ARTICLE

Effect of Extraction Systems on the Quality of Virgin Olive Oil

L. Di Giovacchino*, M. Solinas[1] and M. Miccoli
Istituto Sperimentale per la Elaiotecnica, 65013 Cittá S. Angelo (PE), Italy

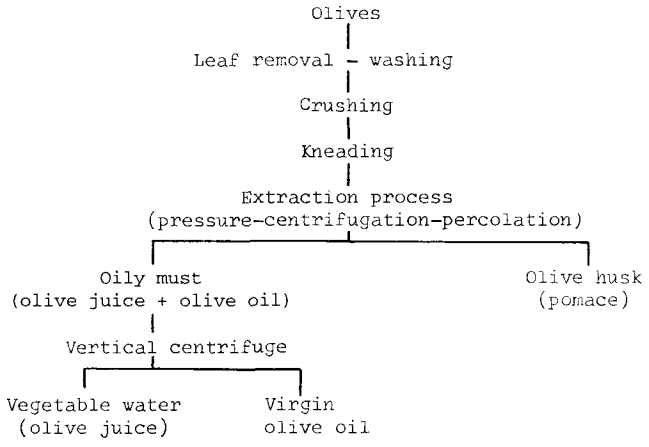
Research has been carried out to ascertain the effects of different processing systems on olive oil quality. Tests were performed in industrial oil mills that were equipped with both pressure and centrifugation systems. Results show that oils extracted from good-quality olives do not differ in free fatty acids, peroxide value, ultraviolet absorption and organoleptic properties. Polyphenols and *o*-diphenols contents and induction times are higher in oils obtained from good-quality olives by the pressure system because it does not require addition of water to the olive paste. The centrifugation system requires the addition of warm water to the olive paste and helps to obtain oils with a lower content of natural antioxidants. Oils obtained from poor-quality or from ripe olives in continuous centrifugal plants are lower in free fatty acids than those obtained by the pressure system.

KEY WORDS: *o*-Diphenols, olive oil, olive oil extraction systems, olive oil quality, polyphenols.

Olive oil is usually extracted with pressure and centrifugation systems in accordance with the diagram shown in Scheme 1. However, percolation systems can also be used to obtain oil from olive paste by dripping oil from a steel blade because there is a difference in surface tension between oil and water (1).

Olive oil extraction systems vary not only in the differences in physical forces necessary to separate the oil but also in the amount of water used.

A pressure system does not require addition of water to the olive paste. However, if ripe olives are processed in such a system, addition of small quantities of water (3–5 L/100 kg of olives) during crushing, kneading and washing of the tower after squeezing may be required. When the olives are difficult to process, and the oily phase does not separate easily from other phases, or when ripe olives are processed, it is necessary to add water to the oily must in the separation stage going to a vertical centrifuge. The oily must is a brown or black liquid consisting of olive juice (vegetable water) and olive oil.



SCHEME 1

The centrifugation system requires addition of warm water (60–80 L/100 kg of olives) to the olive paste to separate the oil from the other phases.

The percolation system does not require addition of water to the olive paste because the extraction of oil is more effective when olives have a lower water content (2).

Phenols present in olive paste are soluble in water and oil, depending on their partition coefficients and temperature. Addition of water to the paste alters the partition equilibrium between liquid phases and causes a reduction of phenol concentration through dilution of the aqueous phase. A coincident lower concentration of these substances occurs in the oily phase. The addition of water to olive oil removes water-soluble phenols.

The occurrence of phenols in virgin olive oil is an important factor in oil stability (3–5) and organoleptic quality (4). Natural phenols provide high resistance to oxidation, and a relationship between polyphenols content and oxidation stability has been reported for virgin olive oil (3–5).

Few studies have been conducted to evaluate extraction systems and their effect on the phenol content of the oil (6–10), and the results are conflicting and contradictory.

Our research was undertaken to determine the effects of extraction systems on oil quality parameters, including total polyphenols and *o*-diphenols contents, induction time and organoleptic evaluation. We also examined the effect of qualitative characteristics and olive ripeness on these parameters.

EXPERIMENTAL PROCEDURES

Olive oil extraction tests with pressure, centrifugation and percolation systems were performed during the 1991–1992 harvest season in an experimental olive oil mill equipped with industrial-size equipment.

Leafless olives from one lot (Table 1) were crushed with either a stone mill (pressure system), a mobile-hammer (percolation system) or a fixed-hammer (centrifugation system) metal crusher.

The following experimental procedures were followed. (i) Pressure: Olive paste was kneaded for 20 min at 22°C and then squeezed with a 16" superpress at 400 atm; the liquid obtained (aqueous and oily) was separated with an automated discharge vertical centrifuge. (ii) Centrifugation: Olive paste was kneaded for 60 min at 22°C and then diluted with water at 22°C (60–70 L/100 kg of olives); oil was extracted with a horizontal centrifugal decanter and liquid obtained was separated with an automated discharge vertical centrifuge. (iii) Percolation: Olive paste was kneaded for 60 min at 22°C and then percolated for 30 min; the oily liquid obtained was separated by an automated discharge vertical centrifuge.

Additionally, similar tests were performed in industrial oil mills equipped with both pressure (16" superpresses) and centrifugation equipment. Olives of the same lot (Tables 2 and 3) were processed with these systems at the

*To whom correspondence should be addressed at Istituto Sperimentale per la Elaiotecnica, Viale Petruzzi 37, 65013-Cittá S. Angelo (PE), Italy.
[1]Dr. Mario Solinas is deceased—May 23, 1993.

TABLE 1

Characteristics of Virgin Olive Oils Obtained from Good-Quality Olives with Three Experimental Extraction Systems

Determinations	System[a]	Mean[b]	Minimum	Maximum
Free fatty acids (%)	A	0.23a	0.18	0.28
	B	0.23a	0.20	0.27
	C	0.22a	0.16	0.28
Peroxide value (meq O_2/kg)	A	4.0a	2.8	5.5
	B	4.6a	3.9	5.3
	C	4.9a	4.0	6.3
Total polyphenols (mg/L as gallic acid)	A	158a	111	197
	B	157a	103	185
	C	121b	87	158
o-Diphenols (mg/L as caffeic acid)	A	100a	66	154
	B	99a	62	149
	C	61b	32	92
Induction time (h)	A	11.7a	8.7	16.4
	B	11.2a	8.9	15.0
	C	8.9b	7.4	10.9
Chlorophyll pigments (ppm)	A	5.0a	3.2	8.1
	B	8.9ab	5.7	18.5
	C	9.1b	6.5	13.7
K_{232}	A	1.93a	1.82	2.11
	B	2.03a	1.89	2.27
	C	2.01a	1.90	2.16
K_{270}	A	0.120a	0.110	0.132
	B	0.124a	0.110	0.132
	C	0.127a	0.090	0.153
Panel test	A	6.9a	6.2	7.4
	B	7.0a	6.7	7.2
	C	7.0a	6.7	7.2

[a]A, pressure; B, percolation; C, centrifugation.
[b]Values with the same letter are not significantly different ($P < 0.05$).

TABLE 2

Characteristics of Virgin Olive Oils Obtained from Good-Quality Olives by Different Industrial Extraction Systems

Determinations	System[a]	Mean[b]	Minimum	Maximum
Free fatty acids (%)	A	0.35a	0.18	0.63
	C	0.29a	0.16	0.57
Peroxide value (meq O_2/kg)	A	4.8a	2.8	7.1
	C	5.7a	4.0	9.0
Total polyphenols (mg/L as gallic acid)	A	155a	96	292
	C	114b	74	158
o-Diphenols (mg/L as caffeic acid)	A	106a	38	263
	C	62b	25	237
Induction time (h)	A	12.0a	8.7	16.4
	C	9.5b	7.1	14.5
Chlorophyll pigments (ppm)	A	6.6a	3.2	14.7
	C	9.9b	4.9	21.5
K_{232}	A	1.91a	1.69	2.11
	C	1.96a	1.65	2.16
K_{270}	A	0.108a	0.095	0.132
	C	0.122a	0.084	0.155
Panel test	A	6.9a	6.2	7.5
	C	6.9a	6.6	7.3

[a]A, pressure; C, centrifugation.
[b]Values with the same letter are not significantly different ($P < 0.05$).

TABLE 3

Characteristics of Virgin Olive Oils Obtained from Poor-Quality Olives by Different Extraction Systems

Determinations	System[a]	Mean[b]	Minimum	Maximum
Free fatty acids (%)	A	1.40a	1.15	1.59
	C	1.03b	0.71	1.19
Peroxide value (meq O_2/kg)	A	8.5a	4.6	11.1
	C	11.1a	6.1	13.3
Total polyphenols (mg/L as gallic acid)	A	87a	61	135
	C	91a	77	118
o-Diphenols (mg/L as caffeic acid)	A	67a	55	86
	C	66a	59	70
Induction time (h)	A	5.7a	4.5	9.1
	C	6.5a	5.0	8.8
Chlorophyll pigments (ppm)	A	6.6a	5.4	8.0
	C	4.9a	2.8	8.7
K_{232}	A	2.09a	1.74	2.39
	C	2.12a	1.80	2.32
K_{270}	A	0.128a	0.106	0.141
	C	0.140a	0.119	0.171
Panel test	A	6.2a	5.7	6.4
	C	6.5a	6.1	6.9

[a]A, pressure; C, centrifugation.
[b]Values with the same letter are not significantly different ($P < 0.05$).

same time according to the following procedures. (i) Pressure: Olives were crushed, with or without leaves, in a stone mill, and olive paste was kneaded for 20 min and then squeezed at 400 atm pressure; the tower was washed, and the aqueous and oily liquids obtained were separated with an automated discharge vertical centrifuge. Water was added in some instances to obtain a cleaner oil. (ii) Centrifugation: Leafless and washed olives were crushed with a stone mill or a fixed-hammer metal crusher; olive paste was kneaded for 60–90 min at 30–35°C, diluted with water (50–60 L/100 kg of olives) and then extracted with a horizontal centrifugal decanter; oil from the liquid obtained was separated by an automated discharge vertical centrifuge.

The ripening index (11) for each olive sample was determined.

On the vegetable water (olive juice) samples, diluted with methyl alcohol (1:4), the total polyphenols content (12), expressed as gallic acid; the *o*-diphenols content (13), valued with Arnow's reagent (14) and expressed as caffeic acid; and the anthocyanin content (15–16), expressed as cyanidin-3-rutinoside, were determined.

The following parameters were determined on olive oil samples: free fatty acids, peroxide value and ultraviolet (UV) specific absorptions (17), total polyphenols (18) and *o*-diphenols contents (14), induction time with a Rancimat 679 apparatus (19), chlorophyll pigments (20) and organoleptic evaluation (21).

RESULTS AND DISCUSSION

Analyses of oils extracted with the tested systems (pressure, percolation and centrifugation) are shown in Table 1. No significant difference in free fatty acids, peroxide value, UV absorption and organoleptic evaluation occurred, due to the choice of extraction system. These results confirm those reported in other studies (7); these parameters depend on the quality of the olives and on possible enzymatic alteration of olive fruits.

The natural antioxidant content of virgin olive oil is significantly affected by the extraction system (Table 1). Similar results have been reported in some studies (6–8), but others (10) are contradictory. Results show that total polyphenols and *o*-diphenols contents of olive oil extracted by centrifugation are significantly lower than those of oil extracted with either a pressure or percolation system. Low antioxidant level in oil extracted with a centrifuge occurs because water is used to dilute the olive paste before extraction with a centrifugal decanter. Water lowers the concentration of phenols in the aqueous phase because of dilution and diminishes the concentration of phenols in the oily phase because of the partition equilibrium. In either a pressure or percolation system, water is not added to olive paste.

Induction time is also significantly lower in olive oils extracted with a centrifugation system. Induction time is correlated with total polyphenols content, as shown in Figure 1.

Chlorophyll pigment content is higher in oil extracted from good-quality olives with centrifugation. A fixed-hammer metal crusher increases chlorophyll content.

Results of analyses of oils extracted from good-quality olives by pressure or centrifugation in industrial and experimental oil mills are presented in Table 2. These results also show that the processing method significantly affects natural antioxidants, chlorophyll pigment content and induction time of oils. This results from the addition of water to the olive paste and use of a metal crusher to crush olives prior to centrifugation.

Analytical data for oils industrially processed from poor-quality olives by pressure or centrifugation are presented in Table 3. Significant differences in free fatty

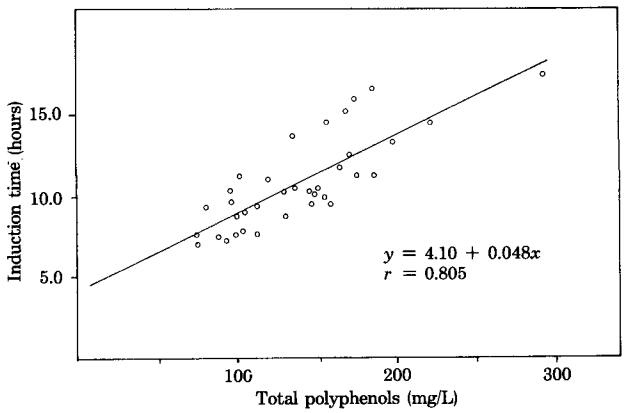


FIG. 1. Relationship between total polyphenols content (as gallic acid) and induction time for 36 virgin olive oil samples obtained from good-quality olives.

acids occur when oil is extracted with centrifugation. No significant differences were found in polyphenols and *o*-diphenols contents or induction times. These findings are consistent with those of other studies and show that low-quality olives yield better quality oil when processed with centrifugation (6,7). Oils from low-quality olives have a lower phenolic content, regardless of the extraction system employed (7).

To explain the differences that extraction systems exert on the antioxidant content (total polyphenols and *o*-diphenols) of oils obtained from olives of varying quality, it is helpful to compare the concentration ratios of antioxidants in vegetable water and olive oil. Results, presented in Tables 4 and 5, indicate that, in a pressure system the total polyphenol concentration ratio averages 44.7 and 110.7 for good-quality and poor-quality olives, respectively. Similar differences (31.9 and 54.4) have been observed with a centrifugation system. Ratios of *o*-diphenols

TABLE 4

Characteristics of Virgin Olive Oils and Vegetable Waters Obtained by Different Systems from Different Varieties of Olives

Olive varieties	Ripening index	System[a]	Total polyphenols		*o*-Diphenols		Anthocyanins
			Olive oil (mg/L)	Vegetable water (mg/L)	Olive oil (mg/L)	Vegetable water (mg/L)	Vegetable water (mg/L)
Good quality							
Dritta	3.2	A	96	4,275	38	3,900	82
		C	80	2,227	25	2,220	38
Dritta	3.0	A	136	4,840	75	4,110	48
		C	102	2,560	60	2,250	20
Peranzana	2.2	A	174	6,255	263	8,700	68
		C	156	5,130	237	6,060	56
Coratina	2.8	A	292	5,544	227	7,860	132
		C	150	3,555	47	3,810	48
Coratina	2.9	A	221	6,705	158	8,790	145
		C	146	3,465	35	3,480	42
Coratina	3.3	A	130	5,810	50	7,130	225
		C	99	3,240	30	2,790	64
Coratina	3.2	A	135	5,720	45	7,060	210
		C	94	3,398	27	3,090	70
Mixed	3.2	A	97	6,615	48	6,150	270
		C	74	3,578	40	3,810	109
Mixed	3.4	A	172	8,865	110	14,100	248
		C	149	4,477	71	4,800	108
Carolea	2.6	A	98	6,322	88	4,800	172
		C	75	2,853	57	2,520	76
Coratina Grossa Cassano	3.5	A	111	6,390	66	7,530	282
		C	87	3,105	50	2,910	108
Coratina	3.0	A	197	8,482	130	12,840	240
		C	158	4,567	78	4,740	87
Poor quality							
Cima Di Mola	5.4	A	135	9,900	86	13,560	2,260
		C	118	6,593	70	8,160	1,040
Oliarola Salentina	6.1	A	72	9,000	57	10,950	2,655
		C	77	5,130	69	6,900	1,125
Oliarola Salentina	6.2	A	61	9,090	55	13.050	2,890
		C	82	4,950	59	5,460	1,310
Cima Di Mola	5.8	A	80	7,659	71	8,880	1,875
		C	86	2,979	67	2,670	990

[a]A, pressure; C, centrifugation.

TABLE 5

Mean Ratios of Total Polyphenols and *o*-Diphenols Content (mg/L) of Vegetagle Waters and Oils Obtained by Pressure and Centrifugation Systems from Good- and Poor-Quality Olives

	Total polyphenols (vegetable water + oil)		*o*-Diphenols (vegetable water + oil)	
Extraction systems	Good-quality olives	Poor-quality olives	Good-quality olives	Poor-quality olives
Pressure	44.7	110.7	91.9	178.0
Centrifugation	31.9	54.4	72.1	87.2

TABLE 6

Variation of Some Characteristics of Virgin Olive Oil Obtained by Pressure System When Adding Water to the Oily Must During the Separation by Vertical Centrifuge

		Determinations		
Processing system	Water added to oily must (%)	Total polyphenols (mg/L)[a]	*o*-Diphenols (mg/L)[b]	Induction time (h)[c]
Pressure	—	156	68	9.8
Pressure	40	129	54	8.3
Pressure	80	115	46	8.0

[a]Expressed as gallic acid.
[b]Expressed as caffeic acid.
[c]Temperature = 120°C; air flow = 20 L/h.

concentration from good- and poor-quality olives have been measured at 91.9 and 170.0 with a pressure system, and at 72.1 and 87.2 with a centrifugation system.

These data show that significantly higher oil-soluble phenols are present in good-quality, not wholly ripe olives than in those of poor-quality or overripe ones. This is confirmed by measurement of the anthocyanin content of the vegetable water (olive juice) sampled during tests from both industrial and experimental oil mills. Results, reported in Table 4, show that large quantities of anthocyanin compounds are present in vegetable water derived from poor-quality and very ripe olives completely black in color, as shown by the ripening index reported in Table 4. Being soluble in water but not in oil, anthocyanins raise the total polyphenols content in vegetable water and, therefore, increase their concentration ratios.

Other factors reduce total polyphenols, *o*-diphenols content and induction time of virgin olive oil extracted by a pressure system. These include duration of the kneading process (8,22) and the addition of water during separation of the oily must. When using a pressure system, it is not necessary to lengthen the kneading time. Crushing olives with a stone mill, a process that takes 20–25 min with constant removal of the olive paste, has the effect of kneading (23).

When olives are difficult to process, of poor quality, very ripe or harvested with nets, water is added during the separation of oil by a vertical centrifuge from oily must to obtain cleaner oil. Addition of water dilutes the concentration of phenols in the vegetable water and also in the oil, due to the effect of the partition equilibrium law, as shown in Table 6. Experimental data indicate that, when separating the oily must with the addition of water equal to 40 and 80% of the volume of the oily must, total polyphenols and *o*-diphenols contents and induction times of the oil obtained are lowered almost to the levels of oils extracted by centrifugation.

Poor olive quality (including very ripe olives) and use of improper operating procedures in conjunction with a pressure extraction system (e.g., extended kneading time or addition of water during separation of the oil from vegetable water) might explain the different results obtained in other studies (10).

REFERENCES

1. Martinez Moreno, J.M., J.M. Martinez Suarez, C. Gomez Herrera, C. Janer del Valle, J. Pereda Marin and E. Munoz Aranda, *Grasas y Aceites 16*:223 (1965).
2. Di Giovacchino, L., *Riv. Ital. Sost. Grasse 63*:119 (1986).
3. Gutierrez, G.R., C. Janer del Valle, M.L. Janer del Valle, R.F. Gutierrez and R.A. Vazquez Roncero, *Grasas y Aceites 28*:101 (1965).
4. Vazquez Roncero, R.A., *Rev. Franç. Corps Gras 25*:21 (1978).
5. Chimi, H., A. Sadik, B. Le Tutour and M. Rahmani, *Ibid. 35*:339 (1988).
6. De Felice, M., T. Gomes and M. Catalano, *Riv. Ital. Sost. Grasse 56*:361 (1979).
7. Di Giovacchino, L., A. Mascolo, M. Solinas and F. Angerosa, *Proceedings of Third International Congress on Biological Value of Olive Oil*, Creta, 1980, pp. 627–633.
8. Montedoro, G.F. and M. Servili, *Proceedings of International Congress on Olive Oil Quality*, Firenze, Italy, 1992, pp. 97–108.
9. Mattei, A., C. Stella and M. Osti, *Riv. Ital. Sost. Grasse 65*:575 (1988).
10. Nergiz, C., and K. Unal, *J. Sci. Food Agric. 56*:79 (1991).

11. International Olive Oil Council, *Document No. 6*, October 8, 1984, Madrid.
12. Singleton, V.L., and J.R. Rossi, *Am. J. Enol. Vitic. 16*:144 (1965).
13. Nichiforesco, E., and V. Coucou, *Ann Pharm. Franç 23*:419 (1965).
14. Vazquez Roncero, A., E. Graciani Constante and R. Maestro Duran, *Grasas y Aceites 25*:269 (1974).
15. Ribéreau Gayon, P., *Tecnologie Alimentari 2*:17 (1979).
16. Vlahov, G., *Industrie Alimentari 29*:11 (1990).
17. *Official Methods of Analysis for Fats and Oils*, Instituto Poligrafico dello Stato, Roma, 1959.
18. Ragazzi, E., and G. Veronese, *Riv. Ital. Sost. Grasse 55*:19 (1973).
19. Laubli, M.W., and P.A. Bruttel, *J. Am. Oil Chem. Soc. 63*:792 (1986).
20. Wolff, J.P., *Manuel d'Analyse des Corps Gras*, Azoulay, Paris, 1968.
21. EEC Rule 2568/91.
22. Solinas, M., L. Di Giovacchino and A. Mascolo, *Riv. Ital. Sost. Grasse 55*:19 (1978).
23. Di Giovacchino, L., *Olivae 36*:14 (1991).

[Received September 20, 1993; accepted August 3, 1994]