia è stata parzialmente sostituita dall'uso di essiccatori professionali (a destra).

orizes the unicity of this product to consumers has been an extremely important step to increase competitiveness of this industry, but it needs to be accompanied by an improvement of horticultural management. Reaching full potential production is probably not possible in the short term, due to structural reasons (Greco, 2001), but evidences suggest that yield improvement is achievable also with limited available resources (Marino et al 2018c). For example, water availability will never reach the quantity needed for meeting full crop evapotranspiration but precision water management of the lower amount of available water is certainly the first path to follow to increase productivity of new orchards.

Mechanization of harvest has already been adopted in the recently planted pistachio orchards, however mechanization of pruning, following the model proposed in California (Ferguson *et al.,* 1991), should be adopted as well in a short time, to decrease production cost and mitigate the alternate bearing.

The "pistachio natural plantations", typical of the steep, poor and volcanic soils of the Etna mountain, should be protected for landscape and ecological function, but not considered as an economically sustainable agricultural systems, considering the impossibility to substantially improve the management and yield of these planting systems.

Finally, the rustic and local *P. terebinthus* rootstock, traditionally used in the past, should be substituted by the more vigorous hybrid of *P. atlantica* × *P. integerrima*, to reduce the unproductive period and make this crop a relatively short-term investment for growers. The adoption of the UCB1 rootstock, already happening in newly planted orchards, could allow a future expansion of this crop in new areas, characterized by heavier soils with a higher percentage of clay, where currently pistachio is not planted because of the sensitivity of *P. terebinthus* to the *Verticillum.* Substituting the less profitable crops that are currently grown in these types of soil in the inland territories of Sicily, with more profitable perennial pistachio plantations, would increase the attractiveness of these territories, strongly affected by the depopulation phenomena (Scrofani and Novembre 2015), to young people that currently leave in search of better working and living conditions.

Regarding the post-harvest management of the product, modern drying techniques should be further implemented, to reduce safety risks associated with aflatoxins contaminations without changing the organoleptic and nutritional properties of the nuts.

Abstract

Pistachio production and consumption have strongly increased in the last years due to its capability to grow under limiting conditions, the profitability of this nut in the market and its well claimed healthy properties. The Sicilian pistachio industry is diminutive in comparison to big producing countries such as California and Iran. Its economical profitability is limited by a low productivity per surface area, strong alternate bearing, and long unproductive period, mainly associated with the lack of implementation of innovative management practices. This "traditional" agricultural system is surviving in a highly competitive international market thanks to the unique organoleptic profile of the sicilian nuts characterized by an intense green color, highly appreciated by processing industries and highly paid by the consumers.

Improved management practices should be applied to renovate the Sicilian Pistachio industry and to increase the profitability of these farming systems. In particular, rainfed orchards should be converted to irrigation to increase the yield and mitigate alternate bearing. Considering the small volumes of water available in the areas where this crop is cultivated, irrigation should be managed carefully, implementing plant-based water management protocols to achieve maximum water productivity. New rootstocks should be used in future plantations, such as the new hybrids of *P. Atlantica x P. integerrima*, in order to improve production, to resist *Veriticullum* and to decrease the long unproductive period. Finally, modern post-harvest drying techniques should be implemented to reduce safety risks associated with aflatoxin contaminations without changing the organoleptic and nutritional properties of the nuts.

The aim of this review is to highlight the next steps towards the implementation of few innovative horticultural management practices in the Sicilian pistachio orchard systems. We also discuss how these changes would be beneficial at farm level, increasing the economic gains of existing growers, and, from a wider perspective, the potential importance of an innovative and modern pistachio production framework for the agricultural economy of the inland territory of Sicily.

Keywords: *Pistacia vera* L.; Irrigation; Alternate bearing; Green Pistachio of Bronte; Nut Quality

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