Report

Tests indicate that imported "extra virgin"olive oil often fails international and USDA standards

Frankel, E. N.; Mailer, R. J.; Shoemaker, C. F.; Wang, S. C.; Flynn, J. D.

July 2010

UC DAVIS OLIVE CENTER

Robert Mondavi Institute for Wine and Food Science
University of California, Davis

Tests indicate that imported "extra virgin"olive oil often fails international and USDA standards - UC Davis Olive Center, July 2010

AUTHORS

Dr. Edwin N. Frankel, Scientific Advisor. Dr. Frankel is among the world's leading authorities on lipid oxidation. An adjunct professor at the UC Davis Department of Food Science and Technology, he ranked in 2003-04 as the world's most-cited author of agricultural research by the Institute for Scientific Information. Most recently he has authored "Chemistry of Extra Virgin Olive Oil: Adulteration, Oxidative Stability, and Antioxidants," *Journal of Agricultural and Food Chemistry,* **2010**, *58*, 5991-6006.

Dr. Rodney J. Mailer, Co-Investigator. Dr. Mailer has been involved in olive research since 1996, and is the principal research scientist at the Australian Oils Research Laboratory in Wagga Wagga, NSW. He heads the laboratory's edible oil research program, which plays a leading role in national olive industry research, and is the Australian representative on the International Standards Organization (ISO) for Fats and Oils.

Dr. Charles F. Shoemaker, Co-Investigator. Dr. Shoemaker is the co-chairman of the UC Davis Olive Center and a professor in the UC Davis Department of Food Science and Technology. He supervises the UC Davis Olive Oil Chemistry Laboratory. Dr. Shoemaker is a specialist in food emulsions, micelles, microemulsions, and food separations.

Dr. Selina C. Wang, Co-Investigator. Dr. Wang received her Ph.D. in Chemistry from UC Davis in 2008. She has since lectured for the UC Davis Department of Food Science and Technology and is a research associate at the UC Davis Olive Oil Chemistry Laboratory.

Dan Flynn, Consultant. Mr. Flynn is the executive director of the UC Davis Olive Center, the only center of its kind in North America. He leads the center's efforts to promote research and education.

We are grateful to Corto Olive, California Olive Ranch, and the California Olive Oil Council for their financial support of this research. We value the leadership of Dr. Richard Cantrill, technical director of the American Oil Chemists' Society (AOCS); the advice of the AOCS Expert Panel on Olive Oil (particularly Bruce Golino, member of the board of directors of the California Olive Oil Council and Paul Miller, president of the Australian Olive Association) and the expertise of Leandro Ravetti, senior horticulturalist and olive specialist at Modern Olives in Australia.

The authors thank Dr. Mike Clegg (laboratory technician); Theresa Leung, Angelina Sansone, and Hanjiang Zhu (graduate student assistants); Jenna Zhang (undergraduate student assistant); and students from UC Davis Extension for assisting in this project.

CONTENTS

Tests indicate that imported "extra virgin"olive oil often fails international and USDA standards - UC Davis Olive Center, July 2010

EXECUTIVE SUMMARY

The UC Davis Olive Oil Chemistry Laboratory collaborated with the Australian Oils Research Laboratory to evaluate the quality of extra virgin olive oils sold on retail shelves in California. The two laboratories evaluated the oils based on standards and testing methods established by the International Olive Council (IOC) and United States Department of Agriculture (USDA), as well as several newer standards and testing methods adopted in Germany and Australia. These latter tests were adopted to help detect the adulteration of extra virgin olive oils with refined olive oils.

Our laboratory tests found that samples of imported olive oil labeled as "extra virgin" and sold at retail locations in California often did not meet international and US standards. Sensory tests showed that these failed samples had defective flavors such as rancid, fusty, and musty. Negative sensory results were confirmed by chemical data in 86 percent of the cases. Our chemical testing indicated that the samples failed extra virgin standards for reasons that include one or more of the following:

- oxidation by exposure to elevated temperatures, light, and/or aging;
- adulteration with cheaper refined olive oil;
- poor quality oil made from damaged and overripe olives, processing flaws, and/or improper oil storage.

Our laboratory tests indicated that nine of ten California samples were authentic extra virgin olive oils, with one California sample failing the IOC/USDA sensory standard for extra virgin.

Our laboratory tests indicated that the IOC and USDA chemistry standards often do not detect defective olive oils that fail extra virgin sensory standards. The IOC/USDA standards would be more effective in assessing and enforcing olive oil quality by including the German/Australian 1,2-diacylglycerol (DAGs) and pyropheophytins (PPP) standards. An elevated level of DAGs indicates that the samples were oxidized, of poor quality, and/or adulterated with cheaper refined oils, while an elevated level of PPP indicates that the samples were oxidized and/or adulterated with cheaper refined oils.

Specific findings of our tests include (see Table 3 for summary of results):

- 69 percent of imported olive oil samples and 10 percent of California olive oil samples labeled as extra virgin olive oil failed to meet the IOC/USDA sensory (organoleptic) standards for extra virgin olive oil. The Australian sensory panel found that each of these samples scored a median of up to 3.5 sensory defects such as rancid, fusty, and musty and were classified at the lower grade of "virgin." Sensory defects are indicators that these samples are oxidized, of poor quality, and/or adulterated with cheaper refined oils.
- 31 percent of the imported samples that failed the sensory standards also failed the IOC/USDA standards for UV absorbance of oxidation products (K232 and K268), which indicates that these samples were oxidized and/or were of poor quality.
- 83 percent of the imported samples that failed the IOC/USDA sensory standards also failed the German/Australian DAGs standard. Two additional imported samples that met the IOC/USDA sensory standard for extra virgin failed the DAGs standard.

- 52 percent of the imported samples that failed the IOC/USDA sensory standards also failed the German/Australian PPP standard. Two additional imported samples that had met the IOC/USDA sensory standard for extra virgin failed the PPP standard.

- The IOC/USDA chemistry standards confirmed negative sensory results in 31 percent of cases, while the German/Australian DAGs and PPP standards confirmed negative sensory results in 86 percent of cases.

INTRODUCTION

"Extra virgin" is the top grade of olive oil according to standards established by the International Olive Council (IOC) and the United States Department of Agriculture (USDA). In addition to establishing chemistry standards for extra virgin, the IOC/USDA have established a sensory standard — the oil must have zero defects and greater than zero fruitiness. Over the past several years, trained olive oil tasters who have served on IOC-recognized sensory panels have reported to the UC Davis Olive Center that much of the olive oil sold in the United States as "extra virgin" does not meet this modest sensory standard.

Moreover, there have been media reports of fraud in the olive oil business, where extra virgin olive oils have been adulterated with cheaper refined oils such as hazelnut oil. Another method is to adulterate extra virgin olive oil with cheaper refined olive oil, thereby making chemical detection of adulteration more difficult.[1]

In this report, the UC Davis Olive Oil Chemistry Laboratory collaborated with the Australian Oils Research Laboratory to evaluate the quality of extra virgin olive oils sold on retail shelves in California. The two laboratories evaluated the oils based on standards and testing methods established by the IOC and USDA as well as by several newer standards and testing methods adopted in Germany and Australia. The German government and the Australian Olive Association adopted these tests to help detect the adulteration of extra virgin olive oils with refined olive oils.

BACKGROUND

The IOC "is the world's only international intergovernmental organisation in the field of olive oil and table olives. It was set up in Madrid, Spain, in 1959, under the auspices of the United Nations."[2] The IOC's duties include adopting standards and quality-management guides for industry, developing chemical and sensory testing methods to assess olive oil quality, and providing official recognition to laboratories that demonstrate proficiency in employing the IOC's recommended testing methods.[3]

IOC member nations "account for 98% of world olive production, located primarily in the Mediterranean region."[4] The United States is not a member of the IOC, although the USDA recently adopted olive oil standards that closely correspond to the IOC standards, which will go into effect on October 25, 2010. The IOC/USDA olive oil standards include, among others, the grades of extra virgin, virgin, refined olive oil and "olive oil" (a blend of virgin olive oil and refined olive oil). [5]

---

[1] See for example, Mueller, Tom, "Slippery Business," *The New Yorker*, August 13, 2007; Orson, Diane, "Connecticut Puts the Squeeze on Olive Oil Fraud," National Public Radio, December 18, 2008; and Weise, Elizabeth, "Something Fishy? Counterfeit Foods Enter the U.S. Market, *USA Today*, January 23, 2009.

[2] International Olive Council (IOC) website (http://www.internationaloliveoil.org/), English version, viewed July 2, 2010.

[3] See IOC COI/T.15/NC No. 3/Rev. 4-November 2009 for olive oils standards; IOC COI/OT/NC No. 1-December 2004 for table olives standards; IOC COI/T.33/Doc. No. 2-4-2006, IOC COI/T.33-1/Doc. No. 2-2-2006, IOC COI/T.33-1/Doc. No. 4-2006, and IOC COI/T.33-2/Doc. No. 4-2006 for quality management guides; Table 1 for chemistry and sensory testing methods; IOC COI/T.21/Doc. No. 13/Rev.12-2009 and IOC COI/T.28/Doc. No. 3/Rev.12-2009 for recognition schemes and chemical and sensory testing laboratories, respectively.

[4] IOC website, Op.cit.

[5] See IOC COI/T.15/NC No 3/Rev. 4 November 2009 for IOC standards and USDA, "United States Standards for Grades of Olive Oil and Olive-Pomace Oil," *Federal Register*, April 28, 2010.

METHODOLOGY

Testing Methods. The analytical methods used in this study and described in Table 1 include the chemistry and sensory testing methods adopted by the IOC and USDA. The study employed additional testing methods to analyze olive oil quality, which are summarized in Table 2. These supplementary methods, which have not

Table 1. IOC- and USDA-adopted chemistry and sensory testing methods used in this study

IOC/USDA ANALYSIS	DETERMINATIONS	INDICATORS*	ANALYSES	EXTRA VIRGIN STANDARDS
Free Fatty Acids (FFA)	Free fatty acids are formed by the hydrolysis of the triacylglycerols in oils during extraction, processing, and storage.	An elevated level of free fatty acid indicates hydrolyzed, oxidized and/or poor-quality oil.	Analytical titration (AOCS Ca 5a-40).	Units: % as oleic acid. Limit: ≤ 0.8.
Peroxide Value (PV)	Peroxides are primary oxidation products that are formed when oils are exposed to oxygen, producing undesirable flavors and odors.	An elevated level of peroxides indicates oxidized and/or poor-quality oil.	Analytical titration (AOCS Cd 8b-90).	Units: mEq O_2/kg oil. Limit: ≤ 20.
UV Absorption (for conjugated double bonds)	Conjugated double bonds are formed from natural nonconjugated unsaturation in oils upon oxidation.	An elevated level of UV absorbance indicates oxidized and/or poor quality oil.	UV spectrophotometry (AOCS Ch 5-91).	Units: $K^{1\%}_{1cm.}$ Limits for K232, K268 and ΔK: ≤ 2.50, ≤ 0.22, and ≤ 0.01.
Stigmastadiene	Stigmastadienes are produced by thermal dehydration of *beta*-sitosterol, a natural sterol found in virgin olive oils.	An elevated level of stigmastadienes indicates adulteration with refined oil.	Gas chromatography (GC) (IOC COI/T.20/Doc No. 11-2001)	Units: mg/kg oil. IOC limit: ≤ 0.10 USDA limit: ≤ 0.15.
Fatty Acid Profile (FAP)	Fatty acids constitute the principal component of fats (saturated or unsaturated). Fatty acid profiles (FAP) are distinguishable markers between olive oils and some seed/nut oils (FAPs vary slightly depending on the varieties and growing region of olives).	Analysis of the fatty acid profile provides information on the authenticity of the olive oil; an indicator for adulteration with refined oils.	Gas chromatography (GC) (IOC COI/T.20/Doc No. 24-2001).	Units: % of total fatty acids. Limits: See Appendix.
Sterols Profile	Sterols are minor constituents of oils and are distinguishable markers between olive oils and some seed/nut oils.	Analysis of sterols provides information on the purity of the olive oil; an indicator for adulteration with refined seed/nut oils, although some sterol values may exceed IOC limits due to climate and olive varietal.	Gas chromatography (GC) (IOC COI/T.20/Doc No. 10-2001).	Units: % of total sterols (mg/kg). Limits: See Appendix.
Sensory (Organoleptic)	Sensory refers to taste, odor and mouthfeel.	Sensory assessment can help identify oils that are of poor quality, oxidized, and/or adulterated with other oils.	IOC-recognized panel of 8 - 12 people evaluates oils for sensory characteristics (IOC COI/T.20/Doc No. 15/ Rev. 2-2007, IOC COI/T.15/ NC No 3/Rev. 4, 11-2009).	Panel must find median of defects = 0 and median of the fruity attribute > 0.

***Hydrolyzed** means oils in which triacylglycerols have been broken down via addition of water.
Oxidized means oils that have become stale and rancid through oxidation, a chemical reaction that is promoted by heat, light, and/or age.
Refined means cheaper, lower-grade oils that are solvent extracted, thermally deodorized and bleached.
Poor quality means oils that were made from poor-quality olives, improperly processed, and/or improperly stored after processing.

Table 2. Other testing methods used in this study

OTHER ANALYSIS	DETERMINATIONS	INDICATORS*	ANALYSIS	EXTRA VIRGIN STANDARDS
Total Polyphenol Content	Polyphenols are important antioxidants that inhibit oxidation and improve the shelf-life of olive oils.	Polyphenol content decreases with prolonged storage, but because polyphenols are influenced by varietal, horticultural, and processing variables the content does not necessarily indicate oil authenticity or quality.	Modified Gutfinger (1981) method. Gutfinger, T. (1981). "Polyphenols in olive oils." *Journal of the American Oil Chemists' Society* 62: 895–898.	Units: mg caffeic acid/ kg oil. Limit: Extra virgin standards have not been established.
Triacylglycerols (TAGs)	Triacylglycerols are the principal components (98%) of olive oil consisting of an ester of three fatty acids and glycerol.	The triacylglycerols method is still being evaluated as an indicator of olive oil purity.	(Gas chromatography (GC) DGF Standard method C-VI 10b).	Units: % of total triacylglycerols. Limits: Extra virgin standards have not been established.
1,2-Diacylglycerol Content (DAGs)	During the breakdown of triacylglycerols, diacylglycerols are formed. Fresh extra virgin olive oil contains a high proportion of 1,2-diacylglycerols to 1,2- and 1,3-diacylglycerols, while olive oil from poor quality fruits and refined olive oil have elevated levels of 1,3-diacylglycerols.	The ratio of 1,2-diacylglycerols to 1,2- and 1,3-diacylglycerols is an indicator for oil that is hydrolyzed, oxidized, of poor quality, and/or adulterated with refined oil.	Gas chromatography (GC) (DGF Standard Method C-VI 16(06) – ISO 29822:2009).	Units: % total 1,2- and 1,3-diacylglycerols. Australian Olive Association (AOA) limit: ≥ 40.
Pyropheophytins (PPP)	Chlorophyll pigments break down to pheophytins and then pyropheophytins upon thermal degradation of olive oil.	An elevated level of pyropheophytins is an indicator for oil that is oxidized and/or adulterated with refined oil.	High performance liquid chromatography (HPLC) (DGF Standard Method C-VI-15(06) – ISO 29841:2009.)	Units: % total pheophytins. Australian Olive Association (AOA) limit: ≤ 15.

***Hydrolyzed** means oils in which triacylglycerols have been broken down via addition of water.
Oxidized means oils that have become stale and rancid through oxidation, a chemical reaction that is promoted by heat, light, and/or age.
Refined means cheaper, lower-grade oils that are solvent extracted, thermally deodorized and bleached.
Poor quality means oils that were (1) made from poor-quality olives, (2) improperly processed, and/or (3) improperly stored after processing.

been adopted by the IOC and USDA, are total polyphenol content, triacylglycerols (TAGs), 1,2-diacylglycerol content (DAGs) and pyropheophytins (PPP). Standards for DAGs and PPP were developed by the German Fat and Oil Society (DGF) and were recently adopted by the German government and the Australian Olive Association (AOA) as useful tools to assess olive oil quality.[6] Tests were performed "blind," without knowledge of brand name or origin, by research and technical personnel within the California and Australian laboratories.

Sample Collections. The UC Davis research team collected 14 imported brands and five California brands of extra virgin olive oils from three different regions of California (County of Sacramento, San Francisco Bay Area, and County of Los Angeles) from March 3, 2010 to March 10, 2010. A member of the research team purchased three bottles of each brand in retail stores in each of the three regions for each of the imported brands. A member of the research team purchased three bottles of each of the California brands in the

[6] The methods were developed in Germany by Dr. Christian Gertz at the DGF http://www.dgfett.de/. The DGF mission: "The DGF is the German network for science and technology of fats, oils and lipids. It will bring together professionals of science, technology and business together to promote scientific research and practical, to improve training and to facilitate information exchange." The DAGs and PPP standards must be met by members of the Australian Olive Association (AOA) to receive AOA certification for extra virgin olive oil. The AOA intends to propose that the DAGs and PPP standards be adopted by the Australian government.

Sacramento and San Francisco Bay Area regions only — the Los Angeles County locations did not stock the California brands. The Appendix includes a list identifying the supermarket purchase locations.

Australia Analysis. In March 2010, the UC Davis olive oil research project team shipped three samples of each imported brand and two samples of each California brand (one sample from each city in which the brand was purchased) to the Australian Oils Research Laboratory in Wagga Wagga, New South Wales. The samples were shipped by FedEx and were five days in transit. The laboratory is recognized by the IOC to provide chemical analysis of olive oil. The Australian laboratory directed the Australian Olive Oil Sensory Panel in Wagga Wagga to conduct sensory analysis of the samples. This panel is recognized by the IOC as qualified to provide sensory analysis of olive oil. The Australian Oils Research Laboratory used the chemical testing methods listed in Table 1 and Table 2 and the Australian Olive Oil Sensory Panel used the sensory methods identified in Table 1. Results from the Australian analysis are summarized in Table 3 and provided in their entirety in the Appendix.

UC Davis Analysis. The UC Davis olive oil research project team analyzed three regional samples of each imported brand and analyzed two regional samples of each California brand (one sample from each region in which the brand was purchased). The lot numbers for the UC Davis samples matched those of the Australian samples in almost all cases. The Appendix indicates the four instances in which the lot numbers were not identical. The samples were analyzed in the laboratory of Dr. Charles F. Shoemaker located on campus. The analytical team was supervised by Dr. Edwin N. Frankel, Dr. Selina C. Wang, and Dr. Charles F. Shoemaker. The UC Davis laboratory analyzed each of the samples using the testing methods identified in Table 1 and Table 2 except for the stigmastadiene, sterols, triacylglycerols (TAGs) and sensory methods. Some of the testing methods (total polyphenol contents and DAGs) are ongoing at UC Davis. The Appendix includes the results of the UC Davis analysis.

RESULTS

The Australian and UC Davis results are highly correlated for the samples with the same lot numbers. See Appendix for a comparison of the results of the two laboratories, and see Table 3 for a summary of the Australian results upon which we base the following findings:

- 69 percent of imported olive oil samples and 10 percent of California olive oil samples labeled as extra virgin olive oil failed to meet the IOC/USDA sensory (organoleptic) standards for extra virgin olive oil. The Australian sensory panel found that each of these samples contained a median of up to 3.5 sensory defects such as rancid, fusty, and musty and were classified at the lower grade of "virgin." Sensory defects are indicators that these samples are oxidized, of poor quality, and/or adulterated with cheaper refined oils.

- 31 percent of the imported samples that failed the sensory standards also failed the IOC/USDA standards for UV absorbance of oxidation products (K232 and K268), which indicates that these samples were oxidized and/or were of poor quality.

- 83 percent of the imported samples that failed the IOC/USDA sensory standards also failed the German/Australian DAGs standard. Two additional imported samples that met the IOC/USDA sensory standard for extra virgin failed the DAGs standard. An elevated level of DAGs indicates that the samples were oxidized, adulterated with cheaper refined oils, and/or of poor quality.

Table 3. Chemistry and sensory data provided by Australian Oils Research Laboratory

Brand Extra Virgin Standards*		PV (<20)	K232 (≤2.50)	K268 (≤0.22)	ΔK (≤0.01)	FFA (≤0.8)	Stigma (≤0.10)	Poly N/A	PPP (≤15)	DAGs (≥40)	Sensory Defects = 0 Fruitiness > 0
Filippo Berio	SAC	11	2.46	0.18	<0.003	0.30	<0.03	200	10.3	42.2	EXTRA VIRGIN
	SF	12	2.18	0.14	<0.003	0.37	<0.03	212	12.0	40.7	***VIRGIN***
	LA	11	2.12	0.15	<0.003	0.35	<0.03	247	13.7	42.0	***VIRGIN***
Bertolli	SAC	9	2.29	0.19	<0.003	0.41	<0.03	195	***17.8***	***38.1***	***VIRGIN***
	SF	9	2.24	0.16	<0.003	0.38	<0.03	266	14.3	***39.2***	***VIRGIN***
	LA	12	2.42	0.17	<0.003	0.32	<0.03	199	***20.8***	43.4	***VIRGIN***
Pompeian	SAC	11	2.50	0.19	<0.003	0.59	<0.03	132	12.1	***38.5***	***VIRGIN***
	SF	13	***2.60***	0.16	<0.003	0.51	<0.03	111	10.5	***31.5***	***VIRGIN***
	LA	13	***2.56***	0.17	<0.003	0.49	<0.03	188	***16.3***	***35.9***	***VIRGIN***
Colavita	SAC	8	1.97	0.13	<0.003	0.44	<0.03	268	1.4	72.9	EXTRA VIRGIN
	SF	11	2.13	0.15	<0.003	0.57	<0.03	189	12.8	***36.7***	***VIRGIN***
	LA	15	***2.88***	***0.25***	0.01	0.72	<0.03	156	***33.1***	***29.0***	***VIRGIN***
Star	SAC	9	2.29	0.15	<0.003	0.49	<0.03	194	12.8	***36.4***	***VIRGIN***
	SF	11	2.38	0.14	<0.003	0.47	<0.03	164	***17.7***	***33.7***	EXTRA VIRGIN
	LA	10	2.25	0.15	<0.003	0.45	<0.03	237	8.3	47.3	EXTRA VIRGIN
Carapelli	SAC	10	2.42	0.20	<0.003	0.49	<0.03	196	***30.6***	***29.4***	***VIRGIN***
	SF	10	2.43	0.21	<0.003	0.48	<0.03	208	***29.3***	***29.1***	***VIRGIN***
	LA	10	***2.65***	0.20	<0.003	0.45	<0.03	219	***17.2***	***39.2***	***VIRGIN***
Newmans Own Organics	SAC	10	***2.55***	0.20	<0.003	0.43	<0.03	165	13.7	***36.3***	***VIRGIN***
	SF	9	2.49	0.17	<0.003	0.42	<0.03	176	14.0	***35.5***	***VIRGIN***
	LA	9	2.36	0.17	<0.003	0.43	<0.03	211	9.8	***39.5***	EXTRA VIRGIN
Mezzetta	SAC	10	2.31	0.20	0.01	0.50	0.07	131	***18.4***	***32.2***	***VIRGIN***
	SF	10	2.33	0.18	<0.003	0.52	0.08	133	***16.6***	***31.0***	***VIRGIN***
	LA	11	2.34	0.17	<0.003	0.51	0.09	125	***16.8***	***32.5***	***VIRGIN***
Mazola	SAC	13	***2.65***	0.19	<0.003	0.65	<0.03	152	***21.7***	***31.4***	***VIRGIN***
	SF	12	***2.70***	0.19	<0.003	0.65	<0.03	159	***21.7***	***30.1***	***VIRGIN***
	LA	15	***3.14***	0.17	<0.003	0.50	<0.03	103	14.0	***39.0***	***VIRGIN***
Rachael Ray	SAC	10	2.42	0.21	<0.003	0.43	<0.03	258	12.9	***36.6***	***VIRGIN***
	SF	9	2.43	0.19	<0.003	0.41	<0.03	239	12.2	***36.3***	***VIRGIN***
	LA	9	2.08	0.15	<0.003	0.43	<0.03	324	2.0	72.1	EXTRA VIRGIN
Kirkland Organic	SAC	9	2.24	0.16	<0.003	0.33	<0.03	244	***16.7***	42.8	EXTRA VIRGIN
	SF	8	2.13	0.16	<0.003	0.26	<0.03	298	8.8	57.4	EXTRA VIRGIN
	LA	7	2.10	0.15	<0.003	0.27	<0.03	292	11.8	55.6	EXTRA VIRGIN
Great Value 100%	SAC	11	2.23	0.13	<0.003	0.35	0.05	161	12.4	45.3	EXTRA VIRGIN
	SF	11	2.23	0.13	<0.003	0.33	0.05	163	12.7	44.6	EXTRA VIRGIN
	LA	10	2.18	0.14	<0.003	0.57	<0.03	185	10.0	45.3	***VIRGIN***
Safeway Select	SAC	12	***2.74***	0.19	<0.003	***0.84***	0.03	141	***19.7***	***29.3***	***VIRGIN***
	SF	11	2.19	0.15	<0.003	0.58	<0.03	213	6.0	45.5	***VIRGIN***
	LA	11	2.20	0.15	<0.003	0.55	<0.03	219	6.1	47.9	EXTRA VIRGIN
365 100% Italian	SAC	11	1.95	0.15	<0.003	0.26	<0.03	112	***40.7***	***32.0***	***VIRGIN***
	SF	10	1.90	0.15	<0.003	0.28	<0.03	112	***40.8***	***31.2***	***VIRGIN***
	LA	10	2.14	0.14	<0.003	0.31	<0.03	140	12.4	53.8	EXTRA VIRGIN
Corto Olive	SAC	7	1.73	0.11	<0.003	0.19	<0.03	82	8.1	59.3	EXTRA VIRGIN
	SF	9	1.74	0.10	<0.003	0.20	<0.03	77	8.1	59.1	EXTRA VIRGIN
California Olive Ranch	SAC	9	2.19	0.12	<0.003	0.22	<0.03	109	11.9	52.0	EXTRA VIRGIN
	SF	9	2.19	0.13	<0.003	0.22	<0.03	102	11.9	52.9	EXTRA VIRGIN
McEvoy Ranch Organic	SAC	7	2.05	0.13	<0.003	0.16	<0.03	380	5.0	82.6	EXTRA VIRGIN
	SF	7	2.12	0.13	<0.003	0.16	<0.03	370	4.8	83.1	EXTRA VIRGIN
Bariani	SAC	8	2.18	0.13	<0.003	0.37	<0.03	373	7.5	64.8	***VIRGIN***
	SF	8	2.16	0.17	<0.003	0.38	<0.03	381	7.4	64.5	EXTRA VIRGIN
Lucero (Ascolano)	SAC	10	2.08	0.15	<0.003	0.28	<0.03	234	9.4	54.8	EXTRA VIRGIN
	SF	13	2.08	0.15	<0.003	0.30	<0.03	238	9.4	54.6	EXTRA VIRGIN

* IOC/USDA standards except Poly (no standards adopted) and DAGs and PPP (extra virgin standards adopted by Germany & Australian Olive Association only).

PV: Peroxide Value (mEq O_2/kg); K232, K268 and ΔK ($K^{1\%}_{1cm}$); FFA: Free Fatty Acids (% as oleic acid); PPP: Pyropheophytin A (% of total pheophytins); DAGs: 1,2-Diacylglycerols (% of total 1,2 - & 1,3-diacylglycerols); Stigma: Stigmastadiene (mg/kg); Poly: total polyphenol content (mg caffeic acid/kg).

- 52 percent of the imported samples that failed the IOC/USDA sensory standards also failed the German/Australian PPP standard. Two additional imported samples that had met the IOC/USDA sensory standard for extra virgin failed the PPP standard. An elevated level of PPP indicates that the samples were oxidized and/or adulterated with cheaper refined oils.

- All but one of the imported oil samples were well within the limit for free fatty acids (FFA). California oils generally had lower FFA values (0.16-0.38) than those of imported oils (0.26-0.84).

- In the sterol profile (see Appendix), one imported oil sample and one California oil sample slightly exceeded the IOC value for campesterol, although both samples were within the USDA standard.[7] Campesterol levels can vary based on olive varietals and climate.[8] In addition, one imported oil sample exceeded the IOC/USDA limit for diols.

- All samples were within the IOC/USDA limit for peroxide value (PV), ΔK, stigmastadiene, and fatty acid profile (FAP) (see Appendix for fatty acid profile results).

- If any of the samples were adulterated, it is most likely that the adulterant was refined olive oil rather than refined nut, seed, or vegetable oils. Unless the adulteration levels were very small, the failed samples would not have met the IOC/USDA standards for fatty acid profile and sterol profile if adulterated with refined nut, seed, or vegetable oils.

- The IOC/USDA chemistry standards confirmed negative sensory results in 31 percent of cases, while the German/Australian DAGs and PPP standards confirmed negative sensory results in 86 percent of cases.

CONCLUSIONS

Our laboratory tests found that samples of imported olive oil labeled as "extra virgin" and sold at retail locations in California often did not meet international and US standards. Sensory tests showed that these failed samples had defective flavors such as rancid, fusty, and musty. Negative sensory results were confirmed by chemical data in 86 percent of the cases. Our chemical testing indicated that the samples failed extra virgin standards for reasons that include one or more of the following:

- oxidation by exposure to elevated temperatures, light, and/or aging;

- adulteration with cheaper refined olive oil;

- poor quality oil made from damaged and overripe olives, processing flaws, and/or improper oil storage.

Our laboratory tests indicated that nine of ten California samples were authentic extra virgin olive oils, with one California sample failing the IOC/USDA sensory standard for extra virgin.

---

[7] USDA standards require further confirmatory tests for levels of campesterol between 4.0 and 4.5 percent.

[8] Aparicio, R., Ferreiro, L., and Alonso, V. "Effect of climate on the chemical composition of virgin olive oil." *Analytica Chimica Acta*, **1994**, *292*, 235–241 and Mailer, R. J. "The natural chemistry of Australian extra virgin olive oil," *RIRDC Report #DAN-239A*, **2007** Publication No. 06/132.

Our laboratory tests indicated that the IOC and USDA chemistry standards often do not detect defective olive oils that fail extra virgin sensory standards. The IOC/USDA standards would be more effective in assessing and enforcing olive oil quality by including the German/Australian DAGs and PPP standards. An elevated level of DAGs indicates that the samples were oxidized, of poor quality, and/or adulterated with cheaper refined oils, while an elevated level of PPP indicates that the samples were oxidized and/or adulterated with cheaper refined oils.

RECOMMENDATIONS FOR FUTURE RESEARCH

In addition to adopting the DAGs and PPP testing methods, the IOC/USDA standards would benefit from the development of improved chemical testing methods for extra virgin olive oils:

- Based on the literature,[9] analyses of TAGs by high-temperature gas chromatography (GC) do not agree with those by high-performance liquid chromatograpy (HPLC). Therefore, the GC analyses of TAGs should be supplemented by HPLC analyses.

- Supplement sensory testing by GC analysis of volatile flavor compounds in extra virgin olive oil to obtain more precise and diagnostic chemical information.

- Determine the effects of minor constituents, including chlorophylls, carotenoids and metal impurities, which decrease the oxidative stability of extra virgin olive oil. Many of the imported olive oil samples that we analyzed were partially oxidized and of poor quality.

[9] Resanka, I.; Mares, P. "Determination of plant triacylglycerols using capillary gas chromatography, high-performance liquid chromatography and mass spectrometry," *J. Chromatogr*. **1991**, *542*, 145–159 and Frankel, E. N. "Chemistry of Extra Virgin Olive Oil: Adulteration, Oxidative Stability, and Antioxidants," *J. Agric. Food Chem.*, **2010**, *58 (10)*, 5991–6006.