

RESEARCH ARTICLE

Postextraction monitoring of dissolved oxygen in virgin olive oil

Piernicola Masella¹ | Giulia Angeloni¹  | Agnese Spadi¹ | Ferdinando Corti¹ |
Silvia Mingione² | Alessandro Parenti¹¹Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali (DAGRI), Università degli Studi di Firenze, Florence, Italy²OLITALIA S.R.L. via A. Meucci 22/a, Forlì, Italy

Correspondence

Giulia Angeloni, Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali (DAGRI), Università degli Studi di Firenze, Piazzale delle Cascine 15, 50144 Florence, Italy.

Email: giulia.angeloni@unifi.it

Funding information

OLITALIA S.R.L. (Forlì, FC, Italy)

Abstract

The issue of the presence of dissolved oxygen (DO) in virgin olive oil (VOO) is neglected in literature. Available information is limited to the extraction stage of the product life cycle, and studies focused on the subsequent stages from extraction to bottling are virtually absent. The present work aims to fill this gap through a dissolved oxygen monitoring experiment performed at industrial scale. Seven different unit-operations of the routine working procedure of an Italian industrial company specializing in the marketing of VOO were studied: oil discharge from tanker truck; blend formation; oil transferring to filtration; oil transferring to bottling; precoat-bodyfeed filtration; polishing filtration; bottling. The overall concentration of DO averages to 2.2 mg L⁻¹, while the oil incoming the company was at 1.5 mg L⁻¹. The unit-operations can be ordered as “mixing-for-blend > precoat-bodyfeed filtration > transfer-to-bottling > bottling,” with a decreasing oxygenation effect. Polishing filtration does not determine a significant DO variation. In the immediate term, the increase in DO does not result in oxidative deterioration of the oil, at least detectable with the peroxides value.

Practical Applications: The results provide important information for the management of virgin olive oil on an industrial scale in the postproduction stages up to bottling. First, it was clearly demonstrated that bulk transport operations led to oxygenation of the oil. From this point on, the oil underwent further oxygenation, the extent of which depends on the specific processing operation considered. The oxygenation effect of each operation is different, which means that different interventions with varying intensity in terms of complexity and cost could be applied on a case-by-case basis to preserve the oil from oxygenation.

KEYWORDS

bottling, filtration, oil mass transfer, oil processing, oils' mixtures formation, oxidation, oxygenation

1 | INTRODUCTION

It is widely accepted that oxidation of edible oil depends on the presence and availability of oxygen dissolving in the oil.^[1] Therefore, the greater the exposure of the oil to oxygen (i.e., greater concen-

tration in the headspace above the oil), the greater the amount of dissolved oxygen (DO).^[2] Consequently, other boundary conditions being equal (temperature, light, and presence of catalysts), the extent of oil oxidation is determined by the amount of DO. According to Przybylski and Eskin,^[3] DO is sufficient to bring about a relevant

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increase in the value of peroxides, such as an increase of about 10 meqO₂ kg⁻¹.

In addition, it appears that oxygen consumption by the oil is very rapid, with an average disappearance rate of about 0.1 mg L⁻¹ per hour, which also largely depends on the initial value of DO concentration (the higher the concentration, the higher the disappearance rate).^[2] At the same time, the rate of oil oxidation is sensitive to the initial DO concentration only below a certain amount, so a threshold effect is likely to occur.^[4,5] However, some authors point out that this effect also depends on the ratio of surface area to container volume for a given mass of oil.^[6,7] The basic mechanisms for oil oxidation are autoxidation and photosensitized oxidation, where the former is due to triplet oxygen and the latter to singlet oxygen. In both cases, lipid radicals are involved. This has been well established in the relevant literature.^[8,9]

Despite this body of knowledge, the measurement, monitoring, and management of DO during virgin olive oil (VOO) processing and storage through bottling are practices whose dissemination and study are rather limited, and the issue of DO is generally neglected. Data on oxygen solubility and measurement systems in VOO date back to the period between 1952 and 1983,^[10–14] with the exception of Fakhri et al.^[15] who recently proposed a current-based measurement method. Ninfali et al.^[16] studied the antioxidant capacity of VOO by ORAC assay. In that work, DO was also measured, but no correlation with ORAC was found. The authors concluded that DO probably affects the ORAC parameter only when long storage occurs. Ottaviani et al.^[17] measured DO in VOO samples, but did not investigate further. Sacchi et al.,^[18] comparing different packaging materials for VOO, concluded that oil shelf-life depends strongly on the initial variable amount of DO in the samples. The same conclusion was drawn by Del Nobile et al.^[19]

Literature works on the relationship between DO and virgin olive oil extraction process is even less numerous and mostly belongs to the research group of A. Parenti and P. Masella. In 2007, Parenti et al.^[20] evaluate the contribution of different processing steps in the mill to the amount of DO in the VOO produced. In 2009, Masella et al.^[21] further investigate the effect of vertical centrifugation on oil quality, emphasizing the role of DO. A few years later, the same authors propose the inertization of the vertical centrifuge to reduce the oxygenation of the oil,^[22] or the possible removal of DO from the oil by flushing with nitrogen.^[23] This aspect was also recently modeled.^[24] The feasibility of applying blanketing to the vertical separator was recently confirmed by Angeloni et al.,^[25] while Masella et al.^[26] showed that pumping the olive paste during the extraction process also affects the DO concentration in the extracted oil. Therefore, there is some information in the literature on the link between oil extraction or packaging and the presence of DO in oil.

However, beyond these references, to the best of the authors' knowledge, the product lifecycle stages from extraction to bottling have not been studied with regard to the presence and kinetics of DO. Several processes/operations can potentially affect the content of DO in the VOO just after the extraction. Oil transfer by mechanical pumping, tank emptying and filling, tank truck transportation, blending, stirring, filtration, and mechanical bottling

are routine operations involved in handling the product until final consumption.

Recently, the authors came into contact with an industrial company specializing in the marketing of VOO. Company personnel reported that they had observed some generalized oxidative decay, not directly explainable, in the quality of the processed oil masses. This evidence was inferred to be a consequence of uncontrolled oxygenation of the oil during the company's processing chain. Hence, a DO monitoring experiment has been set up to confirm the occurrence of the oxygenation event and to assess the relative contribution of the company routine operations involved in handling the product until bottling. The results of such experiment are documented in the present paper.

2 | MATERIALS AND METHODS

2.1 | Dissolved oxygen measurement

A polarographic sensor (Clark type) model InPro 6850i, from Mettler-Toledo S.p.A. (Milano, Italy) was used for DO determination. Main features of the sensor are as follows: working pressure 0.2–6 bar; working temperature 0–80°C with automatic self-compensation; electrodes are Pt (cathode, anode) with Ag as reference; detection limit of 0.0006 mg L⁻¹; accuracy of 0.0006 mg L⁻¹ + 1%. Based on the detection limit and accuracy value, the sensor can return reliable and stable data to the first decimal place of part per million, or 0.1 mg L⁻¹. The operating principle of the sensor is based on an amperometric measuring system, consisting of a working electrode (cathode), a counter electrode (Pt, anode), and a reference electrode (Ag). The measuring system is separated from the product under test by an oxygen-permeable membrane. The measurement technique is based on the measurement of electric current. Briefly, a transmitter (to which the electrode is connected) provides a constant voltage between the cathode and anode. The electrolyte contained in the membrane creates a conductive connection between the electrodes. Oxygen molecules migrate from the medium, through the membrane, to the cathode where they undergo reduction. At the same time, oxidation takes place at the anode. This causes a current flow between anode and cathode, which is directly proportional to the partial pressure of oxygen. Finally, the sensor uses a technology called ISM "Intelligent Sensor Management" by Mettler-Toledo S.p.A, which enables the sensor itself to convert the current into oxygen concentration and then communicate the value to the transmitter (details can be found here: https://www.mt.com/it/it/home/library/operating-instructions/process-analytics/BA_O2_Sensors_Inpro6850i.html).

For the latter, the M700X model (https://www.mt.com/dam/mt_ext_files/Editorial/Generic/3/BA_Transmitter_M700_X_0%D7;00001008409248704001c88d_files/ba_m700x_e_low.pdf) was used. The electrode just described was chosen on the basis of previous experiences in measuring DO on the olive oil matrix, based on the good level of accuracy, precision, and, above all, stability of the values read by the instrument. The same experiences also defined the need to operate the measurements on the moving product, that is, immersing the sensor in a mass of oil flowing at an almost constant flow rate.

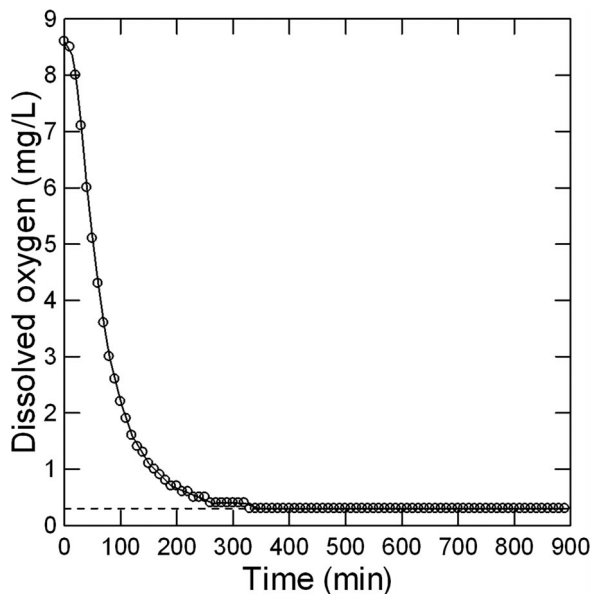


FIGURE 1 Example of dissolved oxygen (DO) measurement; the dashed horizontal straight line indicates a constant DO value.

For this purpose, a cylindrical-shaped flow cell (volume of about 100 mL) made of stainless steel was used, equipped with a housing for the sensor and two openings for the oil inlet and outlet (1/4" GAS inlet/outlet, model INFIT7XX). The pressure force required to move the liquid was obtained through an elevation difference (about 30 cm) between the vessel containing the oil sample to be measured and the cell itself, resulting in a flow rate of about 40 mL min^{-1} . For each sampling point, as will be defined later, oil was sampled in triplicate in plastic containers with a volume of about 3 L (three containers for each sampling point, 9 L in total), equipped next the bottom (about 5 cm from the base) with a valve for the oil to escape. The individual measurements (one independent for each sample, three measurement for each sampling point) were protracted for a defined time of 15 min, ensuring that a stable value was read for at least 2 consecutive minutes (Figure 1). The larger quantity of oil sampled than that actually used for measurement (about 600 mL out of the 3 L sampled in each vessel) had the significance, as did the triplicate sampling, of being able to obtain a sample as representative as possible of the mass of oil to be analyzed and to obtain a more reliable result.

2.2 | Oil analysis

Specification of the Commission Regulation No 640/2008^[27] was followed for peroxide value (PV) determination.

2.3 | Experimental procedure

The study was conducted on an industrial scale at an Italian olive oil processing company specializing in bottling and selling VOO. In the period of the trial, the company processed an average of 90 million liters per year. The routine working procedure of the company can be outlined as follows: procurement of oils from Mediterranean countries

and reception of oil masses by tanker transport; discharge of oil into tanks by mechanical pumping; oil transfers by pumping between tanks due to oil mass management; transfers and stirring for oil blends formation; precoat-bodyfeed filtration; polishing filtration; bottling. The storage capacity of the company was about 8.9 million liters. Basically, processing the oil involves transfers between tanks and/or to other processing lines (filtration, bottling). Mechanical pumps are used for the oil transfers, specifically gear pumps with a nominal flow rate of $30\,000\text{--}45\,000 \text{ m}^3$ per hour (Casali srl, Bologna, Italy). The pipeline system consists of steel pipes (diameter 75 mm) with an overall length from unloading to bottling (variable depending on oil handling and positioning in the plant) of 400 m. The maximum pumping height difference was around 8 m. The oil generally undergoes a main filtration treatment by means of a filter press model EXOOS (Italprogetti spa, Pisa, Italy) allowing for a precoat body-feed filtration (cellulose and perlite as filtration aid). A further filter press (Meccanica Spadoni Srl, Terni, Italy) is used for polishing filtration. The bottling stage is carried out with different lines of machinery: three glass lines for bottling and capping on various sizes from 0.5 to 1 L, two lines from CFT S.p.A (Parma, Italy) and one from Sasib S.p.A (Parma, Italy); two lines with PET preform blowing, filling and capping, on sizes from 0.5 to 5 L, plus can filling, both the lines by Kosme s.r.l. (Mantova, Italy). The main routine operations of the company were considered as sources of possible oxygenation of the oil and are referred to as "unit-operation" in the following. For each unit-operation, the oil was sampled before and after undergoing the corresponding operation. For example, for the unit-operation named "polishing filtration," the oil was sampled immediately before and after the filter press, to be analyzed on-site (i.e., within few minutes) for DO concentration. Within each unit-operation, the comparison between before and after was named operation-effect.

Specifically, the following unit-operations were considered:

1. Oil discharge from tanker truck into storage tanks by mechanical pumping (namely, discharge, 14 replicates);
2. Transfers and stirring for oil blends formation (namely, mixing-for-blend, 10 replicates);
3. Oil transfers from tank to filtration (namely, transfer-to-filter, 14 replicates);
4. Oil transfers from tank to bottling (transfer-to-bottling, 56 replicates);
5. Precoat-bodyfeed filtration by industrial horizontal filter press (namely, precoat-bodyfeed filtration, 10 replicates);
6. Polishing filtration by industrial sheet filter press (namely, polishing filtration, 10 replicates);
7. Bottling (namely, bottling, 34 replicates).

Further details on each sampling point are given in the results and discussion section, when useful to the discussion.

2.4 | Statistical analysis

Basic statistics were computed to describe the data (dissolved oxygen concentration, DO; temperature of measurement; peroxide value, PV). A general linear model was built to be analyzed with a two-way ANOVA

TABLE 1 Descriptive statistics computed over the aggregated data gathered during the experiment.

Statistical descriptors	Temperature	Dissolved oxygen
No. of cases (n)	148	148
Minimum (°C)	19.0	0.2
Maximum (°C)	24.9	6.3
Range (°C)	5.9	6.1
Arithmetic mean (°C)	22.4	2.2
Standard error of arithmetic mean (°C)	0.1	0.1
95.0% Lower confidence limit (°C)	22.1	2.0
95.0% Upper confidence limit (°C)	22.6	2.5
Standard deviation (°C)	1.4	1.5
Coefficient of variation (%)	10.0	70.0

with two sources of variation (namely, the investigated factors), the “unit-operation” and the “operation-effect,” and their interaction. When ANOVA gives significance, if useful, a Tukey’s Honestly Significance Difference post hoc test was applied for pairwise comparison of the mean. The operation-effect factor was further analyzed by a conventional paired *t*-test, where the unit-operation was the pairing criterion. Finally, Pearson’s linear correlation was computed to describe association between variables. In all the cases, probability of significance was set at $p \leq 0.05$, unless otherwise specified or reported.

3 | RESULTS AND DISCUSSION

The experiment lasted for about 300 days over two successive periods in 2020 (July to December) and 2021 (June to September). Seven different unit-operations were studied independently, by gathering samples before and after the corresponding processing stage, thus allowing the study of the operation-effect. In this way, 148 VOO samples total were analyzed for DO concentration on-site, meaning that the measurements were performed next to the processing lines, within few minutes after sampling. The number of replicates for each unit-operation depended on the willingness of the host facility (the oil processing company) on a case-by-case basis, and compliance with a robust representation of the company’s way of operating. The descriptive statistics reported in Table 1 have been computed over the aggregated data, without assigning the samples to a unit-operation (for instance samples from filtration) or by distinguishing in terms of operation-effect (i.e., oil sampled before and after the unit-operation). This is useful to get an overall idea about the behavior of DO during processing through bottling. On the average, DO amounts to 2.2 mg L⁻¹, with a range of 6.1 mg L⁻¹ between a minimum of 0.2 mg L⁻¹ and a maximum of 6.3 mg L⁻¹.

These data fit well with the results reported by Ninfali et al.,^[16] where DO values ranged from 2 to 7 mg L⁻¹ in bottled VOO samples collected from the market. Fakhri et al.^[15] measured substantially lower DO concentrations in VOO samples stored for several weeks in unopened bottles, with values ranging from 0 to 0.9 mg L⁻¹.

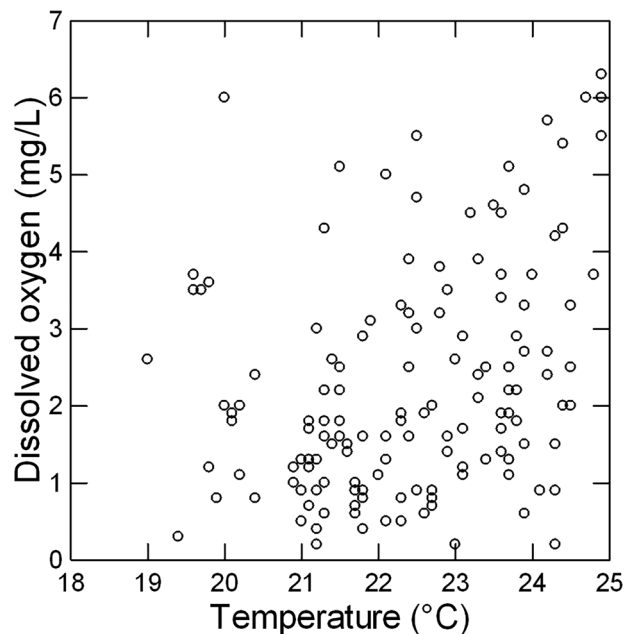


FIGURE 2 Scatter plot of dissolved oxygen (DO) versus temperature recorded during the measurement.

The magnitude of the range measured in the present work is reflected in the marked dispersion of values around the mean, as stated by a standard deviation of 1.5 mg L⁻¹ and a coefficient of variation of 70%. As will be shown below, this wide variation in the observed DO values depends on the extent of the oxygenation effect of the different operation-effect within each unit-operation. During DO measurement, temperature was also recorded, which, according to Table 1, averages about 22°C with little variation (in this case the coefficient of variation was 10%). This verifies the reliability of the measurements, as also confirmed by the result of linear correlation analysis performed between DO and temperature. In fact, according to Figure 2, DO values plotted against temperature are highly dispersed, almost randomly scattered over the whole field of values of temperature. This corresponds to an extremely low correlation coefficient ($r = 0.3$), indicating that the degree of closeness of the linear relationship between the two variables is very poor.

This finding is corroborating because of the expected inverse relationship between oxygen solubility and temperature, also confirmed by Fakhri et al.^[15]

The next step in data analysis has been the application of a general linear model where the source of variation are both the unit-operation factor (7 levels) and the operation-effect (2 levels), and their interaction. The analysis of variance of the model gives significance only for the two main effects ($p \leq 0.05$) (Table 2). The significance of the effect of the unit-operation factor mostly depends on the bottling operation, which shows a certain distance to the other unit-operation (Figure 3, left graph). However, when the paired comparison (Tukey’s Honestly Significant Difference) is applied, the bottling operation significantly differs only from the transfer-to-bottling ($p \leq 0.05$) and mixing-for-blend (p at 0.08). Graph on the right of Figure 3 clearly depict the significance of the operation-effect factor. So, these results seem to indicate that, beyond

TABLE 2 Output of the analysis of the General Linear Model (GLM) applied to dissolved oxygen data.

Source	Type III sums of squares	df	Mean squares	F-ratio	p Value
Unit-operation	31.88	6.00	5.31	2.60	0.02
Operation-effect	8.00	1.00	8.00	3.92	0.05
Interaction	1.74	6.00	0.29	0.14	0.99
Error	273.73	134.00	2.04		

the expected significance of the “operation-effect” factor, there is a general trend indicating a likely additive effect of oxygenation through the processing chain leading to an increase in the final DO concentration of the oil near or at bottling.

This aspect seems to be of paramount importance, since according to Sacchi et al.^[18] and Del Nobile et al.^[19] the amount of DO present in the oil at bottling is of primary importance in determining the subsequent shelf-life of the oil.

However, DO data were collected specifically to be analyzed robustly by a paired t-test, where the pairing criterion is the unit-operation and the effect of the operation is measured by the mean difference between before and after the specific operation (i.e., the operation-effect). Table 3 summarizes these results. Four out of the seven operation-effects give a significant oxygenation of the oil, with mean differences significantly different from 0. The mean difference ranges from a DO concentration of 0.33 mg L⁻¹ to a DO concentration 0.96 mg L⁻¹, for bottling and discharge operation-effect, respectively. Nevertheless, the latter effect has a low significance level, that is a *p* of 0.09, as well as the transfer-to-filter. Fairly similar mean differences were measured for mixing-for-blend and precoat-bodyfeed filtration, with values of 0.78 and 0.74 mg L⁻¹, respectively. However, the rela-

tive oxygenation effect, understood as the percentage deviation from the initial value, is very different across this two operation-effect, being worth about 65% for the mixing-for-blend, against 35% of precoat-bodyfeed filtration. The transfer-to-bottling has a relative effect of about 19%, while the lowest value belong to the bottling operation-effect with a percentage increase of about 12%. Thus, although the latter unit-operation is at higher overall value than the others (see Figure 3), its relative oxygenation effect is less pronounced than the other effects. Once again, it is supposable that an additive effect occurs during the oil processing from discharge to bottling, so that oil gains oxygen until the final treatment of bottling, but at the same time the relative effect of this last treatment is comparatively small. Interestingly the polishing filtration operation-effect was not significant (*p* at 0.29).

These results agree with the previous findings of Parenti et al.^[20] which clearly showed that the different mechanical operations performed during the oil extraction, starting from the olive paste management (malaxation) to the oil extraction and then cleaning by the vertical centrifuge, diversely affect the final DO in the oil. In particular, the latter step of vertical centrifugation had the higher oxygenation effect, followed by the decanter centrifugation and paste malaxation. Moreover, the authors showed that the extent of the mechanical action applied during the oil extraction does not allow to reach the theoretical solubility value of oxygen in the oil. Accordingly, the maximum DO concentration recorded in that work was of about 8–9 mg L⁻¹, close to the values of Ninfali et al.^[16] as well as the highest values reported by Fakhri et al.^[15] Interestingly, the latter authors reach the above-mentioned DO values only after an intense aeration of the oil. This is congruous with the average DO values recorded in the present paper, which are well below the cited values (i.e., about 2 mg L⁻¹ against 8–9 mg L⁻¹ on the average) with a maximum of about

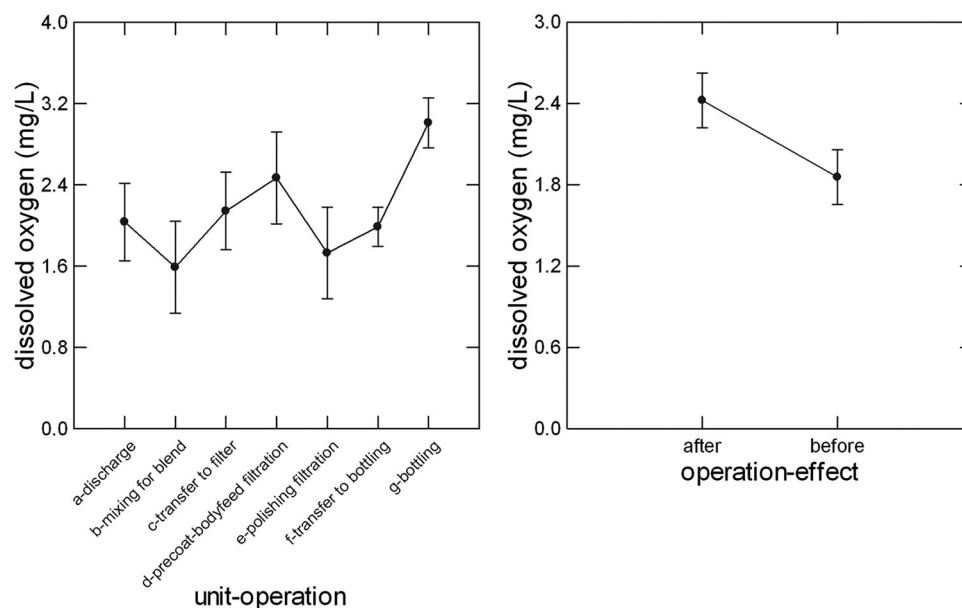
**FIGURE 3** Least square mean values of dissolved oxygen (DO), calculated using the GLM for the main effects of unit-operation and operation-effect factors. Error bars indicate the standard errors of the least squares.

TABLE 3 Results of the paired t-test applied to dissolved oxygen (DO) concentration data paired by the unit-operation.

Operation-effect on DO (mg L ⁻¹)	after ^a	before ^a	Mean difference	Standard deviation ^b	t	df	p Value
Discharge	2.51	1.56	0.96	1.26	2.02	6	0.09
Mixing-for-blend	1.98	1.2	0.78	0.41	4.27	4	0.01
Precoat-bodyfeed filtration	2.84	2.1	0.74	0.42	3.98	4	0.02
Polishing filtration	1.88	1.58	0.30	0.56	1.2	4	0.29
Transfer-to-filter	2.4	1.89	0.51	0.68	2	6	0.09
Transfer-to-bottling	2.16	1.82	0.34	0.61	2.93	27	0.01
Bottling	3.18	2.85	0.33	0.64	2.12	16	0.05

^aValues in column refer to average DO concentration measured before and after the indicated operation.

^bStandard deviation of mean differences.

6 mg L⁻¹. Compared to the oil centrifugation at the mill, it is reasonable to reach DO amount comparatively lower due to management practices such as transportation, pumping, filtration and bottling.

Finally, a tentative inference was made about oil oxidation due to the oxygenation effect. In fact, during the experiment, some of the sampled oils were analyzed for peroxide value (PV), an established index of primary oxidation of VOO. These samples were unevenly distributed among the unit-operations, as they were collected according to the availability of company personnel on a day-to-day basis. Nevertheless, they were whatever collected before and after the specific unit-operation. Once again, this allows for the estimate of the operation-effect. Following the same approach as above for DO, a general linear model has been applied for PV. In this case, analysis of variance did not provide model significance (*p* at 0.33, data not showed). An additional insight was attempted by studying the matrix of linear correlation between DO, PV, the DO mean difference (dDO), and the PV mean difference (dPV). According to Figure 4, linear correlations of DO are quite poor, with *r* values of -0.02 and -0.08 against dPV and PV, respectively. When the DO mean difference is considered, namely dDO, correlation with PV is even missing ($r = 0.00$). Interestingly, a positive correlation of a certain magnitude, however limited, exists between dDO and the correspondent PV variation (dPV), with a *r* of 0.26. Either way, these results confirm the observation of Ninfali et al. that in order to be able to find a link between the DO amount in the oil and the oil oxidation, a prolonged storage experiment should be considered.

This is in agreement with Parenti et al.,^[20] which found a faster oxidative decay of VOO with a greater initial content of DO during a controlled 18 months storage.

4 | CONCLUSIONS

Some important findings arise from the present work. First of all, for the first time, the presence of DO in VOO has been confirmed also in the stages of the product life cycle, which follow the oil extraction. A maximum concentration of about 6 mg L⁻¹ was measured, close to the 60% of the maximum concentration reported in literature and measured in the mill just after production.^[20] Also, the oil arrives at the

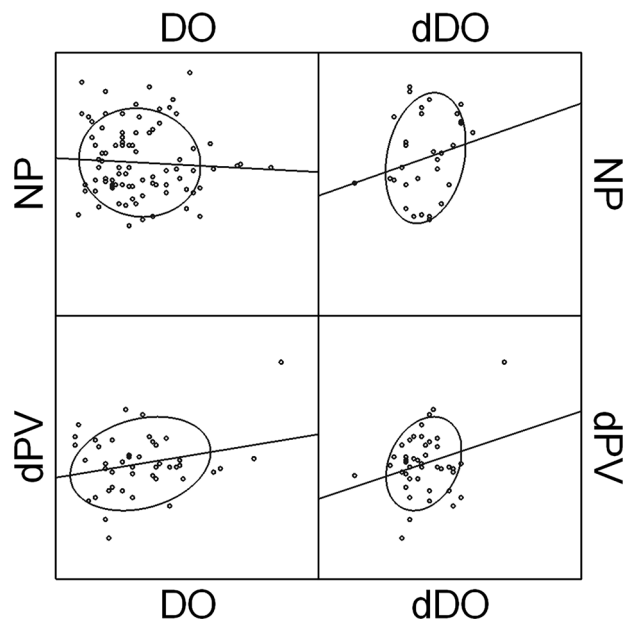


FIGURE 4 Scatterplot matrix of Pearson's linear correlations for dissolved oxygen (DO), peroxide value (PV), relative change in DO (dDO), and relative change in peroxide value (dPV).

company (that is before the unit-operation named discharge) with a load of DO of about 1.5 mg L⁻¹ with a great variation (coefficient of variation close to 90%). This inherited DO amount clearly depends on the transport stage and/or past treatments suffered by the oil. It is likely that the oil undergoes a cyclic oxygenation from extraction onward, because of the various manipulations it undergoes gradually in its life. A second important outcome lies in the fact that the different unit-operations considered in the present work differently contribute to the oil oxygenation. Specifically, with a decreasing oxygenation effect, the operations follow this order: "mixing-for-blend > precoat-bodyfeed filtration > transfer-to-bottling > bottling." Interestingly, the polishing filtration does not determine a significant DO variation, while the discharge operation against a very high average percentage change (roughly +60%) shows only a reduced significance (*p* at 0.09). The same holds true for the unit-operation named transfer-to-filter, which, however, shows a variation of +30%. Hence, it is possible to conclude that

the various stages of processing are susceptible of dedicated improvement to reduce the oxygenation effect, solutions spanning from a modified geometry of the piping system (overflow height, piping length and form), kind and management of the pumps, and implementation of inertization systems (either mechanical or by technical gases).

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The manuscript does not contain experiments using animals. The manuscript does not contain human studies.

ORCID

Giulia Angeloni  <https://orcid.org/0000-0002-4263-5827>

REFERENCES

- Choe, E., & Min, D. B. (2006). Mechanisms and factors for edible oil oxidation. *Comprehensive Reviews In Food Science And Food Safety*, 5(4), 169–186.
- Min, D. B., & Wen, J. Y. E. (1983). Effects of dissolved free oxygen on the volatile compounds of oil. *Journal of Food Science*, 48(5), 1429–1430.
- Przybylski, R., & Eskin, N. A. M. (1988). A comparative study on the effectiveness of nitrogen or carbon dioxide flushing in preventing oxidation during the heating of oil. *Journal of the American Oil Chemists Society*, 65, 629–633.
- Kacyn, L. J., Saguy, I., & Karel, M. (1983). Kinetics of oxidation of dehydrated food at low oxygen pressures. *Journal of Food Processing and Preservation*, 7(3), 161–178.
- Labuza, T. P., & Jr Dugan, L. R. (1971). Kinetics of lipid oxidation in foods. *Critical Reviews in Food Science & Nutrition*, 2(3), 355–405.
- Kanavouras, A., Cert, A., & Hernandez, R. J. (2005). Oxidation of Olive Oil under Still Air. *Food Science and Technology International*, 11(3), 183–189.
- Masella, P., Parenti, A., & Spugnoli, P. (2012). *Rivista Italiana delle Sostanze Grasse*, 89, 161.
- Psomiadou, E., & Tsimidou, M. (2002). Stability of virgin olive oil. 1. Autoxidation studies. *Journal of Agricultural and Food Chemistry*, 50(4), 716–721.
- Tsimidou, M., Papadopoulos, G., & Boskou, D. (1992). Phenolic compounds and stability of virgin olive oil—Part I. *Food Chemistry*, 45(2), 141–144.
- Battino, R., Rettich, T. R., & Tominaga, T. (1983). The solubility of oxygen and ozone in liquids. *Journal of Physical and Chemical Reference Data*, 12, 163–178.
- Battino, R., Evans, F. D., & Danforth, W. F. (1968). The solubilities of seven gases in olive oil with references to theories of transport through the cell membrane. *Journal of the American Oil Chemists Society*, 45(12), 830–833.
- Davidson, D., Eggleton, P., & Foggie, P. (1952). The diffusion of atmospheric gases through fats and oils. *Quarterly Journal of Experimental Physiology and Cognate Medical Sciences*, 37(2), 91–105.
- Ke, P. J., & Ackman, R. G. (1973). Bunsen coefficient for oxygen in marine oils at various temperatures determined by an exponential dilution method with a polarographic oxygen electrode. *Journal of the American Oil Chemists Society*, 50, 429–435.
- Rodnight, R. (1954). Appendix—Manometric determination of the solubility of oxygen in liquid paraffin, olive oil and silicone fluids. *Biochemical Journal*, 57(4), 661–663.
- Ben Fakhri, A., Artaud, J., Cano, G., & Moulin, P. (2023). Development of a measure cell to assess by amperometry dissolved oxygen in vegetable oils. *European Journal of Lipid Science and Technology*, 125, 2200120.
- Ninfali, P., Aluigi, G., Bacchiocca, M., & Magnani, M. (2001). Antioxidant capacity of extra-virgin olive oils. *Journal of the American Oil Chemists Society*, 78, 243–247.
- Ottaviani, M. F., Spallaci, M., Cangiotti, M., Bacchiocca, M., & Ninfali, P. (2001). Electron paramagnetic resonance investigations of free radicals in extra virgin olive oils. *Journal of Agricultural and Food Chemistry*, 49, 3691–3696.
- Sacchi, R., Savarese, M., Del Regno, A., Paduano, A., Terminiello, R., & Ambrosino, M. L. (2008). Shelf life of vegetable oils bottled in different scavenging polyethyleneterephthalate (PET) containers. *Packaging Technology and Science*, 21(5), 269–277.
- Del Nobile, M. A., Bove, S., Notte, E. L. a. & Sacchi, R. (2003). Influence of packaging geometry and material properties on the oxidation kinetic of bottled virgin olive oil. *Journal of Food Engineering*, 57(2), 189–197.
- Parenti, A., Spugnoli, P., Masella, P., & Calamai, L. (2007). Influence of the extraction process on dissolved oxygen in olive oil. *European Journal of Lipid Science and Technology*, 109(12), 1180–1185.
- Masella, P., Parenti, A., Spugnoli, P., & Calamai, L. (2009). Influence of vertical centrifugation on extra virgin olive oil quality. *Journal of the American Oil Chemists Society*, 86(11), 1137–1140.
- Masella, P., Parenti, A., Spugnoli, P., & Calamai, L. (2012). Vertical centrifugation of virgin olive oil under inert gas. *European Journal of Lipid Science and Technology*, 114(9), 1094–1096.
- Masella, P., Parenti, A., Spugnoli, P., & Calamai, L. (2010). Nitrogen stripping to remove dissolved oxygen from extra virgin olive oil. *European Journal of Lipid Science and Technology*, 112(12), 1389–1392.
- Ferrari, F., & Vignali, G. (2017). Modeling and simulation of nitrogen injection in olive oil. *International Journal of Food Engineering*, 14, 20170121.
- Angeloni, G., Spadi, A., Corti, F., Guerrini, L., Calamai, L., Parenti, A., & Masella, P. (2022). Investigation of the effectiveness of a vertical centrifugation system coupled with an inert gas dosing device to produce extra virgin olive oil. *Food and Bioprocess Technology*, 15, 2456–2467.
- Masella, P., Angeloni, G., Guerrini, L., Spadi, A., Corti, F., & Parenti, A. (2021). Pumping contribution to dissolved oxygen in virgin olive oil during processing. *Chemical Engineering Transactions*, 87, 307–312.
- Commission Regulation. (2008). Amending Regulation (EEC) No 2568/91 on the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis. *The Official Journal of the European Union*, L178, 11.

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