

Adulteration of Olive (*Olea europaea*) Oil

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Goal: The goal of this bulletin is to provide general information about olive oil and possible causes of adulteration, mislabeling, counterfeiting, and fraud of the product. The guidelines for genuine olive oil are adapted from the International Olive Council (IOC; Spanish – Consejo Oleícola Internacional [COI]) and other legitimate, appropriate sources. The contents provide information on possible adulterants in olive oil, the underlying causes of adulteration, and how to test for the presence of these adulterants. The bulletin also serves as a summary of the relevant scientific information available, bearing in mind that the amount of published literature on olive oil is extensive. Data on trade and market dynamics are included. Extracts made from olive leaves, which are popular ingredients in dietary supplements, are not covered in this bulletin. Similarly, this bulletin will focus primarily on the current deceptive practices in the global olive oil trade rather than historical adulterations.

Definitions:

Olive: Olive is the fruit of the olive tree (*Olea europaea*, Oleaceae). The fruit is an oval-shaped drupe composed of a pericarp (skin and flesh) and the endocarp (seed or pit). The seed contributes 15-30% of the weight of the olive depending on the cultivar. The olive contains around 50% water and 20% oil, although these proportions vary widely among olive cultivars and the environmental conditions in which they are grown. There are many cultivars grown worldwide and although around 600 can be found in the literature, the precise number is unknown. IOC has published a World catalogue of



Olive *Olea europaea*
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Olive Varieties¹ describing 139 cultivars grown across 23 countries, which IOC claims represent almost 85% of the total world's acreage of olives.

Olive oil: Olive oil is the oil fraction of the olive fruit, i.e., pulp and seed. It is composed basically of triacylglycerols (triglycerides) with the predominant fatty acid being oleic acid (55-83%). The other major fatty acids include palmitic (7.5-20%), stearic (0.5-5%) and linoleic (3.5-21%). The oil contains some minor compounds including phytosterols, aliphatic alcohols, pigments, and a range of more polar phenolic compounds including hydroxytyrosol and tyrosol. Refined olive oils have considerably reduced levels of these minor compounds. A detailed description of the various olive oil grades is provided in section 1.9.

Pomace: Pomace is the solid waste material left after olive oil and water have been extracted by pressing or centrifugation of olives. Generally, the pomace contains 5-10% of the oil after centrifugation and may be further extracted using solvents.

1. General Information:

Unlike most vegetable oils, virgin olive oils (see section 1.9 for a description of various olive oil grades) are consumed in the unrefined state, having been simply mechanically separated from the olive fruit. While many seed and nut oils are extracted with solvents and refined to remove undesirable characteristics, the production of natural olive oil for sale as extra virgin oil is carried out without chemical or thermal processes to maintain flavor and nutritional benefits. As such, the yield is lower than for other plant species and the processing costs are much higher. Natural olive oils are therefore considerably more expensive than other edible oils and are subject to economically motivated adulteration (EMA) by blending with refined olive oil or by mislabeling poor quality oil as "extra virgin" olive oil (EVOO). EVOO is the highest quality grade among natural olive oils. Other adulterants are also used for EMA, including seed and nut oils or refined vegetable oils.

1.1 Common name: Olive

1.2 Other common names

Chinese: Gan (橄)

Danish: Oliven

Dutch: Olijf

French: Olive

German: Olive

Hindi: Jaitoon (जैतून)

Italian: Oliva

Japanese: Oribu (オリブ)

Portuguese: Oliva

Russian: Olivkovyy (ОЛИВКОВЫЙ)

Spanish: Oliva

Swedish: Oliv

1.3 Accepted Latin binomial: *Olea europaea* L.

1.4 Synonyms: None known

1.5 Botanical family: Oleaceae

1.6 Distribution:

The genus *Olea* includes about 35 species of evergreen shrubs and trees. *Olea europaea*, which is used for the production of olives and olive oil, has its origins in the Eastern Mediterranean region (region of Southern Turkey, Syria, Lebanon, Palestine, and Israel) and was slowly introduced to other regions westward along the Mediterranean coast. Olive trees were introduced to Spain and North Africa by Phoenicians in ca. 1000 BCE.³ Other than the Mediterranean countries, olive trees are now grown on the Arabian peninsula (Iran, Jordan, Syria, Israel, Tunisia), in South America (Argentina, Chile, Uruguay), China, the United States, and Australia.⁴ Additionally small scale cultivation is found in Mexico, South Africa, Japan, Peru, and Brazil.

1.7 Plant part and form:

Olive oil is extracted from olive fruit, pulp and seed. Traditionally, olives were harvested by hand and the fruit ground into a paste by millstones, left for 30-40 minutes to develop aroma and taste, and to let oil droplets form. Today, the fruit is hand-harvested less often except for small batch oil production and for fruit destined to be used for table olives.

Farmers traditionally harvest fruit from olive trees using a range of techniques including rakes, vibrating hand-held clamps or tree shakers. Today, in many cases, the fruit is removed using modern over-the-tree harvesters. The former methods cause the fruit to fall on the ground which may result in some damaged fruit. When the fruit is damaged, the level of free fatty acids in the oil increases which ultimately results in oil quality degradation. For EVOO the allowable free fatty acid content is limited to $\leq 0.8\%$ w/w.

The over-the-tree harvester gently removes the fruit by vibrating, flexible fingers.⁵ The fruit falls onto moving conveyor belts which transports it to storage bins on the back of trucks that follow the harvester. The trucks then transport the freshly harvested fruit directly to the processing mill. This method allows rapid harvest and transport of the fruit for processing within a few hours and little fruit damage.

The olives are harvested as the fruit starts turning from green to black. The best quality EVOO has a combination of green, partially ripe, and ripe fruit, giving the oil a complex flavor profile. When the olives are fully ripe (black in color), they have produced close to their maximum amount of oil but quality and shelf stability will be compromised due to the lack of antioxidants that remain in the oil.⁶ It is important that the fruit be processed quickly to avoid oxidation which diminishes the attributes of the oil. Fruit left in storage after harvest will deteriorate, producing fermentations that damage the oil flavor. High temperatures during processing or extended exposure to oxygen can increase oxidation and accelerate oil degradation.

The process of removing oil from the olive involves grinding the fruit to a paste in a mill, followed by stirring or malaxing. A malaxer is a machine with a large rotating stirring blade, used to gently fold the olive paste after the fruit has been ground or crushed in a grinder or hammer mill. This allows the oil to separate from the water and solids. The paste is then centrifuged, separating the oil from the solid waste (pomace), which is removed. The oil is allowed to settle in tanks to separate oil from any remaining water and remaining solid sediments, a process called racking. Some EVOO may also be filtered through a filter press. For optimal quality, the moisture and solids which can harm the oil quality and speed up degradation should be removed as soon as possible.

1.8 General use(s):

The vast majority of EVOO or virgin olive oil (VOO) is consumed as food, either for cooking at home or in commercial restaurants. Olive oil of various grades is used in packaged foods but also in cosmetics, soaps, and as an excipient in softgels (e.g., saw palmetto [*Serenoa repens*, *Arecaceae*] softgels) or in topical formulations such as lotions, creams, ointments, and lip balms. There are a small number of olive oil dietary supplements, which rely on data from epidemiological cohort studies and small clinical trials with EVOO as a food ingredient to support benefits for cardiovascular health, mainly due to improved lipid metabolism and anti-inflammatory activity.⁷⁻¹⁰

How olive oil is used depends on the grade or quality of the oil. EVOO, the highest grade with flawless flavor and highest nutritive value, is used almost exclusively for human consumption in food or in cooking to take advantage of the sensory qualities and health benefits. Other grades including virgin, ordinary virgin, refined, or blended oils are also used for human consumption. Virgin oils are used for cosmetics where antioxidants and anti-inflammatory trace components such as oleocanthal may be beneficial. Refined oil or blended oil may also be used in cosmetics where flavor is not important, although aromatics and actives may be of considered value. These refined oils have a reduced level of the minor compounds that are attributed to health benefits as well as the flavors and aromas of the natural product. The lowest grades, such as refined pomace oil, are commonly used in soap or lubricants. Lampante or crude pomace oils are not used for human consumption as these low grades tend to be rancid or have unpleasant flavors and odors and require refining before use. Once refined, these oils are often blended with other oils to make them palatable.

Data from Japan suggest that most (ca. 60%) of the olive oil is sold into the retail sector as olive oil for home use.¹¹ Approximately 30% of olive oil is used for food production (e.g., packaged seafood, dressings, sauces, mayonnaise), with lesser volumes (ca. 10%) used in cosmetic or pharmaceutical products.^{11,12}

1.9 Nomenclature considerations:

Olive oil by its simplest description is oil obtained from the fruit of the olive tree (*Olea europaea*). The oil is described in countless publications as having high nutritional value

and major health benefits for consumers.¹³ However, this literature often fails to describe the specific type of olive oil investigated, which are quite different in their characteristics. International standards, such as European Union (EU) Commission-delegated regulation,¹⁴ describe eight categories of olive oil, whereas IOC has categorized olive oil into nine distinct classes.¹⁵ Several countries have modified these standards to suit their own requirements.¹⁶ These classes are based on both the method of extraction of the oil from the fruit and on the quality of that oil. Initially, the oil is divided into two classes, virgin (or natural) oil and refined oil, and these have several subclasses within those two groups.

1.9.1 Virgin (or natural) olive oil

The initial division is based on extraction methods used and oil is classified as “virgin” olive oil when it is extracted from the fruit by mechanical means, in a way which will not alter the oil characteristics. This process excludes oils obtained using solvents or re-esterification processes and of any mixture with oils of any other kind or source. Modern methods of extraction of virgin oil involve washing, grinding or crushing the fruit, mixing or malaxing the paste, and then centrifuging to separate the oil from the pomace. This category, virgin olive oil, can be further divided, based on oil quality, into the following four groups:

1. *Extra virgin olive oil* must meet chemical and organoleptic limits. In particular, the free fatty acids (measured as oleic acid) must be less than, or equal to 0.8% w/w. In addition, the sensory requirements of this grade require that the oil have zero “defects” and positive attributes of fruitiness in excess of zero, based on sensory assessment.¹⁵
2. *Virgin olive oil* must have less than, or equal to 2.0% w/w free fatty acids. The sensory requirements are that the oil be between 0 to 3.5 defects, as described by the IOC and greater than zero for fruitiness.¹⁵
3. *Ordinary virgin olive oil* is a category used by IOC but not all countries use this grade. It describes virgin olive oil with a free fatty acid level of not more than 3.3% w/w.
4. *Lampante virgin olive oil*, also referred as “crude” in some standards,^{17,18} refers to any virgin olive oil exceeding the free fatty acid limits discussed above or has a peroxide value (a measure of vegetable oil rancidity) in excess of 20 millequivalents (mEq) peroxide oxygen per kg/oil per the IOC standard, while California’s standard lowers this value to 15. This oil is considered unfit for human consumption in this state and requires refining or is otherwise used for industrial purposes.

All grades of edible virgin olive oil should have a peroxide value of less than, or equal to 20 mEq peroxide oxygen per kg/oil. For lampante oil, there is no limit for peroxide value.

1.9.2 Refined olive oil

- *Refined olive oil*, sometimes called ‘Pure Olive Oil’, is olive oil suitable for consumption after it goes through a food grade refining process. Any process

used for refining must not alter the glyceridic structure of the oil. Due to refining, the free fatty acids content is low and for this grade must be no more than 0.3% by weight.¹⁵

- *Olive oil composed of refined olive oil and virgin olive oil*, is a blend of refined olive oil and virgin olive oil (other than lampante oil). In this case the free fatty acid must be not more than 1.0% by weight.¹⁵

1.9.3 Olive pomace oil

- *Crude olive pomace oil* is the oil extracted, using solvents such as hexane, from the solid waste, after producing virgin olive oil. The oil requires refining if used for human consumption. Otherwise it is used for industrial purposes.
- *Refined olive pomace oil* is obtained by refining crude olive pomace oil in a way that does not change the glyceridic structure of the oil. The free fatty acid concentration must not exceed 0.3% by weight.¹⁵
- *Olive pomace oil composed of refined olive pomace oil and virgin olive oils*. As the name implies, this grade of oil is a blend of virgin olive oil and refined olive pomace oil. The free fatty acid content should not exceed 1.0% by weight.¹⁵

2. Market

2.1. Importance in the trade:

Olive oil is often promoted as the healthiest of all of the edible oils. Olive oil has a high percentage of oleic acid. Additionally, because virgin olive oil is consumed in the crude state, without refining, the oil contains natural compounds such as phenolics, tocopherols and pigments,

which are removed to a large extent during refining.

The actual production volume of olives is small in relation to broad-acre crops like soybeans (*Glycine max*, Fabaceae) and canola/rapeseed (*Brassica napus* and other *Brassica* spp., Brassicaceae). However, as a result of the purported health claims and nutritional value, olive oil makes up a significant share of the financial market and the income of the major olive oil producing countries.

2.2 Supply sources:

Most of the olive oil supply comes from countries around the Mediterranean Sea. About 70% of global production originates in countries of the EU, with Spain being by far the largest producer, followed by Italy, Greece, and Portugal. Other countries providing substantial volumes include Turkey, Syria, and the North African countries Tunisia, Algeria, and Morocco.⁴ Of less significance are Libya, Lebanon, Israel, Jordan, Egypt, countries of the former Yugoslavia, Cyprus, Egypt, and Iran. Olives have spread from the Mediterranean Basin across the world with Argentina being one of the main producers. Australia, Chile, China, Japan, Mexico, South Africa and the United States also produce olives.

While much of the olive oil sold in retail is packaged in Italy, these seemingly Italian products often are blends of olive oils from various countries in the Mediterranean region.^{19,20} Similarly, Turkish military forces allegedly pillaged Syrian olive groves in 2018 to bring the olives to Turkey, where they were processed into oil and sold into the European Union as Turkish olive oil.²¹

2.3 Market dynamics:

While olive oil production has gradually increased from 2,206 million tons in the 1992/93 season to a projected 3,314 million tons in 2017/18, there is substantial fluctuation in the annual production. Supply shortages are usually due to poor harvests, particularly in Spain. In 2012, olive trees in Spain were exposed to an unexpected frost in the spring, combined with a severe drought later in the year,^{22,23} leading to a drop in olive oil production from 1,615 million tons in the 2011/12 season to 618 million tons in 2012/13.⁴ The consequences were an impressive increase in olive oil prices, reported to be over 60% in the months from July – September 2012.²³ A similar impact was observed after a drought hit the Andalusia region of Spain in 2014/15. In the same season, olive trees in Puglia, the main olive producing area in Italy, were affected by blight, again leading to a shortage in olive oil supply and a spike in prices.²⁴ The blight is caused by an infection with the bacterium *Xylella fastidiosa*, which colonizes the olive tree's water-conducting tissues, reducing water flow to leaves and branches, which eventually dry out and die.

Unscrupulous suppliers may “compensate” for supply shortages and price increases by diluting olive oil for packaged food with other vegetable oils, e.g., canola/colza/rapeseed (*Brassica napus*

Table 1. Total Global Production of Olive Oil (in 1,000 metric tons).

Country	2017/18	2018/19
European Union	2186	2219
Morocco	140	200
Turkey	263	183
Tunisia	280	120
Syria	100	100
Algeria	82.5	76.5
Jordan	20.5	24
Lebanon	17	24
Australia	21	21
Argentina	43.5	20
Egypt	28.5	20
Chile	20	20
Israel	17	16
Libya	18	16
United States	16	16
Albania	11	11
Palestine	19.5	10
Iran	5	9
China	6	6
Saudi Arabia	3	3
Montenegro	0.5	0.5
Uruguay	1	0.5
TOTAL	3314	3131

Adapted from the International Olive Council.⁴

subsp. *napus*, Brassicaceae), sunflower (*Helianthus annuus*, Asteraceae), or hazelnut (*Corylus avellana*, Betulaceae) oil, or with extracts from olive pomace. Price pressure on higher quality olive oils (virgin or extra virgin oils) means in turn that undeclared lower grade olive oils may be added in order to be competitive in the market. (L. Ravetti oral communication to S. Gafner, March 21, 2019)

2.4 Pricing

IOC provides average monthly prices at various sites in Europe. For refined olive pomace oil, wholesale prices in Spain ranged from US \$1.68-2.62/kg in 2018. Refined olive oil fetched US \$2.77-4.24/kg, while EVOO was sold at US \$3.04-4.42/kg.²⁵ EVOO prices in the United States fluctuated between approximately US \$2.80-5.80/kg from 2004-2014, with prices highest in summer 2006, and lowest in summer 2012. Apparently, this price drop was caused by the increased substitution of EVOO with lower grade olive oils in the USA, allowing suppliers to sell their merchandise at a lower cost.²⁶ Wholesale pricing for some other common vegetable oils is available from the US Department of Agriculture,²⁷ which lists the following costs (in US \$/kg) for 2018: Canola oil: 0.81-0.85; corn (*Zea mays*, Poaceae) oil: 0.58-0.68; cottonseed (*Gossypium* spp., Malvaceae) oil: 0.63-0.72; palm (*Elaeis guineensis*, Arecaceae) oil: 0.60-0.75; palm kernel oil: 1.23-1.40; peanut (*Arachis hypogaea*, Fabaceae) oil: 1.37-1.50; soybean oil: 0.60-0.68; sunflower oil: 1.16-1.22.

Retail pricing for all grades of olive oil in the US multi-outlet channel varied between US \$2.46-93.88/L* in April 2019. For the most commonly sold volume (500 mL), the costs varied between US \$6.83-83.03/ bottle, with an average price of US \$15.64 (± US \$8.83). The majority of these 500 mL products were offered at US \$9-15/ bottle. High-priced products represent gourmet oils which are produced on a small scale. (S. Gray [Boundary Bend] email to S. Gafner, April 10, 2019).

3. Adulteration

Adulteration of food worldwide is a major issue for health and safety. Numerous cases of food poisoning and health issues have been reported through mislabeling of food or blend-

* A liter of olive oil weighs approximately 920 grams (0.92 kg). The price range of US \$2.46-93.88/L includes units containing between 0.01-3.79 L.

ing with unacceptable components. Nestlé published a booklet on adulteration in which they describe two types of economically motivated adulteration, in contrast to contamination:²⁸

(a) the sale of food which is unfit for consumption including food past its “use by” date and

(b) deliberate mislabeling of food, such as products substituted with an undeclared lower-cost alternative.

Olive is listed in many publications, including the Nestlé publication, as one of the most commonly adulterated products. In fact, in a CBS News report,²⁹ olive oil was rated as the most adulterated of foods. This was further confirmed in the EU Committee on the Environment, Public Health and Food Safety Draft Report.³⁰

Within the EU report, it is made clear that the EU does not have an official definition of food fraud. Spink and



Olive *Olea europaea*
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Moyer²⁸ pointed out that the Food, Drug and Cosmetic (FD&C) Act explains “food adulteration” and “food misbranding” but the regulations do not define food fraud and economically motivated adulteration.³¹

The EU has concentrated more heavily on food safety with terms such as adulteration, authenticity, and mislabeling not clearly defined.³⁰ Recently, a European report has developed a hierarchical system to define the words describing or related to food fraud. The study produced a new standard for the European Committee for Standardisation (CEN), “CWA 17369:2019” titled “Authenticity and Fraud in the Feed and Food Chain”.³²

3.1 Known adulterants:

- a. The most valuable grade of olive oil is EVOO. The most common adulterant found in EVOO are inferior grades of virgin or refined olive oil, as these grades are often products which have failed either the chemical or the sensory (organoleptic) standard to meet the standards of the higher-priced EVOO. They may be blended with EVOO and marketed fraudulently as EVOO. Virgin or refined olive oil have a poorer flavor and a much lower level of the antioxidants for which EVOO is renowned and for which it is purchased. Consumers may think they are getting the organoleptic and nutritional benefits of EVOO, but they are actually consuming an inferior product.
- b. Other lower-cost virgin oil may also contain refined oil or pomace oil to obtain a greater financial return for the producer.³³⁻³⁵ In these cases, the adulterant may contain products from solvent extraction or refining that are not characteristic of olive oil, including traces of hexane solvent or trans fatty acids and glycidyl fatty acid esters. Trans fatty acids and fatty acid esters are generated at high temperature mainly during the deodorization process. Due to the carcinogenic property of glycidol, a tolerance value of 1ppm was recently established in Europe for food grade oils.
- c. Seed oils are significantly less expensive than olive oil and are commonly used as adulterants for EVOO or refined olive oil blends. The most common seed oils include canola/rapeseed/colza, sunflower, and soybean oils.³⁶⁻³⁸ Raids by the Spanish Civil Guard in 2012 and 2016 led to the arrest of several people that sold fake olive oil composed of a mixture of sunflower, palm, and avocado (*Persea americana*, Lauraceae) oils mixed with approximately 15% olive oil.^{39,40} The mixture of seed oils and EVOO produce a product that has a different fatty acid profile to that of EVOO. It is also likely to have reduced antioxidants, as seed oils are generally refined.
- d. Nut-based oils are also used to adulterate EVOO and refined olive oil blends. In particular, hazelnut oil has been reported to be used in blends with Italian olive oil.⁴¹ Hazelnut oil is a concern for authorities as it is difficult to detect levels of less than 10%

in EVOO.

- e. The green pigment, chlorophyll, is highest in newly extracted olive oil and gives the oil a fresh green appearance. This color is much lower or non-existent in refined or old oil. Chlorophyll can be chemically modified with copper to produce a pigment with a permanent green color and this can be added to old oil to give a perception of freshness and higher quality.^{36,39,42,43} Similarly, the orange pigment β -carotene has been found to be added to olive oil to impart a more desirable color.³⁶
- f. EVOO has a reasonably long shelf life when compared with other oils and will deteriorate over time as antioxidants are depleted and the peroxide value and free fatty acids increase. The useful life of EVOO can range from 12 to 24 months, depending on quality of the fruit and oil when it is pressed. This oil may be labeled with “use by”-dates in excess of the oil life, or the oil may simply be sold as EVOO even though its quality has diminished.⁴⁴ The sale of this oil is also fraudulent as it does not provide the health benefits and nutritive value expected of EVOO and declared on the label.

3.2 Sources of information supporting confirmation of adulteration

The adulteration of olive oil is not a new phenomenon; texts describing the substitution of olive oil with oils from poppy (*Papaver somniferum*, Papaveraceae) seeds, peanuts, sesame (*Sesamum indicum*, Pedaliaceae) seeds, or beech (*Fagus sylvatica*, Fagaceae) nuts date back to the 19th century.^{45,46}

In 1981, the death of more than 600 people in Spain was attributed to the consumption of a product sold as olive oil.^{47,48} Investigations led to the belief that it was actually canola seed oil which had been denatured by the addition of aniline to make it suitable for industrial use. Fraudulent operators had tried to refine the oil and had sold it as olive oil.

In 2007, an article on the olive oil trade in *The New Yorker* magazine described a shipping tanker in 1991 in Ordu, Turkey loading several hundred tons of hazelnut oil for which the ship’s official documents listed Greek olive oil. It was delivered to an Italian olive-oil producer and sold as olive oil.⁴¹

A major study from the University of California, Davis in 2010 illustrates the degree of fraudulent olive oil sales in the United States, the world’s largest importer of olive oil.⁴⁹ From 14 imported brands and five Californian brands of EVOO, purchased from retail stores in three regions of California, a total of 69% of imported olive oil samples and 10% of California olive oil samples, labeled as EVOO, failed to meet the IOC and California Olive Oil Council sensory (organoleptic) standards for EVOO. Many of these also failed either IOC ultraviolet (UV) tests and/or pyropheophytin (PPP) and diacylglycerols (DAG) limits. The report was questioned by various importers in defense of their product, and the study was repeated with more

stringent controls. In this study, five imported brands were sampled from each of 18 retail outlets. Of the five top-selling imported “extra virgin” olive oil brands in the United States, 66 of 90 of the samples analyzed again failed the IOC sensory standards for EVOOs analyzed by two IOC-accredited sensory panels.⁵⁰ Although EVOO deteriorates in store shelves if they are subject to light or have been exposed to high temperature, such as transportation in mid-summer, it is expected that the oil will be EVOO quality when consumed.

There is an abundance of published reports on olive oil adulteration over the past decade, which is often covered by the mainstream media based on evidence provided after olive oil analysis and subsequent regulatory actions by government authorities. The *Olive Oil Times*, a digital news outlet covering the olive oil sector, has an entire section devoted to olive oil fraud.⁵¹ Most of these cases involve the sale of lower grade olive oil as EVOO or virgin olive oil, or misrepresenting the country of origin.^{19,43,52-61} Other articles have reported on the sale of olive oil mixed with lower-cost vegetable oils,^{38,62-64} sometimes with the addition of chlorophyll, β -carotene, or other unidentified dyes.^{39,65}

In 2018, the Spanish company Dcoop was accused of blending canola and olive oil and selling it in the United States as Pompeian® brand.⁶⁶ The label on Pompeian OlivExtra Original bottles described the oil as “composed of 85% canola oil and “First Cold Press Extra Virgin Oil”. However, it is reported that the oil contained almost all Canadian canola oil with less than 1% being EVOO.

In April 2018, it was reported that Deoleo USA had paid seven million US dollars to settle a class action in California.⁶⁷ Deoleo had allegedly mislabeled Bertolli® olive oil as “Imported from Italy” whereas Deoleo imported olive oil from several countries including Morocco, Tunisia, Greece, and Turkey. Additionally, the oil failed to meet standards limit for EVOO up to the “best by” date.

3.3 Accidental or intentional adulteration:

Accidental mislabeling:

- a. Olive oil may be labeled as EVOO and marketed as such without testing. However, that oil may not meet the quality parameters of EVOO if the fruit was poor quality or the oil was exposed to poor storage conditions such as heat or light. To avoid this situation it is essential that olive oil be tested at the time of bottling, the oil properly stored, and the “use by” date determined to allow a sufficient margin of error to ensure the oil doesn’t deteriorate below the EVOO standard before it reaches that date.
- b. Even with proper storage, EVOO will deteriorate over time and the oil will lose the quality required of EVOO. Olive oil is influenced by temperature, light and oxygen. Proper storage includes packaging in airtight containers, preferably impervious to light and storing them in temperature controlled environments.⁶⁶ Although the reduction in quality may not be realized by the producer, the failure to analyze

the oil to determine its compliance is not an excuse for marketing olive oil as EVOO if it is not within specification.⁶⁸

There are instances where olive oil simply does not meet some international standards, not because the fruits are faulty, but because the standards do not allow for the environmental variations and cultivar differences.⁶⁹ Cultivars such as *Olea europaea* cv ‘Barnea’ have been found to contain higher levels of campesterol than is allowed in the IOC standards and would therefore be considered not to be olive oil. This is a problem which needs to be addressed by organizations that harmonize standards to allow for natural geographical variation.

Intentional adulteration:

Intentional adulteration is usually done for financial gain or, as commonly referred to, Economically Motivated Adulteration (EMA), as noted by the following examples:

- a. The addition of any category of olive oil other than EVOO to products labeled as being composed solely of EVOO.^{41,50,70,71} Common adulteration in this class include the addition of refined oil to EVOO. Pomace oil is sometimes added to EVOO to maximize financial returns.
- b. The addition of old and degraded oil, which may have previously been EVOO, added to EVOO product to use up old stock of that oil.^{50,71} This may be sufficient to reduce the blended product to a standard less than that of EVOO. However, it may be added at a level to keep the new product above the standard for certain parameters. In either case, the addition of these products is fraudulent. Additives, by definition, may not be added to EVOO.
- c. Seed oils such as sunflower, canola or soybean oils are broad-acre crops that are produced relatively inexpensively compared to olive oil (see section 2.4).⁶²⁻⁶⁵ Although the addition of such oils to olive oil is easy to detect, complete testing is relatively expensive and infrequently carried out. By adding a modest amount (for example 30%) of EVOO to canola oil, the resulting product can have the visual and sensory characteristics of EVOO. Without laboratory analysis, such as GC analysis of fatty acid profile, this will likely not be detected.
- d. Labeling a low-grade olive oil or a blend of anything other than EVOO as EVOO is intentional fraud. Most countries have regulations for labeling containers intended for direct sale to consumers. The IOC also provides guidelines for labeling. The label should contain the following:
 - The name of the product: EVOO, virgin olive oil, ordinary virgin olive oil, refined olive oil, olive oil, refined olive pomace oil, or olive pomace oil,
 - The country of origin,
 - Date marking and storage conditions,
 - Date of minimum durability (best before “date”).

3.4. Frequency of occurrence:

Olive oil is considered the world's most frequently adulterated food based on numerous publications and media reviews.³⁰

- The Organization of Consumers and Users (OCU), an independent consumer awareness organization in Spain, tests the top-selling EVOOs every five years and ranks them for quality. In 2018, 20 of 41 oils tested failed the sensory test for Extra Virgin. Some of the products labeled as EVOO were actually virgin or even lampante.⁶⁹
- *Choice* magazine, a consumer's guide published in Australia, had 50 supermarket oils (26 local and 24 imported brands) labeled as EVOO tested by the IOC-accredited laboratories in Wagga Wagga, Australia in 2017. The tests showed that 73% of Australian olive oils were extra virgin. Only 63% of the imported oils tested met all of the requirements for chemical, sensory, residues, and trueness to labeling.⁷²
- In 2016, the Italian Ministry of Health inspected 4158 samples of olive oil. The agents found that 11.8% of all products had irregularities, which, besides adulteration, included the use of undeclared food additives and the sale of counterfeit merchandise. Olive oil valued at €972,329 (corresponding to US \$1,078,410 using the exchange rate from June 30, 2016) was confiscated.⁶⁴
- Dr. Rüdiger Weißhaar, Chemical and Veterinary Investigation Office Stuttgart (CVUA), reported the results of a study conducted in 2015 of 266 samples labeled EVOO. CVUA, Stuttgart is one of 4 official food control and animal health laboratories of Baden-Württemberg, Germany. Of the 266 oils, 86 (32.3%) failed. For 33 samples (12.4%), there were deficiencies in labeling; 53 samples (20%) showed flaws in quality. Some oils were of such poor quality they were classified "lampante oil" and therefore considered inedible. In Germany, over 90% of all olive oils are marketed as EVOO.⁷⁰
- In a review of supermarket oils in Australia between 2008 and 2010, 265 retail samples, labeled as EVOO, were tested (127 Australian and 138 imported oils). In 2008, of the 97 samples tested, 46% failed international standards of IOC and Codex for EVOO. Again in 2009, from 98 samples 29% failed as EVOO. Similarly, in 2010, of 70 samples tested, 42% failed as EVOO.⁷³
- In 2019, Europol seized 150,000 L of low-quality sunflower oil, modified with chlorophyll, β -carotene, and soybean oil labeled as EVOO. The oil was destined for restaurants in Germany. Twenty people were arrested in a collaboration between the Italian police and the German Tribunal of Darmstadt.⁷⁴
- Several cases of olive oil fraud have been reported in the United States, including the study from the University of California, Davis in 2010 (see section 3.2)⁴⁹ in which 69% of imported olive oil samples and 10% of California olive oil samples, labeled as EVOO, failed to meet the IOC sensory standards for EVOO.
- Another significant US case was the consumer



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class action against Kangadis Food Inc., trading as The Gourmet Factory (“Kangadis”).³¹ Plaintiffs claimed that the company was selling Capatriti-brand “100% Pure Olive Oil” that was actually “olive-pomace oil,” “olive-residue oil,” or “pomace.”

These examples are a mere few of the numerous global reports on olive oil.

3.5 Possible safety/therapeutic issues:

The death of over 600 people in Spain in 1981 was perhaps the worst outcome of oil adulteration in history. The condition causing the deaths was referred to as “toxic oil syndrome.” It is believed to have been the result of consumption of contaminated canola oil intended for industrial use. It was sold in Spain as “olive oil.”^{47,48}

Although such cases are extremely rare, it does show the possible outcomes of blending foreign products with olive oil, or any foodstuff, without indicating on the label what the product actually contains. Illness from adulteration of olive oil with other oils, or even oil that has passed its “use by” date is unlikely to occur. However, dilution of olive oil with olive pomace oil may lead to a higher exposure to carcinogenic polyaromatic hydrocarbons (PAHs). PAHs are not yet regulated in the United States. In Europe oils and fats for human consumption are limited to less than 2.0 ppb of benzo(a) pyrene and 10.0 ppb sum of benzo(a) pyrene, benzo(a)anthracene, benzo(b) fluoranthene, and chrysene. The increase in PAHs is dependent on the drying method of the olive pomace, and the solvent used for extraction.⁷⁵

A more common issue with adulteration of olive oil is the dilution or loss of nutritionally beneficial components of olive oil, for which the public purchases the product. The health benefits of EVOO have been published widely (see section 1.8). Consumers of olive oil mixed with refined olive or seed oils, which contain very little of these beneficial nutrients, are unknowingly not getting what they have paid for.

Although the effects of consuming rancid oil have not been studied in detail, there may be some adverse effects on human health.⁷⁶ No studies evaluating the impact of rancid olive oil to humans have been retrieved, and thorough assess-

Table 2. Analytical Methods and References for EVOO as Described by the International Olive Council.⁸⁰

Number	Title
1	Determination of the free acidity according to COI/T.20/Doc. No 34/Rev.1, “Determination of free fatty acids, cold method”
2	Determination of the peroxide value according to COI/T.20/Doc. No 35/Rev.1 “Determination of the peroxide value”, ISO 3960, or AOCS Cd 8b-90
3	Determination of the fatty acid composition and <i>trans</i> fatty acid content according to COI/T.20/Doc. No 33/Rev.1: “Determination of fatty acid methyl esters by gas-chromatography”
4	<i>Trans</i> fatty acid content (% <i>trans</i> fatty acids) C18:1 T C18:2 T + C18:3 T according to COI/T.20/Doc. No 33/Rev.1: “Determination of fatty acid methyl esters by gas-chromatography”
5	Determination of the sterol content and alcoholic compounds according to COI/T.20/Doc. No 26/Rev.3: “Determination of the sterol content and alcoholic compounds by capillary gas chromatography”
6	Erythrodiol and uvaol content (% total sterols) according to COI/T.20/Doc. No. 30/Rev. 1: Determination of the composition and content of sterols and triterpene diols by capillary column gas chromatography”
7	Determination of wax content by capillary column, gas-liquid chromatography according to COI/T.20/DOC. 18
8	Determination of the difference between the actual and theoretical ECN 42 triacylglycerol content according to COI/T.20/Doc. No 20/Rev.4, “Determination of the difference between actual and theoretical content of triacylglycerols with ECN 42”, or AOCS 5b-89
9	Determination of the stigmastadiene content according to COI/T.20/Doc. No 11/Rev.3, “Determination of stigmastadienes in vegetable oils”, or COI/T.20/Doc. no. 16/Rev.1, “Determination of sterenes in refined vegetable oils”, or ISO 15788-1 or AOCS Cd 26-96
10	Determination of the content of 2-glyceryl monopalmitate according to COI/T.20/Doc. No 23/Rev.1, “Determination of the percentage of 2-glyceryl monopalmitate” or to ISO 12872
11	Determination of the unsaponifiable matter according to ISO 3596, “Determination of the unsaponifiable matter – Method using diethyl ether extraction”, or AOCS Ca 6b-53 or ISO 18609. The results should be expressed in g unsaponifiable matter/kg oil
12	Determination of the content of waxes and alkyl esters according to COI/T.20/Doc. No 28/Rev.2, “Determination of the content of waxes, fatty acid methyl esters and fatty acid ethyl esters by capillary gas chromatography”
13	Determination of the organoleptic characteristics according to COI/T.20/Doc. No 15/Rev.10, “Organoleptic assessment of virgin olive oil”
14	Detection of trace metals according to ISO 8294, “Determination of copper, iron and nickel by direct graphite furnace atomic absorption spectrometry”
15	Determination of the absorbency in ultra-violet according to COI/T.20/Doc. No 19/Rev.4, “Spectrophotometric investigation in the ultraviolet”, or ISO 3656 or AOCS Ch 5-91

ments of the health risks due to consumption of rancid oils are generally lacking. However, deteriorated olive oil has a reduced nutritional value compared to the genuine oil due to degradation of beneficial components such as the antioxidants and pigments,^{77,78} and the consumer is exposed to secondary products of deterioration caused by aging or by refining. These products of oxidation include a range of aldehydes responsible for the unpleasant odors of rancid oil.⁷⁹

3.6 Analytical methods to detect adulteration:

The monetary value of EVOO, and the economical rewards of adulteration, has led to a range of sophisticated methods of adulterating olive oil to avoid detection. The various forms of adulteration and/or fraud require an array of equally sophisticated tests to determine deviations from authentic products. Therefore, there are many tests utilized for specific purposes to determine if the oil is legitimate. The methods can be divided into various groups based on the type of fault. In many cases, it may be possible to target a specific problem to avoid the time and expense of doing all of the tests.

A summary of analytical methods to determine the grade of olive oil, or possible adulteration, is shown in Table 2 below. If a particular fault is perceived, the most relevant tests can be selected. Based on Table 2, those tests may reveal the following findings:

- **Oil produced from poor quality fruit or poor processing conditions:** If the fruit is damaged by disease, frost damage, insects or merely by harsh harvest and storage conditions, there will be an increase in free fatty acids and possibly increased peroxide value. In this case, tests 1, 2, 15 and DAGs would be employed.
- **Poor quality olive oil labeled as EVOO:** Olive oil has to meet certain criteria to be labeled as EVOO. In particular, it must meet the sensory requirements of fruitiness and no defects. It must also be within prescribed limits for free fatty acids, peroxide value and UV absorbency. Therefore, tests 1, 2, 13, 15, as well as PPP and DAGs, would be applied.
- **Refined olive oil labeled as virgin olive oil:** Oil is refined generally to remove undesirable components such as free fatty acids and peroxides, which are the result of the oil's deterioration. Refining may also be used to remove natural pigments and/or products which may give the crude oil unpleasant flavor or odor, as in the case of crude rapeseed oil. Refining generally has three steps: refining, bleaching, and deodorizing (RBD). These steps, particularly deodorization, involve application of heat to the oil. When oil is heated, there are some common changes which can be detected by testing. Fatty acids, which make up the majority of the oil, can change their configuration from cis to trans fatty acids. Heating also affects the amount of stigmastadienes[†] and the proportions of proportions of PPP[‡] and DAG in the oil. To determine the presence of refined oil, tests 4, 9, PPP, and DAG should be used.
- **EVOO mixed with seed and nut oils:** Seed oils are often refined and therefore tests applied to refined oil would also apply here. However, a more appropriate test would be to measure parameters specific for individual species. For example, the fatty acid composition and the sterol profile are generally good "fingerprints" for specific species. Canola oil, for example, has around 5-10% linolenic acid in the fatty acid profile whereas olive oil has less than 1% by IOC standards. Canola oil also contains a phytosterol named brassicasterol. Brassicasterol is not present in plant species other than those of the genus *Brassica* in the family Brassicaceae. A range of tests can be applied to determine the presence of seed or nut oils based on the fatty acid composition and sterols. These include tests 3, 5, 8, 9, 10, 11, and 15.
- **Solvent extracted oils including "pomace oil" and seed oils:** Solvent extraction, generally with hexane or a similar solvent, is a much more efficient extraction process than merely squeezing or centrifuging the olive paste. However, by definition, solvent is not permitted in EVOO extraction, and it requires heating to remove any residual solvent traces from the oil. No solvents or extraneous chemicals are permitted in the processing of virgin olive oil. As solvents remove additional compounds from the olive fruit not extracted by regulation methods, analysis for the presence of these compounds can show if solvents have been used. Only traces of wax from the fruit skin are extracted by mechanical means but the wax will dissolve in the extraction solvent. Oils containing excessive amounts of wax are obtained by solvent extraction. The pentacyclic triterpenes erythrodiol and uvaol are extracted from olive pits (seeds), and the presence of these compounds also indicates solvent extraction. Tests to determine solvent extraction include 6 and 7.
- **Old or badly stored olive oil sold as EVOO:** Oil degrades over time, and the by-products are generally similar to that seen in oils that have been heated.⁶⁸ Heating causes accelerated aging. Some of the tests used for refined oil can also be used to test for old, or badly stored, oil. Free fatty acids may increase slightly with time. Sensory characteristics will change with a decrease in fruitiness and an increase in defects as the oil becomes rancid. PPP and DAG proportions also change, and these tests are particularly useful to determine aging or poor storage conditions. Tests include 1, 2, 13,15, PPP, and DAG.

3.7 Additional analytical methods and references for

[†] Stigmastadienes are degradation products of phytosterols. In olive oil the most abundant is stigmasta-3,5-diene which is formed after dehydration of β -sitosterol.

[‡] Pheophytins are thermal degradation products of chlorophyll.

EVOO as described by the International Standards Organisation

Pyropheophytin and 1,2-diacylglycerol content:

Two methods published by the International Organization for Standardization (ISO) involve the determination of the proportions of PPP⁸¹ and DAG⁸² in virgin olive oil. A recent study highlights the value of PPP and DAG indicators of olive oil quality and freshness.⁷³ There is also a strong correlation with organoleptic defects. The measurement of pyropheophytins helps detect deodorized olive oils and, together with DAG, is effective in determining oil storage conditions and aging.

3.8 New analytical approaches not yet adopted by the mainstream olive oil manufacturing companies

Spectroscopic and chemometric methods: Numerous chemical methods for the detection of olive oil adulteration have been published over the past two decades. Infrared (IR) methods have the advantage of little to no sample preparation, and lower instrument costs compared to nuclear magnetic resonance (NMR) or mass spectrometric (MS) methods. Near-infrared (NIR) has been shown to detect adulteration with vegetable oils present at 1-10%, although such low detection levels are achieved only when a statistical model specific for a known adulterant is used.^{83,84} Unknown adulterants were detectable at 25% or higher.⁸⁴ Similar results were obtained using Fourier-transform (FT)-IR.⁸⁴⁻⁸⁶

The advantage of NMR is its versatility and the ability to obtain structural information of the compounds in the sample. Proposed methods use ¹H-NMR, ¹³C-NMR, ³¹P-NMR, or two-dimensional NMR to detect olive oil adulteration with lampante oils or vegetable oils.^{85,87-96} Dais and Spyros reported the addition of undeclared refined olive oil and vegetable oils (including hazelnut oil) at 5% or higher could be noticed using a combination of ¹H- and ³¹P-NMR with subsequent statistical evaluation.⁸⁷ Efforts to determine the geographic origin of olive oil by ¹H NMR with multivariate statistical analysis have shown promising results,^{61,97-99} leading to a proposition to create a ¹H-NMR-metabolic profiles database suitable for cultivar and/or geographical origin assessment.⁹⁷ Of interest for olive oil quality control is the availability of low-field benchtop NMR spectrometers, which can rival costs and adulterant detection capabilities of IR instruments.^{95,96} Several methods using MS without prior chromatographic separation have also been developed, including direct analysis in real time (DART)-MS, direct infusion, and headspace MS.¹⁰⁰⁻¹⁰⁴ These methods allow the detection of vegetable oils at 5% or higher. An important part of the spectrometric and spectroscopic methods is the use of appropriate statistical methods to enable accurate classification of the materials in question. A review of chemometric methods to measure olive oil authenticity has been published by Avramidou et al.¹⁰⁵

Another approach to detect adulteration and estab-

lish the geographic origin of olive oils is the measurement of the stable isotope ratios of carbon, oxygen, and hydrogen. This is most often done using isotopic ratio MS,¹⁰⁶⁻¹¹¹ but stable carbon and hydrogen isotope ratios can also be obtained by site-specific natural isotopic fractionation (SNIF)-NMR.¹¹² Camin et al. used the stable carbon, oxygen, and hydrogen ratios of 539 authentic Italian extra-virgin olive oils from 2000 to 2005 to build an Italian databank as a means to verify geoauthenticity.¹⁰⁸

Traceability: Despite the number of chemical and sensory analyses carried out on olive oil to ensure authenticity, fraud is still a major problem. Methods have been described that give some assurance of Protected Designation of Origin (PDO) of the oil in a fashion similar to that used for wine production. In providing detailed data on the site of production, crop size, the producer and other data, it is perhaps the best way to ensure other products are not mixed with the original product.

Variations to this methodology are described by individual companies such as Galpagro, a Spanish company focused on high-yield olive groves and Certified Origins Italia which describe the use of blockchain technology to trace all stages of EVOO production and distribution, from the olive tree to the consumer.¹¹³

Genomics: Many researchers have described the extraction of DNA from olive oil to authenticate the product on the basis of its genetic markers.^{114,115} Although the low amount of DNA and its poor quality are viewed as a limitation to these methods, new techniques have seen adequate quantities of good quality DNA extracted for analysis.^{115,116} Reports from the University of Évora describe a method using single sequence repeats (SSR) microsatellite markers for the identification of olive genotypes for the PDO and others using single nucleotide polymorphic markers.¹¹⁷ Rebai et al. have developed an SSR marker database for approximately 200 olive cultivars which can be used to authenticate olive oils.¹¹⁸

Other researchers have investigated the use of DNA barcoding or single nucleotide polymorphisms (SNPs) to verify the authenticity of olive oil.^{119,120} A comparison between a DNA barcoding approach using the *trnL* genomic region and fatty acid profiling using gas chromatography with a flame-ionization detector (GC-FID) gave similar results with regard to the detection of seed oil admixture, except that the genetic method was able to find admixture of hazelnut oil to olive oil, which went undetected by GC-FID.¹¹⁹

Despite the possibility of determining which cultivars were used to extract the oil, and the potential to determine approximate PDO, there are obvious limitations to these methods. Suppliers often sell blends of oil from many sources, and the DNA fingerprint would represent a range of cultivars from many sites and even countries. Additionally, the mixture of a refined seed oil with

virgin olive oil may not reveal the adulteration due to the limited DNA in refined oil. These methods need further verification.

International Standards: Each country may have its own definition of olive oil and its own limits for particular oil parameters and monitoring guidelines. Generally, these standards are based on the IOC and Codex standards¹⁶ but often there are alternatives. Individual standards include the following:

- *Codex Alimentarius:* Standard for Olive Oils and Olive Pomace Oils. CXS 33-1981. Adopted in 1981. Revised in 1989, 2003, 2015. Amended in 2009, 2013.¹²¹
- *European Union:* Commission Regulation (EEC) No 2568/91 of 11 July 1991 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. Consolidated version: 04/12/2016.¹²²
- *International Olive Council:* Trade Standard. COI/T.15/NC No 3/Rev. 11. 2016.¹⁵
- *United States:* Standards for Grades of Olive Oil and Olive-Pomace Oil.¹⁷
- *State of California:* Department of Food and Agriculture. Grade and Labeling Standards for Olive Oil, Refined-Olive Oil and Olive-Pomace Oil.¹⁸
- *Australian Standard:* Olive oils and olive-pomace oils. AS 5264—2011.¹²³
- *Argentina:* Código Alimentario Argentino. Capítulo VII. Alimentos Grasos. Aceites Alimenticios. Artículos 535 y 536.¹²⁴
- *South Africa:* South African National Standard. Olive oils and olive-pomace oils. SANS 1377:2015 Edition 1.¹²⁵
- *Brazil:* Ministério da Agricultura, Pecuária e Abastecimento. Gabinete do Ministro. Instrução normativa No 1, 30 de Janeiro de 2012.¹²⁶

In a comparison of international standards, grades, limits, and tests for several countries were identified.¹⁶ In many cases, olive oil might be accepted in some countries as EVOO but rejected in others. This lack of uniformity creates trade barriers and is a further complication in fighting fraud.

4. Conclusions

The adulteration of olive oil, particularly EVOO, is prolific because the financial gains are large and the availability of the highest grades low. Seed oils from broad-acre farming are relatively inexpensive due to the lower cost of production and the more efficient (solvent extraction) methods of processing. Lower quality olive oils are more abundant and cheaper to produce. There is a significant financial gain for fraudsters who might blend seed oils or refined/lower quality olive oils and sell them as EVOO. Because testing is sporadic and expensive, the chance of being caught is relatively remote and the potential consequences not severe under the law of most countries. Blending a small portion of aromatic EVOO with tasteless, colorless, refined seed oil can produce a product with some

sensory and visually characteristics that make it appear to be authentic.

Adulteration of EVOO with seed oil and/or refined and/or poor quality olive oil is not known to cause severe health issues (with the exception of the toxic oil syndrome cases in 1981). There is some evidence from animal studies of possible adverse effects, as discussed in section 3.5 of this document.⁷⁶ However, the main issue is more likely the decline in health benefits due to degradation of beneficial components of EVOO. The fact that adulteration is not perceived as a health issue is no doubt part of the reason authorities have largely ignored the olive oil adulteration problem because of higher priorities for other food safety issues. Only in recent years has any testing been done within the United States and even today there are very few laboratories qualified to test the authenticity of EVOO. The current standard for the United States was released as recently as 2010.

Despite this, consumers continue to buy olive oil for the perceived and documented nutritional benefits and for the sensory qualities of freshness and fruitiness. Clearly, a more determined global effort from authorities is required to overcome the corrupt practices. More testing of products, particularly from government facilities, is warranted to ensure the oils meet the expectations expressed on the label. There needs to be more government support in export/import situations and higher penalties for those that abuse the regulations.

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REVISION SUMMARY

Version # , Author,	Date Revised	Section Revised	List of Changes
Version 1, R. Mailer, PhD, S. Gafner, PhD	N/A	N/A	None