Scientia Horticulturae 236 (2018) 106–122

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Youth tree behavior of olive (*Olea europaea* L.) cultivars in Wudu, China: Cold and drought resistance, growth, fruit production, and oil quality

Jia-wei Wang[a,b], Lu-yi Ma[a], María Gómez-del-Campo[b], Dong-sheng Zhang[c], Yu Deng[d], Zhong-kui Jia[a,*]

[a] Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University, 35 E Qinghua Rd, Beijing, 100083, PR China
[b] Research Centre for the Management of Agricultural and Environmental Risks, Universidad Politécnica de Madrid, Madrid, 28040, Spain
[c] Forest Resources Supervisor Office of State Forestry Administration in Urumqi and the Urumqi Branch of China CITES Office, Xinjiang, 830000, PR China
[d] Olive Department, Longnan Economic Forest Research Institution, Wudu, Gansu, 746000, PR China

ARTICLE INFO

Keywords:
Olive cultivation
Introduced cultivar
Resistance evaluation
Vegetative growth
Fruit yield
Oil quality

ABSTRACT

The wet, hot summers and cold, dry winters in Wudu, China differ from the climate in the Mediterranean olive-growing region. Eight olive (*Olea europaea* L.) cultivars ('*Arbequina*', '*Hojiblanca*', '*Manzanilla de Cacereña*', '*Cornicabra*', '*Picual*', '*Arbosana*', '*Koroneiki*', and '*Empeltre*') were grown in Wudu and evaluated for 5 years after planting. We evaluated the behavior of the youth trees, including their cold and drought resistance, tree growth, oil content, fruit characteristics, fruit production, and oil quality. The results showed that '*Empeltre*', '*Picual*', and '*Arbequina*' were the most cold-resistant cultivars, while '*Arbosana*' was the least cold resistant. '*Empeltre*', '*Hojiblanca*', and '*Koroneiki*' were the most drought-resistant cultivars, while '*Arbequina*' and '*Arbosana*' were the least drought resistant. '*Empeltre*' and '*Picual*' showed the most vigorous tree growth, and '*Koroneiki*' and '*Arbosana*' grew slowest. The oil contents of cultivars before harvest ranged from 33.61% ('*Cornicabra*') to 50.09% ('*Arbosana*'). The fruit productivity was highest in '*Arbosana*' and lowest in '*Empeltre*'. The olive oils of all cultivars were EVOO (extra virgin olive oil) according to the IOC (International Olive Council) standard, but '*Empeltre*', '*Hojiblanca*', and '*Cornicabra*' had higher linolenic acid contents in oil. We concluded that '*Arbosana*' was the cultivar with the greatest potential for cultivation in Wudu. It had the highest fruit production and oil content even in the smallest trees, its EVOO quality met the IOC standard, and it was suitable for growth in areas with abundant water and without continuous frost below −4 °C. We concluded that olive trees grow faster in Wudu than in Mediterranean regions, but have lower cold resistance and olive fruit production in Wudu. These results show how olive cultivars can flourish in a new environment and provide an important basis to expand the cultivation of these cultivars to other suitable regions in southern China.

1. Introduction

Olive (*Olea europaea* L.) is one of the most important oil crops in the Mediterranean basin. This species is thought to have been domesticated in the Bronze age in the Near-East Mediterranean region (at Ugarit, Syria) (Newton et al., 2014). It is now cultivated in regions beyond its original area under diverse environmental conditions (Ouazzani et al., 1996) and its cultivation area has spread to the entire the Mediterranean basin since the Roman Age (Loumou and Giourga, 2003). Olive was introduced into China from the Mediterranean in 1956, and it has been cultivated in China since then. The first large-scale introduction of olive trees from Albania to China was in 1964. In 1979, the United Nations Food and Agriculture Organization provided funding ($1.75 million) to support training and the introduction of olive cultivars into China. The first standard olive groves were established in Wudu in 1990, and the benefits of olive industry were demonstrated in 1995 (Xu, 2001; Deng and Yu, 2011). The olive industry in China has developed rapidly, especially over the last 10 years (Wang et al., 2017).

Abbreviations: A, acidity; D, diameter; DW, dry weight; DWSF, dry weight of a single fruit; EVOO, extra virgin olive oil; EC, electrolyte conductivity; FW, fresh weight; FWSF, fresh weight of a single fruit; FS, fruit size; FP, fruit production; H, height; HC, hierarchical clustering; IOC, International Olive Council; LT_{50}, semi-lethal temperature; MI, maturity index; MDA, malondialdehyde; MUFA, monounsaturated fatty acid; NBT, nitroblue tetrazolium; NMR, nuclear magnetic resonance; ODLEFRI, Olive Department of Longnan Economic Forest Research Institute; OC, oil content; PEG, polyethylene glycol; PC, proline content; PR, pulp rate; P/P, pulp/pit; PV, peroxide value; PPC, polyphenol content; PUFA, polyunsaturated fatty acid; PCA, principal component analysis; SOD, superoxide dismutase; SCC, soluble sugars content; SFA, saturated fatty acids; TBA, thiobarbituric acid; UFA, unsaturated fatty acid

* Corresponding author.
E-mail addresses: wjw_bjfu@163.com (J.-w. Wang), maluyi@bjfu.edu.cn (L.-y. Ma), maria.gomezdelcampo@upm.es (M. Gómez-del-Campo), zds6868@163.com (D.-s. Zhang), LKSDengyu@126.com (Y. Deng), jiazk@bjfu.edu.cn, 279063516@qq.com (Z.-k. Jia).

https://doi.org/10.1016/j.scienta.2018.03.033
Received 18 October 2017; Received in revised form 9 March 2018; Accepted 16 March 2018
0304-4238/

Although olive fruit production in China cannot compare with that in Mediterranean countries, approximately 63,600 ha were planted with olives in 2015, with fruit production of 27,907 tons (Zhang, 2015). Wudu is the main olive-producing region of China with 30,000 ha planted with olive trees and fruit production of approximately 20,000 tons in 2015.

The climate and terrain features differ between China and Mediterranean areas. In the Mediterranean, the summers are hot and dry and the winters are wet and warm. Most regions suitable for olive cultivation in China have a mountainous terrain with wet, hot summers and dry, cold winters (Mooney et al., 1974; Xiao et al., 2009). Because of these differences in the climate and terrain, only 21 out of more than 165 olive cultivars that have been introduced from the Mediterranean are able to produce fruit well in China (Wang et al., 2017).

Before expanding cultivation, several excellent phenotypes or performance characteristics of olive trees should be evaluated so the most valuable cultivars can be identified. In this context, we need to evaluate the most important agronomic traits of different olive cultivars, such as cold resistance, drought resistance, tree growth, oil content, fruit characteristics, fruit production, and oil quality.

Cold resistance is an important part of the adaptive ability of olive cultivars, because their optimum temperature for growth is 20–30 °C. For most olive cultivars, their upper frost limit ranges from −12 to −7 °C in Mediterranean countries (Bartolozzi and Fontanazza, 1999; Gómez-del-Campo and Barranco, 2005; Cansev et al., 2011). Frequent frosts during winter or spring in China may restrict olive growth, so it is important to select cold-resistant cultivars. To evaluate the cold resistance of olive cultivars in Wudu, the lethal temperature at which 50% death occurs (LT_{50}) based on relative electrolyte conductivity (EC) can estimate the degree of frost damage under cold stress (Barranco et al., 2005). Cold resistance can also be estimated from the concentration of malondialdehyde (MDA), a byproduct of lipid peroxidation that occurs during low-temperature-induced oxidative stress, and the activity of superoxide dismutase (SOD), a key antioxidant enzyme in cold resistance (Qin et al., 2011; Hashempour et al., 2014). Therefore, the MDA content and SOD activity may be used to compare cold resistance among cultivars.

Most olive cultivation areas in China have a shortage of irrigation on hills, and so the drought resistance of cultivars is also important, especially in areas with long dry seasons. Olive trees are naturally drought resistant and have adaptive mechanisms to tolerate even severe drought (Gucci et al., 1997; Dichio et al., 2003). Studies on olive metabolism under drought stress may provide useful information for introducing olive trees into dry regions, and for their cultivation in such regions (Fernández et al., 1997; Rousseaux et al., 2008; Bacelar et al., 2009). Proline and total soluble sugars in leaves play important roles in counteracting the negative effects of water deficit (Dichio et al., 2009; Ahmed et al., 2008). Drought stress simulated by polyethylene glycol (PEG) is widely used to investigate plants' adaptive mechanisms. Solutions of PEG 6000 with different water potential gradients have been used to simulate drought and result in changes in various biochemical and molecular processes in plants (Pei et al., 2010; Zhang et al., 2011; Xing and Wu, 2012).

Tree growth could reflect the adaptability for introduction into new environments, in that strong vegetative growth might be related to good fruit yields (Cantini et al., 1999). Oil content and fruit production are the most important economic factors for the characterization of olive cultivars, because they are the key components of oil production (Beltrán et al., 2003; Gómez-del-Campo, 2013). Fruit characteristics have been used to describe the main phenotypes of cultivars (León et al., 2016). Only a few studies have focused on the quality of olive oil produced in China. Cheng et al. (2017) analyzed olive oil produced in Xichang, Sichuan Province, and found that the linoleic acid ($C_{18:3}$) content was much higher than that listed in data provided by the International Olive Council (< 1%) (International Olive Council (IOC), 2015), but the unsaturated fatty acid (UFA) and monounsaturated fatty acid (MUFA) contents were significantly lower in Chinese olive oil than in that produced in the Mediterranean (Cheng et al., 2017). In general, the acidity, fatty acid composition, peroxide values, and polyphenol contents of olive oil have been used as quality markers for olive oil produced in the Mediterranean (Yousfi et al., 2006; Gómez-González et al., 2011; Fernández-Espinosa, 2016).

There are many potential advantages of olive cultivation in China, including the use of marginal land and economic benefits. Although many studies have characterized olive cultivars, most have been conducted on olive trees in Mediterranean countries and few have focused on olive trees in China. Therefore, the aim of this study was to evaluate the performance of olive cultivars in China to identify those that are the most suitable for extensive cultivation. Our study also provides information to support the cultivation of young olive trees in different regions with specific climate conditions.

2. Materials and methods

2.1. Field site and plant materials

2.1.1. Field site

This experiment was carried out at the experimental farm of the Olive Department of Longnan Economic Forest Research Institute (ODLEFRI), located in Wudu, a city in southern Gansu Province, China (33° 24′03″N, 104° 53′30″W. 1036 m asl.). The farm is in a hot dry valley of the Bailong river, in the north subtropical zone with hot, rainy summers (June to August: mean 25.3 °C, ma x 38.2 °C in July, 231.1 mm rainfall, 59.9% humidity) and cold, dry winters (December to February: mean 5.1 °C, min −7 °C in January, 16.6 mm rainfall, 43.2% humidity), with higher evaporation (ETo, 1810 mm) than rainfall (474 mm) and an annual average temperature of 14.9 °C. The terrain is mountainous, but the olive farm has a flat surface, with sandy soil with a high stone content and good permeability. The soil, which is derived from loess, is alkali with pH 7.5–8.5.

2.1.2. Plant materials

Eight olive cultivars ('*Arbequina*', '*Hojiblanca*', '*Manzanilla* (*de Cacereña*)', '*Cornicabra*', '*Picual*', '*Arbosana*', '*Koroneiki*', and '*Empeltre*') were planted at the ODLEFRI experimental farm, with 60 trees per cultivar, except for '*Arbequina*' (200 trees). The saplings were generated by vegetative propagation. Cuttings were taken from strong branches, and then planted in plastic bags and grown for 1 year in Spain. Strong plants with no visible disease symptoms were imported into China on 9 February 2011. The saplings were quarantined in a greenhouse for a 91-day preliminary observation period before being transplanted to the farm in Wudu on 11 May 2011. Trees were planted with a 4 m × 5 m (east to west) spacing. Twelve trees from the same cultivar were planted in a single 4-m column, with each cultivar planted in more than five columns that were never adjacent to each other. Thus, each 5-m row included more than five trees of each cultivar, with 12 rows for cultivar replicates. Standard pest and disease control measures, irrigation and fertilization management, as well as weeding and staking for upright growth were used to ensure healthy growth. Trees were irrigated in January, March, June, September, October, and December, and were fertilized (alongside watering) in March (N-P-K), June (N), September (P-K), and December (N-P-K).

2.2. Cold resistance

Fifty samples of 1-year-old branches (approximately 30 cm, with 1-year-old leaves) were randomly taken from more than 10 olive trees of each cultivar on 30 March 2013. To evaluate the cold resistance of olive cultivars, the EC, MDA content and SOD activity of 1-year-old shoots and leaves were evaluated. All branches of each cultivar were subjected to a cold treatment in which the temperature was decreased by 4 °C every 24 h (i.e. 24 h at 4, 0, −4, −8, −12, −16, −20, and −24 °C,