The Extra-Virgin Olive Oil Handbook
The Extra-Virgin Olive Oil Handbook

Edited by

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I am also indebted to Valérie Ganio Vecchiolino, a student at the University of Gastronomic Sciences in Pollenzo (Italy), who drew plant and designs with great care, precision and patience.
Introduction

This handbook deals with the basic science and technical aspects of extra-virgin olive oil, from harvesting the olives to processing, storing and using the oil at the consumer’s table. It is divided into three parts: the product, the process and the process control system. One chapter gives some fundamental information about the best culinary uses of olive oils. Some important physical and physical-chemical parameters are summarized in the appendix and a detailed subject index indicates where major topics can be found in the handbook.

The main purpose of the handbook is to guide those involved in the extra-virgin olive oil chain in making the most appropriate decisions about product quality and operating conditions in the production and distribution processes. The approach of the handbook is mainly educational, providing guidelines for good extra-virgin olive oil practice. Basic information about various phenomena is presented in an easy-to-understand form, while systematic methods for choosing the most appropriate operating conditions are suggested. The instructive approach is evident in many parts of the text: (i) in the presentation of the principles, methods and examples of quality and safety management; (ii) in the presentation of methods to calculate mass and cost balances because they are considered as important as evaluating the chemical and sensory characteristics of the oil; (iii) in the choice of time–temperature relationships in olive storage, in olive paste malaxation and in olive oil storage. The semi-log plots in Chapters 9, 12 and 15 are a contribution to critical points management based on sound scientific principles; (iv) in the presentation of the health-promoting properties of extra-virgin olive oils and in the choice of the analytical parameters for their evaluation; (v) in the discussion and presentation of sensory profiles as essential tools of product style and differentiation.

The second purpose of the handbook relates to quality as the guiding factor of managerial and operating strategies. A producer of olive oil has different options. The first is to put aside quality and focus on yield increase and cost reduction. Overripe olives are harvested by letting them drop to the ground and then collected mechanically; in this case ‘lampante’ oil is produced and sold to refineries to produce refined olive oil. This approach has proven profitable in some cases and is sometimes unavoidable due to olive spoilage, pest attack or lack of appropriate harvesting equipment. The handbook describes the olive oil refining process and explains why
refined olive oil should be considered as a good, reliable and useful product among the vegetable oils.

Another option is to produce an olive oil that meets extra-virgin standards. This requires considerable care to ensure that the olives are healthy and undamaged and that proper operating conditions are used in the milling and handling operations. With this choice, the quality of the olive oil reaches a high level.

The handbook points out that the standards of extra-virgin olive oil can be further improved beyond the present legal requirements and levels of excellence can be achieved. Attention is focused on neglected but critical issues such as: (i) residence time distribution in olive paste malaxation; (ii) hygienic design of plants and equipment and, most of all, (iii) in Chapter 15 on olive oil storage and handling, where the principles of the quality-proximity matrix are presented and thoroughly discussed.

It can be said that producing a ‘lampante’ olive oil does not require special care and skill. Producing an extra-virgin olive oil is a much more challenging and demanding task. Finally, only excellent operators can make excellent extra-virgin olive oils available to the final consumer. The goal of this handbook is to guide the operators in the olive oil chain towards excellence, all the way from the olive grower to the restaurant chef. With a chapter on the culinary uses of extra-virgin olive oil, we would like to activate a new alliance between excellent producers, retailers and chefs for the production and use of excellent extra-virgin olive oil. We hope to contribute to spreading a new consumer culture about this exceptionally good, healthy and natural product, which is so old in its millenarian tradition, so young in present-day processing technologies and so well tailored to the health, taste and dietary needs of new and traditional consumers around the world.
Part I
The product
1

The extra-virgin olive oil chain

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Abstract

This chapter presents the classification and commercial denomination of six olive oil categories recognized in international law (two virgin and four refined). Extra-virgin olive oil is the highest quality olive oil. The extra-virgin olive oil chain, is presented as a sequence of five processes: (i) olive tree cultivation, (ii) olive harvesting and processing, (iii) oil storage, bottling and distribution, (iv) selling bottled oil and (v) oil use in culinary preparations. Processes (ii) and (iii), the subject matter of this handbook, are further presented as a sequence of unit operations. The main steps and conditions determining oil quality and yield are outlined.

1.1 The legal classification and denomination of olive oils

When talking or reading about olive oil, the first point to be clarified is the category of olive oil that is being discussed. Ignoring the category that the oil belongs to can be a source of confusion and misunderstanding and can lead to mistakes in buying, tasting or using it. Figure 1.1 is a flow-chart of the classification and denomination of the various categories of virgin and refined olive oils as globally agreed (see Council Regulation (EC) No. 1234/2007 of 22 October 2007, (Single CMO Regulation), consolidated version 2013-01-26, Annex XVI).

The six categories highlighted by the grey background are suitable for human consumption.

The flow-chart starts with the olive milling process, whose products are the ‘virgin’ olive oils. Two of them, namely extra-virgin and virgin, are allowed for consumption. The third category, lampante, becomes edible only after a physical-chemical refining process and it is called ‘refined olive oil’.

On the other hand, the pomace, which is the solid residue from the milling process, still contains a small amount of olive oil that is impossible to extract by mechanical means. It can be extracted with solvents; the raw oil from this extraction
is refined with a process very similar to that applied to lampante oil. The refined oil derived from pomace is called ‘refined olive-pomace oil’.

Both the ‘refined olive oil’ and the ‘refined olive-pomace oil’ can be mixed with extra-virgin or virgin olive oil in various undefined proportions in order to improve their flavour. These are called, respectively, ‘olive oil composed of refined and virgin olive oil’ and ‘olive-pomace oil’.

Chapter 17 gives a short presentation of the refining process. It is important that olive oil producers, retailers and consumers know the difference in technological and compositional terms between a virgin oil and a refined oil.

Regarding quality, extra-virgin olive oil is higher in quality than virgin olive oil and refined olive oil is higher in quality than refined olive-pomace oil. Refined olive oil is very mild and almost neutral in taste: it is very good for cooking, frying and for preserving canned vegetables or meat or fish. Extra-virgin olive oil
is flavourful and tasty. A picture of the culinary uses of olive oil and especially excellent extra-virgin olive oils is given in Chapter 24.

1.2 The subject of this handbook

Focusing on extra-virgin olive oil opens a wide panorama because the oil varies depending on cultivar, climate and soil, and the conditions of the production-extraction-storage-and-distribution process. Extra-virgin olive oils can be of common or good or excellent quality. The purpose of this handbook is to discuss the technological and management conditions that allow an operator of the extra-virgin olive oil chain to improve the quality of the product, which is finally served at the consumer’s table.

1.3 The extra-virgin olive oil chain

The extra-virgin olive oil chain can be divided into a series of five processes: (i) olive tree cultivation, (ii) olive harvesting and milling, (iii) oil storage, bottling and distribution, (iv) oil selling and (v) oil use in culinary preparations (Table 1.1).

These five processes have different structural and operational requirements, different marketing policies and different economies of scale. They are therefore usually managed and owned by different companies.

<table>
<thead>
<tr>
<th>Process</th>
<th>Input</th>
<th>Output</th>
<th>Ownership and responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Olive tree cultivation</td>
<td>Olive trees (plus soil, atmospheric conditions, machinery, services, information, work, …)</td>
<td>Olives</td>
<td>Agricultural companies</td>
</tr>
<tr>
<td>(ii) Olive harvesting and milling</td>
<td>Olives (plus the mill, services, information, work …)</td>
<td>Batches of oil</td>
<td>Milling companies</td>
</tr>
<tr>
<td>(iii) Oil storage, packaging and distribution</td>
<td>Batches of oil (plus packaging plant and materials, services, information, work …)</td>
<td>Oil in bottles or other suitable containers</td>
<td>Packaging and distribution companies</td>
</tr>
<tr>
<td>(iv) Sale of packaged oil</td>
<td>Packaged oil (plus sales facilities, services, information, work …)</td>
<td>Packaged oil sold to the final user</td>
<td>Retail companies</td>
</tr>
<tr>
<td>(v) Culinary use of oil</td>
<td>Packaged oil (plus cooking facilities, services, information, work …)</td>
<td>Oil in culinary preparations</td>
<td>Restaurants, foodservice and families</td>
</tr>
</tbody>
</table>

Table 1.1 The processes of the extra-virgin olive oil chain.
Processes (ii) and (iii) represent the core content of this handbook. There is some discussion about process (i) in Chapters 5 (olive tree cultivars) and 7 (olive harvesting), whereas Chapter 24 gives some general indications about the use of extra-virgin olive oil in culinary preparations.

### 1.3.1 Compact versus complex chain organization

The most compact organization of an extra-virgin olive oil chain entails a direct connection between only two parts (or modules): the first is represented by the producer and the second by the final consumer. In this case, which is very common in olive oil producing regions, a producer who is responsible for the chain from the field to the package, sells his oil directly to the final consumer, either a family or a restaurant. This organization is typical of traditional markets in a narrow area close to production, but sometimes it is also implemented in a global market and across continents. It is common to find commercial agreements between a restaurant in Los Angeles or Tokyo and a producer in Andalusia or Tuscany.

On the other hand, very complex chain organizations are implemented in large-scale and global businesses with multiple inputs and outputs connecting the five processes listed in Table 1.1.

Traceability of product origin and identity is easy in the case of the compact chain, whereas it may be very difficult or impossible in complex chain organizations.

### 1.3.2 The extra-virgin olive oil processes

As chains can be considered sequences of processes, processes can similarly be considered as sequences of unit operations. Processes are interconnected in series in a chain, so unit operations are interconnected in series in a process with the output of a unit operation being the input of the following one (Peri et al. 2004). Table 1.2 presents the unit operations of processes (ii) and (iii).

### 1.4 Yield and quality

The primary objective of an extra-virgin olive oil company is to maximize oil yield and quality. Obtaining the largest quantity of oil with a high level of quality is the ultimate measure of process effectiveness and efficiency.

Contrary to the situation with other agricultural products, yield and quality are not competitive in extra-virgin olive oil production, but independent or concurrent parameters. Conditions determining quality losses also determine yield losses. Figure 1.2 represents the critical steps and conditions determining extra-virgin olive oil yield and quality.

The extra-virgin olive oil chain is divided into two parts. In the first part, corresponding to olive tree cultivation, the basic condition for success is olive integrity. If, due to climatic conditions or pest attack, olives are seriously damaged, the unavoidable consequence is an irreversible loss of yield and quality.
### Table 1.2  The unit operations of extra-virgin olive oil processes.

<table>
<thead>
<tr>
<th>Preliminary activities</th>
<th>Unit operation</th>
<th>Ancillary activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring of olive maturity.</td>
<td>Harvesting</td>
<td></td>
</tr>
<tr>
<td>Supply and maintenance of harvesting nets, crates and equipment</td>
<td>Storage and transportation of olives</td>
<td></td>
</tr>
<tr>
<td>Mill plant maintenance, cleaning, and start trial</td>
<td>Olive reception at the mill plant</td>
<td></td>
</tr>
<tr>
<td>Standards agreed upon between the olive grower and the milling company</td>
<td>Visual inspection, control of origin and olive integrity</td>
<td>Decisions in case of nonconformity to standards</td>
</tr>
<tr>
<td></td>
<td>Milling batches, identification and weighing</td>
<td>Record of milling batches</td>
</tr>
<tr>
<td>Deleafing at the olive grove site. Supply of potable water</td>
<td>Olive cleaning and washing</td>
<td>Disposal of solid residues and dirty water</td>
</tr>
<tr>
<td></td>
<td>Olive milling or pitting</td>
<td>In case of pitting: discharge and use of olive stones</td>
</tr>
<tr>
<td></td>
<td>Olive-paste malaxation</td>
<td>Monitoring and control of the time-temperature relationship</td>
</tr>
<tr>
<td></td>
<td>Solid-liquid and liquid-liquid separation</td>
<td>Pomace to treatment and use. Wastewater to disposal</td>
</tr>
<tr>
<td>Supply of filter aids or filter pads</td>
<td>Oil filtration</td>
<td>Disposal of exhausted filtering material</td>
</tr>
<tr>
<td>Agreed upon standards of oil quality and yield</td>
<td>Oil weighing, chemical and sensory evaluation</td>
<td>Decisions in case of nonconformity</td>
</tr>
<tr>
<td>Maintenance of storage facilities</td>
<td>Storage batches formation and identification</td>
<td>Standard documentation of storage batches</td>
</tr>
<tr>
<td></td>
<td>Oil storage</td>
<td>Waste disposal</td>
</tr>
<tr>
<td>Customers’ orders and requirements</td>
<td>Oil blending, packaging batches formation</td>
<td>Chemical and sensory evaluation of packaging batches. Record of packaging batches</td>
</tr>
<tr>
<td>Maintenance and supply of packaging material</td>
<td>Packaging</td>
<td>Waste disposal</td>
</tr>
<tr>
<td></td>
<td>Shipment of consignment to customers</td>
<td></td>
</tr>
</tbody>
</table>
If, on the other hand, olives are undamaged and healthy, the final result is determined by three factors of similar importance: (i) the cultivar and the environment (climate and soil); (ii) the ripeness of olives at harvesting; (iii) the oil processing and storage conditions.

Processing of the olives and storage of the oil are the last and hence the decisive steps affecting oil quality. The product of the best, healthy and undamaged olives can be a very common oil or even a bad oil, as a consequence of errors and carelessness in the processing and distribution steps.

A point that should be kept in mind is that the loss of quality of virgin olive oil is irreversible. Feedback control is not possible and amplification instead of slowdown of the negative effects takes place: spoiled olives produce spoiled oil and spoiled oil tends to spoil further at a much faster rate than good oil. Process control should be based on prevention. The only corrective action available in the case of a spoiled oil is downgrading and refining it.

**Reference**

Virgin olive oil: definition and standards

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Abstract

Basic information is given about virgin olive oil standards according to European legislation. Standards are divided into two groups: (i) quality standards aimed at classifying extra-virgin, virgin and inedible ‘lampante’ olive oil and (ii) authenticity standards aimed at identifying oil adulteration by mixing virgin olive oil with refined olive oil or oil of other kinds. The importance and meaning of free acidity, peroxide value, UV absorption values and sensory defects are discussed.

2.1 The legal definition of virgin olive oil

Definitions and standards for virgin olive oil are primarily based on European legislation, especially Commission Regulation (EC) No. 1019/2002 of 13 June 2002, on marketing standards for olive oil, and Commission Regulation (EC) No. 702/2007 of 21 June 2007, on the characteristics of olive oil and on the relevant methods of analysis. Other standardization organizations, such as the International Olive Council (IOC; www.internationaloliveoil.org/) and The Codex Alimentarius Commission (www.codexalimentarius.org/), take part in defining olive oil standards, but European legislation is the first and main reference worldwide. The European Community recognizes several categories of olive oil, each with its particular qualities and market value.

Virgin olive oil is defined by EC Regulation No 1019/2002 (Art. 3) as follows: ‘Virgin olive oil is the olive oil obtained directly from olives and solely by mechanical means.’ Conformity with this definition is the basic authenticity requirement for virgin olive oil.
Three categories of virgin olive oil are further defined, based on quality criteria, as: ‘extra-virgin olive oil’, ‘virgin olive oil’ and ‘lampante olive oil’. Lampante (literally ‘lamp oil’ according to its use in ancient times) is a virgin olive oil obtained from bad fruit or careless processing and it is of such a low quality that it cannot be used for human consumption and must be refined in order to become edible.

Regulation (EU) No 29/2012, dated 13 January 2012, codifies the substantial amendments that have taken place since regulation No 1019 on olive oil marketing standards was introduced in 2002. One of those, Council Regulation (EC) No 1234/2007 of 22 October 2007, establishes a common organization of agricultural markets and specific provisions for certain agricultural products, olive oil included. According to this regulation, ‘virgin olive oils’ are defined as:

“oils obtained from the fruit of the olive tree solely by mechanical or other physical means under conditions that do not lead to alterations in the oil, which have not undergone any treatment other than washing, decantation, centrifugation or filtration, to the exclusion of oils obtained using solvents or adjuvants having a chemical or biochemical action, or by re-esterification processes and any mixture with oils of other kinds.”

Commission Regulation (EC) No 702/2007 of 21 June 2007 defines the analytical and sensory standards of all the categories of olive oils, virgin or refined. Only the standards related to the three categories of virgin olive oil are presented here. These standards have been established by law as indicators of oil quality and authenticity.

Quality standards are analytical parameters that allow virgin olive oils to be classified according to a scale of quality. In general, these parameters indicate oil spoilage. Therefore, it is assumed that the lower their values, the higher the quality of the oil.

Authenticity standards are analytical parameters that allow an oil to be declared as ‘virgin’, in compliance with the definition reported above. In general, these parameters indicate the presence of refined olive oil (violation of the condition of ‘solely by mechanical means’) or other vegetable oils (violation of the condition of being obtained ‘directly from olives’).

### 2.2 Quality standards of virgin olive oil

Quality standards of virgin olive oil can be divided into two groups: chemical and sensory standards.

#### 2.2.1 Chemical quality standards

The chemical standards that must be evaluated for classifying the quality levels of virgin olive oils are reported in Table 2.1. Quality standards are useful to verify hydrolytic and oxidative degradation that takes place in the olives and the oil.
2.2 QUALITY STANDARDS OF VIRGIN OLIVE OIL

Table 2.1 Chemical standards of virgin olive oil.

<table>
<thead>
<tr>
<th>Chemical standard</th>
<th>Extra-virgin</th>
<th>Virgin</th>
<th>Lampante</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free acidity (%)</td>
<td>≤ 0.8</td>
<td>≤ 2.0</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>Peroxide index (mEqO₂/kg)</td>
<td>≤ 20</td>
<td>≤ 20</td>
<td>–</td>
</tr>
<tr>
<td>K₂₃₂</td>
<td>≤ 2.50</td>
<td>≤ 2.60</td>
<td>–</td>
</tr>
<tr>
<td>K₂₇₀</td>
<td>≤ 0.22</td>
<td>≤ 0.25</td>
<td>–</td>
</tr>
<tr>
<td>ΔK</td>
<td>≤ 0.01</td>
<td>≤ 0.01</td>
<td>–</td>
</tr>
</tbody>
</table>

Spectrophotometric values in the UV at 232 and 270 nm depend on conjugated double bonds derived from oxidation (they are therefore quality indicators) or from refining (therefore, they are also authenticity indicators).

during processing and storage. Olive oil producers should concentrate on the quality standards presented in Table 2.1, making a coherent decision about the processing procedure and conditions according to the level of quality they want to achieve.

Free acidity

Hydrolysis of triglycerides due to lipolytic enzymes (lipases) causes free fatty acids and monoglycerides or diglycerides to be released from the triglycerides. The products of the lipolytic reaction are tasteless and odourless and therefore no sensory defects can be perceived. Hence, it is not correct to refer to ‘acidity’ as a flavour sensation of an olive oil. Sometimes, the sensation of pungency is mistakenly interpreted as ‘acidity’.

The lipolytic reaction is due to the endogenous lipases that are naturally present in the olive. When the integrity of the olive is lost due to mechanical action, lipases that are present in the pulp or in the seed cells come into contact with the oil, originally contained in specialized vacuoles. At this point, lipolysis starts and free fatty acids are produced. The reaction accelerates with increase in temperature and is a function of the time of contact between the lipases and the oil. Lipases are hydrophilic and they are active only in the presence of an aqueous phase. When water is separated, by decanting and centrifugation, lipolysis slows down or is totally stopped if the water and cell residues are completely separated from the oil. This is the reason why filtering the oil, removing the suspended materials and partially reducing the amount of water, is important.

In any case, the lipolytic reaction due to the endogenous lipases in the olives is relatively slow. Oil obtained from healthy fruit, regardless of the cultivar and processed just after harvesting, have very low values of free acidity. Free acidity rapidly increases in the presence of moulds and micro-organisms, which produce large quantities of very active lipases (exogenous lipases). In broken, dirty, unhealthy
olives, lipase activity causes a rapid increase in free acidity beyond the limits for extra-virgin or virgin olive oils, with an obvious loss in quality and value. A further and very rapid acceleration of this reaction takes place due to olive fly attacks. The intestines of the olive flies and their excrement, in fact, contain very high concentrations of lipases that cause a very rapid increase in free acidity. It is most unfortunate that this happens when the fruit is still on the tree. Thus at harvesting time, the damage has been irreversibly done. Other factors affecting the integrity of olives are attacks by parasites, mechanical crushing and bruising, extended contact with soil, delayed harvesting (over-ripeness), prolonged heaping and storage before processing.

Free acidity is expressed as the percentage of free fatty acids on the basis of oleic acid, which is the main fatty acid of olive oil. Each producer should be able to determine free acidity at the milling site, not only to verify the quality of the oil, but also to avoid mixing good and bad oil.

The legal limit of 0.8% for extra-virgin olive oil is not very demanding. A good oil should have a free acidity value less than 0.5% and an excellent oil less than 0.3%.

**Peroxide value and spectrophotometric absorption in the UV**

The two main spoiling reactions of olive oil are lipolysis and lipid oxidation. Lipolysis can be easily estimated as free acidity, but oxidation is more difficult and complex to evaluate.

Assessment of the degree of olive oil oxidation is based on determinations of both the primary and secondary products of oxidation. The primary stage of oxidation is the formation of hydroperoxides from polyunsaturated fatty acids, through a radical mechanism (see Chapter 6).

Peroxides are primary oxidation products and they are used as indicators of oil quality and stability. Their value increases, reaches a maximum and then decreases because of their further degradation into secondary products of oxidation such as aldehydes, ketones and conjugated dienes. These substances, that are formed at an advanced stage of oxidation, are responsible for the rancid flavour of the oil.

Thus, the peroxide value is a measure of the degree of oxidation of the oil at an early stage of oxidative spoilage, long before a rancid smell or taste becomes perceivable. An increase in the peroxide value should be considered as a warning signal that oxidation is taking place.

*Spectrophotometric values:* Specific absorbances (conventionally indicated as K) are measured in the UV region, at the wavelengths corresponding to the maximum absorption (about 232 and 270 nm) of secondary products formed in the autoxidation process. An increase in absorption at K_{232} and K_{270}, may also be due to the presence of conjugated dienes and trienes, which are formed in oils that have been heated during the refining process. Conjugated dienes contain two double bonds that alternate with single bonds. A conjugated triene contains three alternating double bonds.