Olive Oil: History, Production, and Characteristics of the World's Classic Oils

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***Abstract*. The true origin of the olive is not known but is speculated to be Syria or possibly sub-Saharan Africa. For more than 6000 years, the cultivated olive has developed alongside Mediterranean civilizations and is now commercially produced on more than 23 million acres (9.4 million ha) in the Mediterranean basin. New plantings also exist in California, Chile, Argentina, South Africa, and Australia. Various nonscientific selection processes created a multitude of different cultivars. Many villages in Europe, the Middle East, and North Africa feature distinct varieties. However, it is also common to see the same cultivars with different names and, in some cases, different cultivars with the same name. This is currently being sorted out with DNA identification. The olive tree requires some chilling; tolerates hot, dry conditions; does not like moisture during bloom, and actually produces better with some stress. As a result, olives were traditionally relegated to lands where little else would survive. For thousands of years olives were grown primarily for lamp oil, with little regard for culinary flavor. World production of table olives is now about 1.5 million t/year. The "California Style" black table olive is virtually unknown outside the United States, and this very mild-flavored olive is largely used on pizzas. Elsewhere, table olive recipes are as varied as the villages in the Mediterranean region. Oil styles are also varied, and most olive fruit (≈16 million t/year) is processed into oil. There are about 19 classic styles of olive oil produced in the world, primarily based on specific varieties grown in different regions. In some cases oils are made with a blend of regional varieties. Defective olive oil is common worldwide. The author discusses six of the world's most influential olive oil varieties 'Picual', 'Coratina', 'Koroneiki', 'Arbequina', 'Frantoio', and 'Leccino'; covers some horticultural history of oil olive cultivation and processing; and describes the most current trends toward superhigh-density plantings and automated continuous oil processing.**

BOTANICAL CLASSIFICATION OF THE OLIVE

The true genetic origin of today's cultivated olive *Olea europaea* L. var. *communis* is not known. Some scientists believe that the "European" olive, which has the only *Olea* with sufficiently large fruit to be edible, is a hybrid between two or more distinct species. Other scientists consider the genus *Olea* and species *europaea* to represent just one group of widely diverse plants with "ecotypes" or "subspecies" that are located in different geographic areas. In almost every location where cultivated olives grow, wild olive trees and shrubbery called oleaster or acebuche also exist. These plants may be seedlings of cultivated varieties spread by birds and other wildlife feeding on the fruit, or they could be more native forms of subspecies or ecotypes that already existed there before the introduction of the cultivated olive. All the *Olea* genera have the same chromosome number (2n = 46), and crosses between many of them have been successful. Most scientists now use the nomenclature of *Olea europaea* L. *sativa* to distinguish it from the wild olive subspecies *oleaster* (Lavee, 1996).

DEVELOPMENT OF OLIVE GROWING IN THE MEDITERRANEAN

The edible olive seems to have coexisted with humans for about 5000 to 6000 years, going back to the early Bronze Age (3150 to 1200 BCE). Its origin can be traced to areas along the eastern Mediterranean Coast in what are now southern Turkey, Syria, Lebanon, Palestine, and Israel based on written tablets, olive pits, and wood fragments found in ancient tombs. Ancient documents in Syria indicate that around 2000 BCE the value of olive oil was five times that of wine and two and a half times that of seed oils. The spread of the olive tree probably coincided with the vegetative propagation and trade of superior wine grape, date palms, and fig selections. Propagation of olive trees by seed is very frustrating, because the juvenile nonbearing phase is so long (10–15 years) and the progeny very often do not even resemble the original mother tree. These first nurserymen and agriculturists probably also selected for varieties that came into bearing early, produced heavy yields every year, grew on poor soils in arid areas, and were easy to harvest. The spread of the olive tree in commerce is well documented. The primary movement, however, was to the west.

Records indicate the introduction of olives into Greece, Egypt, and western Turkey. In those areas, there are many archeological sites with olive-related findings, such as milling stones, decantation basins, storage vessels, frescos, and ancient writings. In the Palace of Knossos on the island of Crete, clay tables recording the trade of olive oil can be traced to 1700 BCE. In Turkey at Urla, near Izmir, there is an ancient olive oil processing facility dating to 600 BCE. Many clay vessels, called amphora, which were used to store and transport olive oil, can be found in ruins throughout the area.

Olives continued to move westward into Sicily, Sardinia, Italy, France, Spain, Portugal, Algeria, Tunisia, and Morocco. It is generally believed that the Phoenicians took olives to Spain and North Africa around 1000 BCE, and the Greeks imported the trees into Italy. The first recorded agronomic writings can be attributed to the Romans, and certainly the expansion and prosperity of the Roman Empire was instrumental in the spread of olive plantings and oil processing facilities all around the Mediterranean basin. The Iberian Peninsula (Spain and Portugal) and the north coast of Africa became large production areas of olive oil that was shipped in large amphorae to England, Germany, France, and Italy. Olive oil in these times had many documented uses. All the cultures used olive primarily as lamp fuel, which was its greatest value. Many rituals involved the use of olive oil, including the anointing of royalty, warriors, and the general public for religious purposes. The term Messiah means "the anointed one." Fragrant olive oils were used to make offerings to the Gods, as pharmaceutical ointments to cure diseases, and to make the skin and hair appear healthier. The Greeks ceremoniously rubbed olive oil onto athlete's skin then scraped it off with the sweat and dust after competition. It was also used to make soap and to consecrate the dead. Very little record exists of olive oil being used for human consumption.

During the Middle Ages, olive oil continued to increase in production and importance primarily in Spain, Italy, and Greece. It declined in North Africa and other areas taken over by Turks, but was revived later in Arab-controlled countries. The greatest expansion of olive oil production came after the 1700s, when large plantings of olives, largely relegated to the worst land, were made to supply the growing populations of cities. In the late 19th and 20th centuries, the development of low-cost solvent extraction techniques for seed oils and the use of other sources for light (gas and electricity) resulted

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in a drop in the demand for olive oil. As little as 40 years ago there was a glut of olive oil on the world market. The widespread poverty in Spain, southern Italy, and Greece made the use of expensive products like olive oil prohibitive for many people. To compete in price with seed oils, olives were not often grown with quality in mind (Blazquez Martínez, 1996; Civantos, 2001; Filo della Torre, 2002; Rallo, 2005).

Olives were left in piled heaps to rot for months before being processed, to facilitate greater extraction of the oil. It has been well documented that various types of seed oils such as cotton, hemp, sesame, palm nuts, sunflower, and hazelnut have been used to adulterate olive oil and to make it more cost competitive. The development of the International Olive Oil Council was in part a response to widespread fraud in the olive oil trade surrounding the sale of olive pomace oil, mislabeled as extra virgin olive oil (Aparicio et al., 1997; Baeten and Aparicio, 2000; European Commission, 2001; Fiorino and Alessandro, 1996; International Olive Oil Council, 2003b; Schafer-Schuchardt and Wetenkamp, 2005).

Because olive trees can live for hundreds of years and take many years to reach full production, the selection and spread of better varieties would have been mostly into newly planted areas. This lack of orchard turnover and difficulties in travel for farmers probably are the reasons why many different olive varieties still exist in parts of Europe. In some cases, each village or different growing area has their own obscure variety, sometimes with different names for the same variety, and sometimes different varieties have the same name. There was certainly some natural selection that occurred, but it was more likely that better varieties were brought in from other areas through trade. Only the vastly superior varieties would have been more widely planted. This is certainly true today; only about 20 primary varieties have been imported into California, South Africa, Australia, New Zealand, Chile, and Argentina (Bartolini et al., 1994; Civantos López-Villalta, 1998; Vossen, 2005).

The world has ≈23 million acres of olives (9.4 million ha), producing ≈1.5 million t of table olives and 16 million t of olives that are processed into 2.56 million t of oil. Spain has about one-quarter of the world's acreage, with 5.98 million acres (2.42 million ha) of olive trees under cultivation and 36% of the oil production (≈800,000 t/year), which ranks it as the top producer. In 2001–02, Spain produced 50% of the world's oil as a result of a very high yield and poor crops in many other countries. Italy is ranked second, with 3.53 million acres (1.43 million ha) and ≈24% of the world's oil production (≈520,000 t/year). Greece is third, with ≈17% (≈400,000 t/year) of the world's oil production, and is fourth in world acreage with 2.55 million acres of olive trees (1.03 million ha). Together the big three produce 77% of the world's olive oil (Fig. 1). Projected production in 2008 is expected to increase by 8% to 10% as new land comes into bearing. Most of the increase in production will be coming from Spain and new world plantations in Australia and South America (International Olive Oil Council, 2003a, 2004).

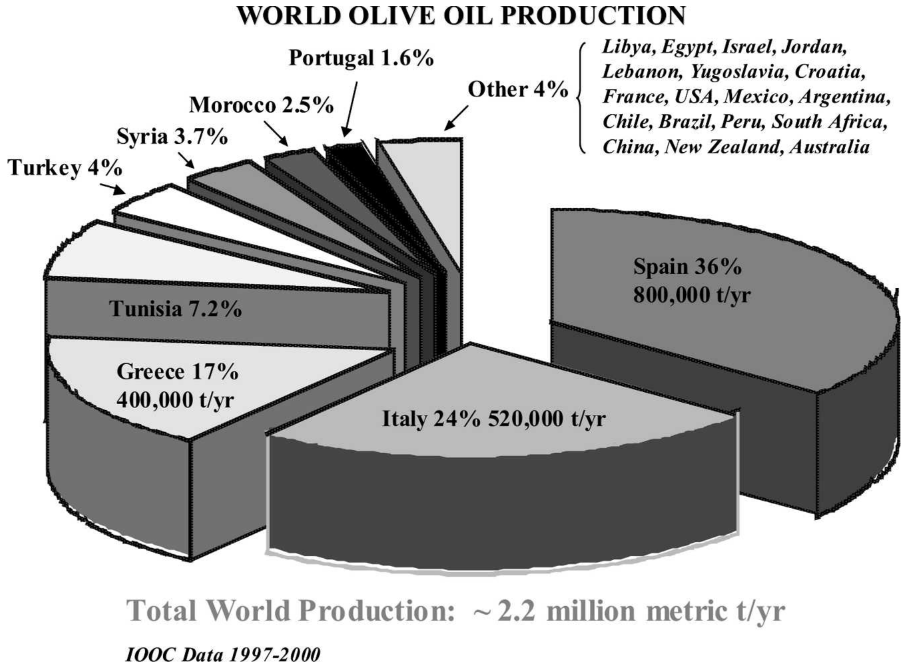

Fig. 1. World olive oil production.

Tunisia, Turkey, Morocco, Syria, and Portugal have serious olive oil acreage, but low production and underdeveloped processing technology. For the past few years, world oil production has been steadily increasing by ≈1.4% per year. The average annual production is 2.2 million t year. Most olive orchards in the world are dry-farmed, with an average yield per acre of ≈0.5 t of fruit, but good irrigated orchards can produce 10 times that amount (European Commission, 2003).

OLIVE PRODUCTION IN THE UNITED STATES

Among the first European settlers in California were the Spanish missionary priests who brought with them selected cuttings of their 'Mission' olive variety via Baja California, Mexico. This 'Mission' variety probably originated in Peru as a seedling of a Spanish variety. Around 1870, several small orchards with many different European varieties were planted for oil all along the California coast from San Diego up to Sonoma, and in various foothill areas of the Sierra Nevada Mountains. The first commercially produced olive oil in California came from the Camulos oil mill in Ventura, established in 1871. By 1885, California olive growers were producing oil from ≈2000 acres (809 ha) and several mills, but found they could not compete well against seed oils and olive oil imports from Europe.

The "California Style" firm, black olive was invented in the northern Sacramento Valley in the early 1900s, and a new planting boom started, but this time with table varieties. The table fruit industry ultimately grew to more than 35,000 acres (14,164 ha), most of which are located in the southern San Joaquin Valley. The small olive oil industry was maintained as a salvage operation of the table fruit industry for many years, using culled undersized olives. The current California table olive industry is finding it very difficult to compete against lower priced imports primarily because of the differences in hand harvest costs, so there is an incentive for table olive growers to sell more of their crop for oil production. Table olive orchards are being taken out; current acreage is about 31,000 acres (12,545 ha) (Connell, 2005; Sibbett and Ferguson, 2005; USDA National Agricultural Statistics Service, California Field Office, 2006; Vossen, 2005).

During the past 15 years there has been a resurgence of interest in olive oil as an ingredient to flavor gourmet food and as a healthier alternative to other forms of fats and oils in the U.S. diet. Olive oil sales in U.S. markets increased by 100% from 1991 to 2003 and are continuing to increase. Currently about 8% of all fats and oils consumed in the United States is olive oil. Because of its large population, the United States ranks as fourth overall in world consumption of olive oil. The U.S. consumption of olive oil is about 0.7 L/person/year compared with 26 L consumed by the Greeks, 15 L in Spain, and 13.5 L in Italy. During the last few years, the United States imported more than 60 million gallons of olive oil per year. All the significant domestic production of olive oil is in California, where production has been increasing each year, from 247,500 gallons in 1999–2000 to nearly 400,000 gallons in 2004–05, but only represents about 0.6% of our national consumption. During the past 8 years (1999–2006), Californians have planted just less than 8000 acres of oil olive cultivars, bringing the total acreage devoted to olive oil production to 10,168 acres (4,115 ha). By 2013, the projections are for a potential production of more than 1 million gallons/year (3.8 million kg/year) (INFOSCAN Statistics, 1999; MarketResearch.Com, 2002; North American Olive Oil Association, 2004; Senise Barrio and Carman, 2005; Supermarket Business Magazine, 1999; USDA Economic Research Service, 1999; Vossen and Devarenne, 2005, 2006).

The most prominent oil varieties in the world are listed in Table 1. Thousands of other varieties exist, most of which are confined to small regional areas. Many of these varieties, along with their traditional pollenizer and blending varieties, have been introduced into California during the past few years (Barranco et al., 2000; Civantos et al., 1997; Griggs et al. 1975; Rallo et al., 2005; Tous et al., 2005; Vossen, 2005).

PRODUCTION SYSTEMS FOR OIL OLIVES

High production costs, especially for harvest, have accelerated the redesign of olive orchards during the last 30 years. A traditional spacing of more than 25 feet (7.6 m) between trees (≈70 trees/acre; 173 trees/ha) is no longer popular anywhere in the world except for dry-farmed areas. Modern olive oil producers are planting trees at ≈250 trees/acre (617 trees/ha) in the high-density system and ≈900 trees/acre (2224 trees/ha) in the superhigh-density system. The more trees that are planted per acre, the faster the planting comes into full bearing, but when full production is reached, yields are equal (Civantos López Villalta and Pastor, 1996; Pastor, 1994; Tous et al., 1999). The high-density system can be planted to steep ground and harvested with tree shakers or various hand methods. It allows for the use of any variety and is less intensively managed. The superhigh-density system is designed to accommodate an over-the-row modified grape harvester, so the land must be relatively flat. Only compact varieties can be grown, and the long-term performance of the system is not known. It costs more to establish, but overall production costs are much lower (Vossen, 2002; Vossen et al., 2004).

Traditional system. The old, traditional olive production system in dry-farmed areas around the Mediterranean range in tree spacing from 25 to 60 feet (7.6–18.3 m) apart, giving 12 to 70 trees/acre (30–173 trees/ha). Their yields were somewhere between 0.5 to 2 tons/acre (1.1–4.5 t/ha) with a long delay before full production (15–40 years) and severe alternate bearing. Harvest of trees grown in the traditional system is very inefficient. The trees are almost always harvested by hand or by beating the fruit off with long poles onto nets. Because the trunks are so large, it is difficult and expensive to harvest the trees with mechanical shakers, because individual branches are shaken (Civantos, 2001; Rallo, 2005).

High-density production system. The high-density production system started around the early 1980s to reach full production faster in irrigated orchards. Hedgerows and a central-leader training system are being used, but most high-density orchards are still trained to the open-center form. Many orchards have been planted at different spacing combinations, usually with the in-row spacing closer than the between-row spacing to create a hedgerow with tree densities of ≈100 to 340 trees/acre (250–840 trees/ha). The overall benefits have been significant increases in yields per acre, usually double to triple what had been achieved previously. The orchards also come into full production sooner (>7–10 years), suffer less alternate bearing problems, and are more efficient to harvest (Pastor, 1994; Tous et al., 1999).

In high-density plantings, the fruit is primarily harvested with trunk shakers; however, there are some growers using other types of very large, single-sided or over-the-row comb-type harvesters. The high-density system has wide adaptability and will accommodate any olive variety, soil type, terrain, or training system. On steep terrain where tractors and mechanical shakers cannot function, the trees can be harvested by hand or with various assisted hand-harvesting methods. The main problems with the high-density system are that the trees still require 8 to 10 years for full production, harvest costs

Table 1. Primary world olive oil cultivars, including several California table varieties for comparison.

Cultivar and origin	% Oil	Cold hardiness	Fruit size	Polyphenol content[z]	Pollenizer varieties[y]
Arbequina, Spain	22–27	Hardy	Small	Low	Self-compatible
Aglandau, France	23–27	Hardy	Medium	Medium	Self-compatible
Ascolano, Italy	15–22	Hardy	Large	Medium	Manzanillo, Mission
Barnea, Israel	16–26	Sensitive	Medium	Medium	Self, Manzanillo, Picholine
Barouni,[x] Italy	13–18	Hardy	Large	Medium	Manzanillo, Ascolano, Mission
Bosana, Italy	18–28	Hardy	Medium	High	Tondo de Cagliari, Pizzé Carroga
Bouteillan, France	20–25	Hardy	Medium	Medium	Aglandau, Melanger Verdale
Chemlali, Tunisia	26–28	Hardy	Very small	High	Self-compatible
Coratina, Italy	23–27	Hardy	Medium	Very high	Self, Cellina di Nardo, Ogliarola
Cornicabra, Spain	23–27	Hardy	Medium	Very high	Self-compatible
Empeltre, Spain	18–25	Sensitive	Medium	Medium	Self-compatible
Frantoio, Italy	23–26	Sensitive	Medium	Medium–high	Pendolino, Moraiolo, Leccino
Farga, Spain	23–27	Hardy	Medium	Medium	Arbequina
Hojiblanca, Spain	18–26	Hardy	Large	Medium	Self-compatible
Kalamon, Greece	15–25	Moderate	Large	Medium	Mastoides
Koroneiki, Greece	24–28	Sensitive	Very small	Very high	Mastoides
Leccino, Italy	22–27	Hardy	Medium	Medium	Frantoio, Pendolino, Moraiolo
Manzanillo,[w] Spain	15–26	Sensitive	Large	High	Sevillano, Ascolano
Maurino, Italy	20–25	Hardy	Medium	High	Lazzero, Grappolo
Mission,[w] USA	19–24	Hardy	Medium	High	Sevillano, Ascolano
Moraiolo, Italy	18–28	Sensitive	Small	Very high	Pendolino, Maurino
Pendolino, Italy	20–25	Hardy	Medium	Medium	Moraiolo, Frantoio, Leccino
Picudo, Spain	22–24	Hardy	Large	Low	Picual, Hojiblanca
Picual, Spain	24–27	Hardy	Medium	Very high	Self, Picudo
Picholine, France	22–25	Moderate	Medium	High	Self, Aglandau
Sevillano,[x] Spain	12–17	Hardy	Very large	Low	Manzanillo, Mission, Ascolano
Taggiasca, Italy	22–27	Sensitive	Medium	Low	Self-compatible

[z]Oils with high polyphenol content have a longer shelf-life and are generally more bitter and pungent.
[y]Most olive varieties are somewhat self-incompatible. They will usually set a better crop with cross-pollination, especially under adverse weather conditions. 'Leccino', 'Pendolino', 'Moraiolo', and 'Maurino' are self-sterile and require a pollen source from another variety.
[x]'Barouni' and 'Sevillano' are not compatible cross-pollenizers for each other.
[w]'Manzanillo' and 'Mission' are not compatible cross pollenizers for each other (Barranco et al., 2000; Cimato et al., 1997; Griggs et al., 1975; Rallo et al., 2005; Tous et al., 2005).

are high, mechanical hedging removes too much of the tree's productive wood, and pest control is less efficient than for smaller trees (Civantos López Villalta, 1998; Vossen, 2002).

Superhigh-density production system. Successful superhigh-density olive orchards were pioneered by the Agromillora nursery and growers in Catalonia, Spain. This system uses specific varieties planted at tree spacings of ≈3 to 5 feet (0.9–1.5 m) within the row to ≈12 to 13 feet (3.7–3.9 m) between rows for ≈670 to 1210 trees/acre (1655–2990 trees/ha). The three best known varieties for superhigh-density systems, observed to date are 'Arbequina', 'Arbosana', and 'Koroneiki'. They can be grown in an upright fashion, trained as a central leader, throw few large lateral branches, and yet are compact compared with other varieties. They are very precocious, tend to produce a good crop every year, start bearing at an early age, and have excellent oil quality characteristics. However, these are not dwarf varieties and, if grown in a wider spacing with different management, they will eventually become just as large as any other olive trees (Vossen, 2002; Tous et al., 1999, 2003).

The 'Arbequina' variety has been the most widely planted variety for several years in both high-density and especially in the superhigh-density systems. The variety has several clones, one of which is the I-18, which in some trials came into bearing earlier and produced heavier yields. The 'Arbosana' variety has fruit that look very much like 'Arbequina', but matures ≈3 weeks later and has 25% less vigor than 'Arbequina'. 'Koroneiki' is the primary oil variety of Greece, produces excellent oil, and has annual heavy cropping and precocious bearing. It has about the same vigor as 'Arbequina', but smaller fruit size, and requires greater force for fruit removal.

Superhigh-density orchards are coming into bearing in the second year, with full production in the fourth or fifth year. Their yields ranged from 1.2 to 7.8 t/acre (2.7–17.5 t/ha). It is very likely that production levels of about 4 t/acre (9 t/ha) can be maintained with this system. However, the long-term production of the superhigh-density orchard system is not known. The main problem is maintaining light exposure into the trees' interior canopies. This system has been quite successful the first 14 years, but plant manipulation techniques to maintain high production have a steep learning curve (Table 2). The cost savings associated with superhigh-density orchards can make olive oil production in California competitive with European imports at every marketing level (Vossen et al., 2004). Some researchers believe this system to still be too experimental and has not been proved in the long term, especially if the trees cannot be maintained small enough to accommodate the over-the-row harvesters (Pastor et al., 2005).

The superhigh-density system requires fairly flat ground and requires the ability to control tree vigor through pruning, fertility management, and controlled deficit irrigation. There is a higher capital investment needed because of the extra trees, trellises, and more closely spaced irrigation system. The superhigh-density system also requires a high degree of technical skill by the farm manager because of the requirement to manage the size, light exposure, and disease susceptibility of the closely spaced trees (Vossen, 2002, 2004).

Table 2. Comparison of management needs and costs for high-density olive orchards versus superhigh density in California.

High density	Superhigh density
8 ft. × 16 ft. to 11 ft. × 22 ft. typical spacing (2.4 m × 4.8 m to 3.3 m × 6.7 m)	4 ft. × 12 ft. to 5 ft. × 13 ft. typical spacing (1.2 m × 3.66 m to 1.5 m × 3.96 m)
100 to 340 trees/acre (247–840/ha)	670 to 1,210 trees/acre (1655–2990/ha)
Spacing matched to variety, site, and management	Spacing matched to variety, site, and management
Trees OK on deep soils with plenty of rain	Excess vigor on deep soils with plenty of rain
Begins bearing in the fifth year	Begins bearing in the third year
Full production by the 10th year	Full production by the fifth year
Full production of 5 t/acre/yr (11.2 t/ha/yr)	Full production of 5 t/acre/yr (11.2 t/ha)
Harvest by hand, shakers, or very large machines	Harvest with proven over-the-row technology
Harvest cost is $300 to $500/t	Harvest cost is $40/t
Highest cost is harvest ≈50% of production	Highest cost is pruning ≈25% of production
Medium establishment costs	High establishment costs
UC cost study ≈$11 to produce 0.5 L oil	UC cost study ≈$5 to produce 0.5 L oil
Periodic pruning for light management	Very specific pruning for light management
Controlled deficit irrigation is helpful	Must control irrigation to keep trees small
Medium-intensity fertility management	Very high-intensity fertility management
Can use any variety	Must plant specific compact varieties
Can plant on any terrain	Must plant on flat or gentle rolling terrain
Can delay processing with undamaged fruit	Must process fruit very quickly because of bruising
Can harvest in almost any weather	Heavy harvest equipment sinks in wet ground
Foliar diseases are more easily managed	Foliar diseases must be managed intensively
Proven system that has worked for 40 years	New system with only 14 years of experience

PROCESSING OLIVES INTO OIL

To produce high-quality oil, the olives must be harvested without breaking the fruit skins, and fruit should be processed within 12 to 24 ha of harvest. Fruit should be separated by quality, with each grade processed separately (Hermoso Fernández et al., 1998).

Washing and leaf removal

Most mills pass the olives over a vibrating screen and blower that removes leaves and other debris. Olives are washed only if they have been harvested from the soil or have spray residues. The extra moisture can reduce extraction efficiency, because water/oil emulsions form. Oils made from washed olives are usually less desirable, with a reduction in bitterness and pungency, but also have a less fruity flavor (Civantos, 1999; Hermoso Fernández et al., 1998).

Milling or crushing

The olives are crushed to break the cells and release the oil for extraction. Two primary types of machines are used to crush olives: the stone mill and the hammer mill. Most olives are crushed with the pit, and the size of the pit fragments designates the fineness of the paste.

Stone mills, the oldest method, consist of a stone base and upright millstones enclosed in a metal basin, often with scrapers and paddles to spread the fruit under the stones and to circulate and expel the paste. The slow movement of the stone crushers does not heat the paste and results in less emulsification, so the oil is easier to extract. The disadvantages of this method are the bulky machinery and its slowness, its high cost, and its inability to be continuously operated. Most stone mills have been replaced during the past 20 years because of their inefficiency; however, some producers prefer this method for excessively strong-flavored varieties.

Hammer mills generally consist of a metal body that rotates at high speed, hurling the olives against a metal screen. The major advantage of hammer mills is their speed and continuous operation, which translate into high output, compact size, and low cost. The rapid crushing of the fruit, however, creates more emulsification of the oil and water within the paste, and higher temperatures. Oil produced from a hammer mill is generally stronger flavored because the pulp is broken up more. The size of the hammer mill mesh screen is normally adjusted as the season progresses and the fruit becomes riper and softer (Alba Mendoza, 2001; Civantos, 1999; Di Giovacchino et al., 2002b).

Mixing of the olive paste (malaxation)

Malaxation prepares the paste for separation of the oil. It is done to reverse the emulsification that occurred during the crushing process and is particularly important if the paste was produced in a hammer mill. The mixing process optimizes the amount of oil extracted through the formation of larger oil droplets and a reduction of the oil–water emulsion. Optimally, the malaxator is designed to ensure thorough mixing, leaving no portion unmixed. The paste is slowly stirred for 30 to 60 min. Temperature of the paste during malaxation is very important. It should be warm, 80 to 86 °F (26.6–30 °C), which is still cool to the touch, to improve the viscosity of the oil and to improve extractability. Temperatures more than 86 °F (30 °C) can cause problems such as loss of fruit flavors, increases in bitterness, and increases in astringency. The newest trend in the management of olive oil paste is to exclude oxygen, which can be done by either flooding the surface of the mixing tanks with nitrogen, or vacuum exclusion of oxygen in special malaxation tanks. Limiting oxygen exposure is believed to reduce enzyme activity that can break down polyphenols, which are major flavor compounds of olive oil (Alba Mendoza, 2001; Di Giovacchino et al., 2002a; Hermoso Fernández et al., 1998).

Oil extraction from the paste

The next step is extracting the oil from the solids and fruit–water. The oil can be extracted by pressing, centrifugal decanters, selective filtration, or through combinations of the different methods.

Traditional press. Pressing is one of the oldest methods of oil extraction. This method involves applying pressure to stacked filter mats, each covered with about 0.5 inch (1.25 cm) of paste, that alternate with metal disks. A central hollow spike allows the expressed oil and water (olive juice) to exit in both directions. This process requires more labor than other extraction methods, the cycle is not continuous, and the filter mats can easily become contaminated, introducing fermentation and oxidation defects into the oil. Consequently, the use of traditional presses is becoming obsolete (Alba Mendoza, 2001).

Selective filtration: sinolea process. With In this process, no pressure is applied to the paste. It operates on the principle that in a paste containing oil, solid particles, and water, the oil alone will adhere to metal. The machine has stainless steel blades that dip into the paste; the adhering oil then drips off the blades into a separate container, and the solids and water are left behind. This produces a light ‘‘free-run’’ oil with a unique quality. The equipment is complicated and requires frequent cleaning and maintenance, and a constant heat source to keep the paste at an even temperature. Extraction is stopped when fruit–water begins to appear in the oil (Alba Mendoza, 2001).

Centrifugal decanters: three phase and two phase. Historically, olive paste, or olive juice containing both water and oil was allowed to sit in containers until the oil rose to the top, where it could be skimmed off. The long time required for this, however, increases oil contact with enzymes and the likelihood of fermentation, producing defective oils. Modern decanters are large, horizontal centrifuges that separate the oil from the solids and water in much less time. The decanters spin at ≈3000 *g*n. Centrifugal force moves the heavier solid materials to the outside; a lighter water layer is formed in the middle, with the lightest oil layer on the inside. In a three-phase system, water is added to get the paste to flow through the decanter, but this washes away some of the flavor and antioxidants, and results in a lower polyphenol content.

Two-phase system decanters were introduced in the early 1990s. They are also large centrifuges that spin on a horizontal axis, but they separate the oil from the solids and fruit–water that exit together. No water needs to be added, so there is better retention of polyphenols. Two-phase extracted oils typically show higher levels of fruitiness, green flavors, bitterness, pungency, and overall flavor, but are not as sweet. The two-phase system also produces almost no wastewater compared with the three-phase system, and its wastewater has a much lower biological oxygen demand, but the solid waste is quite wet and more difficult to manage (Civantos, 1999; Hermoso Fernández et al., 1998).

Vertical centrifuge. Vertical centrifuges spin at two times the velocity of a decanter on a vertical axis and provide four times the separation force (2^2) for the solid, water, and oil phases. The additional separation of the three phases further removes solid particles and water from the oil. Fresh warm water is usually added to ‘‘clean’’ the oil, creating a greater separation of the phases. Three-phase system processors use two centrifuges: one for the ‘‘wet’’ oil from the decanter and a second one to separate the oil from the fruit–water of the decanter (Alba Mendoza, 2001).

Processing waste

In countries with significant olive oil production, the waste from premium oil extraction is used for further oil extraction with solvents. No solvent extraction plants are currently making pomace oil in California.

Oil filtration, storage, and bottling

After processing, oil should be stored in bulk for 1 to 3 months to settle out further any remaining particulate matter and fruit–water. This eliminates sediment in bottles and oil contact with processing water residues that could lead to off flavors. Some oils are filtered before bottling to remove any residual fruit–water or suspended solids. ‘‘New’’ oil, which is bottled and sold immediately after processing, must be consumed quickly (within about 6 weeks) to avoid flavor changes within the bottle. Premium-quality oils should be stored in stainless steel and maintained at a constant temperature of between 45 to 65 °F (7.2–18.3 °C) (Alba Mendoza, 2001; Hermoso Fernández et al., 1998).

SENSORY EVALUATION OF OILS

One of the objectives in olive oil sensory evaluation is to determine whether the oils contain defects from improper fruit storage, handling, pest infestation, oil storage, or processing problems. There should be no vinegary or fermented odor or flavor. The oil should also not be rancid or have any other off flavor that is essentially not of the olive. Human sensory evaluation is much more accurate (100 times) than laboratory equipment for certain olive oil characteristics. Aroma and taste are very complex and cannot be determined in the laboratory. The tongue can also detect texture differences difficult to measure analytically. The second objective of oil sensory evaluation is to describe the positive characteristics of the oil in relation to its intensity of olive–fruity character. Olive oil should have a fruity olive flavor that is characteristic of the variety or blend of varieties making up the oil. Bitterness and pungency are often present in olive oils, especially when newly made. They are not defects and will mellow as the oils age (Alba Mendoza et al., 1997; Harwood and Aparicio, 2000; International Olive Oil Council, 1996; Kiritsakis et al., 1998; Uceda Ojeda, 2001). The International Olive Oil Council defines the following olive oil attributes:

Standard: positive attributes

- *Fruity:*- Olfactory sensations characteristic of the oil, which depends on the variety and comes from sound, fresh olives, either ripe or unripe. It is perceived directly or through the back of the nose (retronasal).
- *Bitter:* Characteristic taste of oil obtained from unripe olives. Perceived on the back of the tongue.
- *Pungent:* ‘‘Picante’’ or biting tactile sensation characteristic of certain olive varieties or oil produced from unripe olives. Perceived in the throat.

Standard: negative attributes

- *Fusty:* Characteristic flavor of oil obtained from olives stored in piles, which have undergone an advanced stage of anaerobic fermentation. Associated with n-octane, produced from the decomposition of 10-hydroperoxide of oleic acid and isoamyl alcohol formed from fermentation.
- *Musty:* Characteristic moldy flavor of oils obtained from fruit in which fungi and yeast have developed as a result of its being stored in humid conditions for several days.
- *Muddy sediment:* Characteristic flavor of oil that has been left in contact with the sediment in tanks and vats.
- *Winey–Vinegary:* Characteristic flavor of certain oils reminiscent of wine or vinegar. This flavor is mainly the result of aerobic fermentation in the olives leading to the formation of acetic acid, ethyl acetate, and ethanol.
- *Rancid:* Flavor of oils that have undergone a process of oxidation and a fragmentation of hydroperoxides into compounds (aldehydes, ketones, acids, alcohols, lactones, furans, and esters) with characteristic disagreeable odors such as varnish, wax, putty, crayons, old paint, and so forth.
- *Heated or Burnt:* Characteristic cooked flavor of oils incited by excessive or prolonged heating during processing.
- *Hay or Woody:* Characteristic flavor of certain oil produced from olives that have dried out or were frozen.
- *Greasy:* Flavor of oil reminiscent of that of diesel oil, grease, or mineral oil.
- *Vegetable water:* Flavor acquired by the oil as a result of prolonged contact with the

liquid, nonoil fraction of the olive (also called fruit–water).

- *Briny:* Flavor of oil extracted from olives that have been preserved in brine.
- *Earthy:* Flavor of oil obtained from olives that have been collected with earth or mud on them and not washed.

OLIVE OIL FLAVOR AND STYLE

There are hundreds of imported and domestic oils available to American consumers. Each has a different flavor, keeping quality, and antioxidant content. They also vary in the way the olives were grown, how they were processed, their varietal makeup, and price. The following is a brief description of the most common styles of olive oil.

Spanish olive oils

Catalan 'Arbequina'. These oils come from the regions in northeastern coastal Spain (Tarragona and Lleida). The oils are predominantly made from the 'Arbequina' variety, which produces a very aromatic oil with a clean, fresh, herbal olive flavor, often with apple, sweet almond, and artichoke undertones, and with a very light pungency and bitterness. Unfortunately, later harvested 'Arbequina' oils tend to lose much of their aromatic character within a few months, and by the end of the sales year are flat and bland. Most go rancid after 18 months.

Aragon 'Empeltre'. These oils are from the northeastern inland Spanish regions of Huesca, Zaragoza, and Teruel, but also La Rioja and Navarra and down to Castellón on the coast. The dominant variety produced is 'Empeltre', which makes a very light, fruity oil that is aromatic with little bitterness or pungency. Other varieties include 'Farga', 'Sevillenca', 'Morrut', and 'Verdeña'. Oils from this area have excellent quality, especially when consumed within the first few months of production.

Extremadura, Castilla la Mancha, Castilla y Leon, and Madrid. These oils come from the inland dry-farmed rolling hills located in the west central portion of Spain in the provinces of Cáceres, Badajoz, Toledo, Ciudad Real, Avila, Salamanca, Zamora, and Madrid. Excellent-quality oils are produced primarily from the varieties of 'Cornicabra', 'Carrasqueña', 'Morisca', 'Verdial Badajoz', 'Manzanilla Cacereña', 'Castellana', and 'Alfafara'. 'Cornicabra' oils have achieved the most recognition.

Valencia 'Blanqueta'. These oils are produced primarily in the regions of Murcia, Alicante, and Valencia in the dry-land central coastal hills of Spain. The major variety grown in that area is 'Blanqueta', but others include 'Villalonga', 'Lechín', 'Changlot', and 'Cornicabra'. The oils from 'Blanqueta' are usually quite bitter and pungent, and are lightly fruity and sweet with mostly a ripe fruity character and very high quality.

Andalucia 'Picual'. These oils come from a huge production zone (60% to 80% of the country's oil) located in southern Spain that includes the regions of Jaén, Córdoba, Granada, Málaga, Huelva, and Sevilla. The olives are mostly grown on the hillsides under dry-farming conditions with traditional plantings that have very wide spacings and two to four tree trunks arising from one spot. The early-season fruit that is harvested in November and December is of excellent quality and is very highly fruity. The oils from 'Picual' are high in polyphenols, strongly bitter, very pungent, and keep well. More than half the fruit is harvested late in the season, some of it from the ground, which is a salvage operation that produces a high volume but very low-quality oil, for refining (Romero et al., 2005; Vossen, 1997).

Italian olive oils

Liguria: 'Taggiasca'. Liguria is in the Italian Riviera area along the coast and contiguous with the French border. The primary variety grown in this region is 'Taggiasca', and it is commonly harvested late to produce a very light, fruity oil that goes well with the typical seafood diet of the region.

Toscana: 'Frantoio' and 'Leccino' blends. The famous Tuscan-blend oils come primarily from the inland area of Tuscany around Firenze, where 'Frantoio' is the dominant variety and most of the fruit is harvested early to avoid losses resulting from the frosts that are quite likely to occur after mid December. 'Frantoio' harvested somewhat green has the characteristic strong, aromatic, grassy, fruity flavor and the bright-green color, with strong pungency. 'Leccino' is an important part of the blend because it matures earlier and is much lighter in flavor with its own spicy character. It is used to mellow and add complexity to 'Frantoio' and the Tuscan blend. Closer along the coast around Lucca, the growers tend to grow more of the 'Leccino' variety, so their oils are generally less intense in flavor and color. Southern Tuscany has larger olive orchards and many now include the 'Coratina' variety. Tuscan oils have considerable market recognition all over the world.

Umbria: 'Frantoio', 'Leccino', and 'Coratina' blends. The rolling hills of South–Central Italy are covered with a mix of forest, grain crops, and olive orchards. They primarily grow 'Frantoio', 'Leccino', and 'Coratina', with some other minor varieties like 'Dolce Agogia', 'Rociola', and 'Moraiolo'. The olives tend to be harvested a bit later and have a riper fruitiness flavor. The oils have characteristic strong fruitiness, medium bitterness, medium pungency, good stability, and excellent quality.

Puglia: 'Coratina'. The plain around Bari in southeastern Italy is the high-volume production area for olive oil in Italy. 'Coratina' is the primary variety and in some orchards is grown in solid blocks, whereas in others it is mixed with 'Cellina di Nardo', 'Ogliarola Barese', and 'Cerignola'. The 'Coratina' variety is extremely late maturing and in some cases never turns color. The oils are very high in polyphenols, very stable, and care must be taken to moderate bitterness in the oil. 'Coratina' oils have a very strong green olive, grassy, and herbaceous character and are often used to blend with refined oils.

Sardinia: 'Bosana'. The island of Sardinia is covered with olive trees primarily of the variety 'Bosana', which produces an excellent strong, aromatic, fruity olive oil that is crisp and clean. Sardinian oils are recognized for their good balance between fruitiness, bitterness, and pungency.

Lazio: 'Canino'. The West–Central region of Italy produces oil from many dispersed orchards. The primary variety grown is 'Canino'. The oils are usually green, quite olive fruity, and have a light bitterness and pungency.

Calabria: 'Carolea'. The southwest mainland of Italy grows primarily one variety called 'Carolea', which is usually harvested quite mature to produce a complex golden green fruity, sweet oil.

Sicily: 'Biancolilla', 'Nocelara de Belice', and 'Cerasuola' blends. Classic oil from the southernmost region of Italy is usually quite green with a golden undertone. It has good body with medium ripe fruitiness, some bitterness and pungency, and very interesting complexity. Many oil producers in this region have recently introduced their proprietary brands by variety and they are excellent oils (Cimato et al., 1996; Vossen, 2000).

Greek olive oils

'Koroneiki' blends. The 'Koroneiki' variety is dominant all over Peloponnisos, Zakinthos, and Crete. It is sometimes blended with 'Kalamon', 'Konservolia', and 'Chalkidiki' in table fruit-growing areas and with 'Mastoides' in oil-growing areas. 'Koroneiki' oils are high in polyphenols, very stable, and very aromatically fruity with herbaceous and green banana characteristics. The fruit is very small and difficult to get off the tree. Much of the oil from Greece is made from olives with olive fly damage, or are mishandled in transport and stored for a while before processing. When the fruit is clean and processed quickly, however, some excellent oils are produced (Vossen, 1999).

California olive oils

Central Valley: 'Manzanillo'. The 'Manzanillo' variety represents about 70% of all the olive acreage in California. It is primarily used as a table olive that is grown in the southern San Joaquin Valley in Tulare County around Visalia and in the northern Sacramento Valley in Glen and Tehama counties around Corning and Orland. It also produces excellent oil and contains a fairly high oil content when allowed to ripen into November. When harvested early and green, the oil is quite grassy, herbaceous, bitter, and pungent in character. Later harvested fruit produce oils that are very aromatic with a nice ripe olive fruity character.

Central Valley and coastal 'Mission'. The 'Mission' variety is a dual-purpose olive with a high oil content. Oils produced from the 'Mission' variety are usually either extremely green and bitter or overripe and buttery (bland). There seems to be a very short window of ideal fruit maturity that results in excellent-quality oils with less bitterness and good fruity character. Producers who have paid close attention to fruit maturity have produced some excellent 'Mission' blend oils with fruitiness, harmony, and complexity. Blending early and later harvested fruit also produces some outstanding 'Mission' olive oils.

Central Valley: 'Sevillano' and 'Ascolano'. 'Sevillano (Gordal)' and 'Ascolano' are grown exclusively as table fruit varieties that are harvested in late September and October. They contain only about half the oil of normal oil varieties. Some fruit make their way into the oil market when they cannot be sold as table fruit. Because the fruit are mostly harvested hard green, both varieties produce oil that is extremely grassy and herbaceous. Recently, some producers have harvested 'Ascolano' much later, when the fruit is turning color and is ripe. This produces an extremely ripe fruit-flavored olive oil with strong expressions of other ripe fruits such as peach, apricot, apple, citrus, and mango.

Central Valley: 'Arbequina'. New super-high-density olive oil orchards have primarily been planted with specially selected clones of the varieties 'Arbequina', 'Arbosana', and 'Koroneiki'. 'Arbequina' tends to dominate in volume, providing a very positive olive fruitiness that is not very bitter or pungent. 'Arbosana' and 'Koroneiki' are much more bitter and pungent with higher levels of polyphenols. Their increased stability in a blend with 'Arbequina' makes a more complex and longer lasting oil.

Coastal Tuscan. Several small-scale coastal California producers have imported Italian varieties primarily from Tuscany ('Frantoio', 'Leccino', 'Moraiolo', 'Maurino', and 'Pendolino') to produce a "New World Tuscan Blend" olive oil. The results have been excellent from the perspective of oil quality, producing oils with very similar characteristics to the same blends of oil varieties produced in various parts of Italy. The oils are typically harvested at color change or slightly green and the blends in general are extremely fruity, often very green, bitter, and pungent in character, with green apple, artichoke, green almond, and herbaceous undertones (Vossen, 2003, 2005; Vossen et al., unpublished).

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