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1 **An opto-electronic system for in-situ determination of peroxide value and total phenol content**  
2 **in olive oil**

3

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10

11 **Abstract**

12 The quality of olive oil is essentially determined by the product free acidity and peroxide value,  
13 while the total phenol content is also important for a high antioxidant capacity. Generally, these  
14 parameters are measured with laboratory analysis, that are expensive and may require a few days.  
15 Thus, a cheap and easy technique usable by untrained personnel, “on-site” and producing results “in  
16 real time” during production is desirable, particularly as far as small olive oil mills and packaging  
17 centers are concerned. This paper describes a technique to determine peroxide value and total  
18 phenol content in olive oil, that is based on the measurement of optical density of an emulsion  
19 between a suitable chemical reagent and a small quantity of the oil of interest. The optical density is  
20 measured by illuminating the sample with a LED with peak wavelength of 569 nm for peroxide  
21 value and 835 nm for total phenol content. The experimental results show good correlation ( $R^2 =$   
22 0.883 and 0.895 for peroxide value and total phenol content, respectively) between data measured  
23 with the standard methodology and the technique of this work, implemented also in the form of a  
24 portable embedded system.

25

26 *Keywords:* olive oil, peroxide value, total phenol content, sensor, optical density.

27

## 28 **1. Introduction**

29 Olive oil is a vegetable lipid obtained by extraction process from olives (the fruits of *Olea europaea*  
30 *L.*, family Oleaceae) highly appreciated for its beneficial effects on human health, mainly due to a  
31 high content of oleic acid and phenolic compounds (Tulipani et al., 2012). Clinical studies provide  
32 evidence that regular olive oil consumption reduces the risk of coronary heart diseases (Keys et al.,  
33 1986), oxidative damage to DNA and RNA (Machowetz et al., 2007) and Alzheimer disease  
34 (Abuznait et al., 2013; Monti et al., 2011).

35 Olive oil quality is related to its chemical composition, oxidative stability and sensory  
36 characteristics. Quality parameters, such as free acidity, peroxide value, UV extinction coefficients,  
37 fruity attribute, other sensory characteristics and defects, are strongly dependent on olives' ripeness  
38 (Rotondi et al., 2004) and processing technology in the olive mills (Boselli et al., 2009). In addition,  
39 the peroxide value, defined as milliequivalent of active oxygen per kilogram of oil (meq O<sub>2</sub>/kg oil)  
40 and qualifying the oil primary oxidation, is also related to storage conditions (oxygen, light  
41 exposure and temperature) after production. Another important quality parameter is the amount of  
42 phenolic compounds that contribute to the oil sensory taste producing a distinctive bitter and a  
43 pungent perception (Gutierrez-Rosales et al., 2003). Phenolic compounds found in olive oil are  
44 principally secoiridoids (oleuropein and ligstroside isomers) and their derivatives, such as tyrosol  
45 and hydroxytyrosol, that exhibit a strong antioxidant activity: they act as free radicals traps  
46 protecting from heart disease and displaying anticancer activity (Notarnicola et al., 2011; Zanoni,  
47 2014). Phenolic compounds are also largely responsible for the shelf-life of the oil (Lerma-Garcia et  
48 al., 2009).

49 The European Commission regulation No. 2568/91 and subsequent amendments define manual  
50 titration methods to measure acidity and peroxide value in olive oil (EEC 2568, 1991), to be carried  
51 out in a laboratory environment by trained personnel. Instead, no official determination is currently  
52 established for the total phenol content, usually determined using spectrophotometry or high

53 performance liquid chromatography (HPLC), techniques requiring expensive instrumentation, a  
54 laboratory environment (IOC/T.20/Doc No 29, 2009; Tasioula-Margari and Okogeri, 2001) as well  
55 as preventive extraction of the polyphenols.

56 From the production point of view, the need to ship oil samples to a laboratory for analysis leads to  
57 high costs and long delays. Therefore, simple and fast techniques useable for on-site quality control  
58 are desirable, in particular for small oil mills and packaging centers. For this reason, innovative  
59 solutions have been proposed, such as: Near-InfraRed (NIR) spectroscopy (Armenta et al., 2007;  
60 Ozdemir and Ozturk, 2007) to estimate acidity and peroxide value; Time Domain Reflectometry  
61 (TDR) to determine water content (Ragni et al., 2012) and detect adulteration (Cataldo et al., 2012)  
62 in extra virgin olive oil; Rapid Fourier Transformed Infrared (FTIR) spectroscopy (Cerretani et al.,  
63 2010) and voltammetric sensors (Rodriguez-Mendez et al., 2008) to estimate total phenol content.  
64 However, all these techniques require expensive instrumentation and/or need frequent calibration  
65 for olives of different varieties, country of origin and harvest season.

66 As viable alternatives, amperometric and pH-metric techniques have been proposed to measure  
67 peroxide value (Kardash-Strochkova et al., 2001; Adhoum and Monser, 2008) and total phenol  
68 content (Capannesi et al., 2000), but these methods are still at research stage and have been  
69 validated only on small amounts of samples in laboratory environment. Moreover, some techniques  
70 use toxic compounds (such as chloroform) to increase oil solubility in reagents, unsuitable for use in  
71 normal working environment.

72 Recently, we have proposed a novel technique based on Electrical Impedance Spectroscopy to  
73 measure olive oil acidity that is fast (response time in about 30 seconds) and can be easily  
74 implemented in the form of a low-cost portable embedded system (Grossi et al., 2013).

75 To complete this work, we here present a simple and effective technique to measure peroxide value  
76 and total phenol content in olive oil that, as will be shown, is fast, accurate and can be implemented  
77 in the form of a low-cost embedded electronic system.

78

79 **2. Materials and methods**

80 *2.1 Technique*

81 The technique used in this work is based on the creation of an aqueous emulsion between the oil  
82 sample and a chemical reagent. The optical density (OD) of such an emulsion is determined by  
83 illuminating the sample with a LED and measuring the transmitted light through the sample with a  
84 photodiode. A large set of experimental results show a good correlation between the measured OD  
85 and the quality parameters determined by reference methods. The proposed technique is suitable to  
86 be implemented in the form of a portable instrument suitable for quick in-situ quality control, as  
87 will be discussed in sub-Section 3.3.

88 *2.2 Experimental set-up*

89 In order to validate the technique used in this work, measurements on olive oil samples have been  
90 initially carried out using an ad-hoc experimental set-up of bench-top instruments.

91 The sensor, depicted in Fig. 1 (a), consists of a cylindrical chamber (designed using Solid Edge by  
92 Siemens Systems and fabricated with a MakerBot Replicator 3D printer) devoted to host the 25ml  
93 polystyrene vial containing the emulsion between a suitable aqueous reagent (discussed in section  
94 2.2) and the oil sample. The chamber features two diametrically opposed structures hosting a LED,  
95 used as light source and a photodiode to detect the light transmitted through the sample. In the case  
96 of peroxide value, the LED has a peak emission at 569 nm wavelength (biased with a 30 mA  
97 current), while the photodiode is a BPW21R by Vishai (with wavelength peak sensitivity at 565  
98 nm). In the case of total phenol content, instead, the LED has a peak emission at 835nm (biased  
99 with a 80 mA current) and the photodiode is a OSD5-5T device by Centronic, with wavelength  
100 peak sensitivity between 700 and 900 nm. As discussed in Section3, both the LED peak  
101 wavelengths have been chosen by means of preliminary measurements on phenolic and peroxide  
102 compounds using a SmartSpec 3000 spectrophotometer.

103 The experimental set-up is presented in Fig 1 (b). A DC power supply Agilent E3631A is used to  
104 provide the LED operating current ( $I_{LED}$ ) and the power supply for the operational amplifier. The

105 photodiode current ( $I_{\text{photo}}$ ), related to the detected light intensity, is converted into a voltage ( $V_{\text{out}}$ )  
106 by a current-to-voltage converter. The voltage  $V_{\text{out}}$  is acquired by a NI USB-6211 Data Acquisition  
107 (DAQ) board by National Instruments and transmitted to a PC for further analysis. All the software  
108 for DAQ control, analysis, data presentation and filing has been realized with LabVIEW (National  
109 Instruments). Statistical analysis on the experimental data has been carried out with Microsoft  
110 EXCEL.

### 111 2.3 Chemicals and media

112 Phenolic reference standards (oleuropein, tyrosol, hydroxytyrosol, *p*-coumaric acid) and peroxide  
113 compounds (hydrogen peroxide,  $\text{H}_2\text{O}_2$ , and tert-butyl hydroperoxide, tBuOOH) were purchased  
114 from Sigma-Aldrich (St. Louis, MO, USA). The reagent for peroxide value determination was  
115 prepared diluting 8 mL of ferrous ion oxidation xylenol orange (FOX) reagent (an aqueous solution  
116 of ferrous ammonium sulphate, sorbitol, sulphuric acid and xylenol orange, Sigma-Aldrich)  
117 (Cheeseman, 2006) in 7mL of distilled water. The reagent detects the peroxides concentration by  
118 oxidation of ferrous ions  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  according to the following reaction:



120  $\text{Fe}^{3+}$  ions formed in the reaction are then detected using the dye xylenol orange which binds  $\text{Fe}^{3+}$   
121 forming a complex that strongly absorbs in the wavelength range 540-580 nm.

122 For the total phenol content, instead, the reagent was prepared mixing: 13 mL of distilled water, 1  
123 mL of Folin-Ciocalteu reagent (a mixture of phosphomolybdate acid  $\text{H}_3\text{PMo}_{12}\text{O}_{40}$  and  
124 phosphotungstate  $\text{H}_3\text{PW}_{12}\text{O}_{40}$ ) and 1 mL of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) 15% (i.e. 15g di sodium  
125 carbonate in 100mL of distilled water). As a consequence of the reaction with the phenolic  
126 compounds, the acids are reduced to tungsten and molybdenum oxides ( $\text{W}_8\text{O}_{23}$  and  $\text{Mo}_8\text{O}_{23}$ )  
127 featuring a typical blue colour.

128 In both cases, the reagent was then mixed with 0.5 mL of the oil sample, all stirred for 30 seconds  
129 to create the emulsion, then the vial is placed in the sensor for the measure.

130 All the chemicals used in the experiments are of analytical grade. The olive oil samples used in the  
131 experiments were purchased by local markets as well as olive oil mills.

#### 132 *2.4 Reference methods*

133 Olive oil peroxide value has been determined by European standard reference method with starch as  
134 indicator and sodium thiosulphate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) as titrant, while total phenol content has been  
135 determined according to spectrophotometric method proposed by Singleton and Rossi (Singleton  
136 and Rossi, 1965). Phenolic fraction has been extracted using about 4 g of virgin olive oil (VOO)  
137 with 5 mL of methanol:water (60:40). The extraction procedure has been repeated two time and the  
138 hydroalcoholic fractions have been combined and evaporated by rotavapor up to complete dryness.  
139 The concentrated extract has been dissolved in 5 mL of aqueous methanol (50%), and filtered  
140 through Minisart RC15 (0.2  $\mu\text{m}$ ) regenerated cellulose syringe filters (Sartorius AG, Göttingen, D).  
141 Total phenol content has been determined using the Folin-Ciocalteau reagent (Sigma-Aldrich, St.  
142 Louis, MO, USA) and measuring at 750 nm with a Shimadzu spectrophotometer UV-VIS 1204  
143 (Kyoto, Japan). The results have been expressed as mg of gallic acid per kg of VOO (gallic acid  
144 calibration curve  $R^2= 0.993$ ).

145

### 146 **3. Results and discussion**

147 The reagents response was initially characterized with peroxide and phenolic compounds using a  
148 SmartSpec 3000 spectrophotometer. Then a set of 25 olive oil samples have been analyzed with the  
149 technique and the bench-top set-up described in Section 2.1. Finally an electronic board has been  
150 designed and fabricated to avoid the use of all bench-top instrumentation, thus demonstrating the  
151 feasibility of a simple and economical instrument for easy, fast and in-situ analysis of olive oil.

#### 152 *3.1. Spectral characterization of reagents response*

153 At first, the reagents were inoculated with known concentrations of peroxide and phenolic  
154 compounds and the absorption spectra acquired with a SmartSpec 3000 spectrophotometer.

155 In the case of phenols, four different compounds were tested: three of these are typically present at  
156 high concentration (oleuropein, hydroxytyrosol and tyrosol) while the fourth one (*p*-coumaric acid) is  
157 present in small concentration. Fig. 2 (a) shows the absorption spectra in the case of different  
158 concentrations of oleuropein in the 400 – 800 nm wavelength range. As can be seen the different  
159 concentrations of phenolic compound can be discriminated for wavelength > 500 nm with the  
160 sensitivity increasing with the wavelength. In Fig. 2 (b) the absorbance measured at the wavelength  
161 of 800 nm is plotted vs. the phenol content for all the tested compounds. Except for tyrosol for  
162 which a higher sensitivity for concentrations below than 15 ppm is registered, in all cases a linear  
163 relation between absorbance and concentration is found. The linear regression lines of the four  
164 cases are calculated to estimate the compound sensitivity (Abs800/ppm) to the reagent with the  
165 following results: 0.0199 (oleuropein), 0.1159 (hydroxytyrosol), 0.0248 (*p*-coumaric acid), while in  
166 the case of tyrosol the sensitivity is 0.0755 for concentrations lower than 15 ppm and 0.019843 for  
167 concentrations higher than 15 ppm. As depicted in Fig 2 (b), the intensity of blue color obtained by  
168 reduction of tungsten and molybdenum oxides is proportional to the concentration of each phenol  
169 but shows a different response respect to the phenol structure which reacted. In fact Folin-Ciocalteu  
170 detects the total reducing capacity that is different for different compounds (Apak et al., 2007). As  
171 described in several paper, during the storage of VOO the trend of phenolic fraction, measured by  
172 Folin-Ciocalteu assay showed a fluctuation due to the oxidation and lysis of phenolic compounds  
173 disperse in the matrix. This result confirms the different response factor that the reaction mixture  
174 presents towards individual phenols (Boselli et al., 2009; Fiori et al., 2014).

175 In the case of peroxides, two different compounds were tested: hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and tert-  
176 butyl hydroperoxide (tBuOOH). The absorbance spectra in the wavelength range 400 - 800 nm are  
177 shown in Fig. 3 (a) for different tBuOOH concentrations. As expected, the reaction of Fe<sup>2+</sup> ions  
178 with peroxide compounds results in the formation of Fe<sup>3+</sup> ions that bind to xylenol orange  
179 producing an absorbance peak between 560 and 580 nm. The measured absorbance at 580 nm is  
180 plotted vs. compound concentration for both H<sub>2</sub>O<sub>2</sub> and tBuOOH in Fig. 3 (b). From the measured



181 data, the absorbance can be empirically modelled as a linear function of the square root of the  
182 compound concentration. The results indicate that  $\text{H}_2\text{O}_2$  ( $y = 0.297\sqrt{x} + 0.436$ ) is characterized by  
183 higher sensitivity than tBuOOH ( $y = 0.115\sqrt{x} + 0.265$ ). In both cases a determination coefficient  $R^2$   
184 higher than 0.96 is achieved. The different response of FOX reagent to  $\text{H}_2\text{O}_2$  and tBuOOH can be  
185 due to the ability of sorbitol to scavenge hydroxyl radicals to yield peroxy radicals which would  
186 propagate  $\text{Fe}^{2+}$  oxidation (Jiang et al., 1990).

### 187 3.2. Experimental results

188 A set of 25 olive oil samples have been tested using the technique and the experimental set-up  
189 described in Section 2. The voltage  $V_{\text{out}}$  is acquired at time intervals of 5 seconds for a total of 1200  
190 seconds for both tests (total phenol content and peroxide value).

191 In the case of total phenol content, the logarithm of  $V_{\text{out}}$  has been found to be linearly related with  
192 the phenols concentration. The coefficient of determination  $R^2$  has been calculated after different  
193 time intervals and plotted as function of time in Fig. 4 (a): the correlation between  $\text{Log}_{10}(V_{\text{out}}/V_{\text{M}})$   
194 (where  $V_{\text{M}}$  is the measured voltage in the absence of oil sample, i.e. due to the reagent only) and the  
195 total phenol content increases with time, reaching a plateau after 600 seconds. Fig. 4 (b) shows the  
196 measured values of  $\text{Log}_{10}(V_{\text{out}}/V_{\text{M}})$  after 600 seconds plotted vs total phenol content as determined  
197 using the reference method. The linear regression line equation is  $Y = 0.0343 - 2.389 \cdot 10^{-3} \cdot X$  and the  
198 coefficient of determination 0.895. The accuracy is slightly higher to what reported by Cerretani  
199 (Cerretani et al., 2010) when a  $R^2$  of 0.87 was obtained by FTIR attenuated total reflectance  
200 spectroscopy using a wavelength range  $3610 - 816 \text{ cm}^{-1}$  and a PLS chemometric analysis. The use  
201 of an array of voltammetric sensors (Rodriguez-Mendez et al., 2008) reported an higher accuracy  
202 ( $R^2 = 0.986$ ), but the samples tested were only 6 olive oils and all above the 400 ppm; instead, in the  
203 present work, 25 samples were analysed and the level of detection achieved was of 100 ppm.

204 In the case of peroxide value, a linear relation between the measured values of  $V_{\text{out}}/V_{\text{M}}$  and the  
205 peroxide value has been found. As shown in Fig. 4 (c), the coefficient  $R^2$  increases with time  
206 reaching a plateau after about 600 seconds. Fig. 4 (d) shows the measured values of  $V_{\text{out}}/V_{\text{M}}$  plotted

207 vs. the peroxide value as determined by the reference method. The linear regression line equation is  
208  $Y = 0.6368 - 13.8 \cdot 10^{-3} \cdot X$  and the coefficient of determination 0.883. The dispersion between  
209 measured data and the reference technique can be mainly associated with the property of the FOX  
210 reagent that is able to determine all kinds of conjugated dienes including those without a peroxide  
211 group, and not able to react with peroxides included in molecules without conjugated double bonds.  
212 Furthermore the accuracy of the quantification can be also diminished by the presence of several  
213 other compounds present in olive oil, such as carotenoids and chlorophyll, absorbing at 500-600  
214 nm, and chain-breaking antioxidant able to reduce the color yield (Bou et al 2008). The obtained  
215 accuracy is however higher than that reported in (Armenta et al., 2007) where a coefficient of  
216 determination  $R^2$  of 0.6558 resulted by NIR spectroscopy combined with PLS chemometric  
217 analysis.

218 In both cases there is a linear relation between the parameter measured with the experimental set-up  
219 ( $\text{Log}_{10}(V_{\text{out}}/V_{\text{M}})$  for total phenol content and  $V_{\text{out}}/V_{\text{M}}$  for peroxide value) and the oil quality  
220 parameter measured with the reference methods. Thus, using the equation of the linear regression  
221 line, the oil quality parameters can be estimated.

### 222 *3.3. Implementation as a portable embedded system*

223 To demonstrate that the technique proposed in this work can lead to a portable embedded system  
224 suitable for in-situ measurements, all the operations performed by the bench-top instrumentation  
225 and DAQ PC board have been implemented inside an electronic board designed “ad hoc”, based on  
226 the  $\mu$ controller Dspic33ep512mu810, whose schematic is presented in Fig. 5 (a).

227 The LED is supplied with a square wave current (frequency 1 kHz) to allow removing the  
228 contribution of the environment radiation. In particular, a square wave voltage ranging from 0 to  
229 830 mV is generated by the  $\mu$ controller and fed to the noninverting input of an operational  
230 amplifier. In turn, this latter drives a BJT transistor providing the LED with the supply current  $I_{\text{LED}}$   
231 (selectable with the value of the resistance  $R_{\text{LED}}$ ). The radiation transmitted through the sample is  
232 received by the photodiode that generates the current  $I_{\text{photo}}$  proportional to the incident radiation. An

233 I/V converter generates a voltage  $V_A$  proportional to  $I_{\text{photo}}$ . A couple of programmable switches  
234 allows to select two different feedback resistors ( $R_{F1}$  or  $R_{F2}$ ). The voltage  $V_A$  is then fed to a AC  
235 coupling stage that generates a square wave voltage ( $V_B$ ) with mean value 2.5V. Such a voltage is  
236 then fed to a synchronous rectifier (built with an AD8271 difference amplifier and an ADG733  
237 triple single pole double throw SPDT switch) that provides a DC voltage ( $V_C$ ) equal to the high  
238 level of  $V_B$ . Then, a 18 bit ADC driver ADA4941 generates a differential voltage  $V_{\text{OUT}}$   
239 (proportional to  $V_C$ ) that is fed to a 12 bit ADC (AD9220AR) providing the 12 bit digital  
240 codification of  $V_{\text{OUT}}$  ( $D_{\text{OUT}}$ ) to be processed by the  $\mu$ controller. The measured data are sent to a  
241 portable PC (via USB interface) to display the results and file the data. The system has been built by  
242 using low-cost electronics and its total cost has been estimated in about 300 \$. All the software has  
243 been developed using LabVIEW. Fig. 5 (b) and (c) present pictures of the sensor, while Fig. 5 (d) is  
244 a photograph of the electronic board.

245 A significant subset of the olive oil samples have been tested using both the bench-top instrument  
246 set-up described in Section 2.1 and the embedded system presented above to compare the results.

247 Fig. 6 (a) shows a plot of  $\text{Log}_{10}(D_{\text{OUT}}/4096)$  vs. time (acquisitions every 5 seconds) for 3 samples  
248 featuring different values of total phenol content (the division by 4096 represents a normalization  
249 necessary for comparison with  $V_{\text{out}}/V_M$  of sub-Section 3.1). As can be seen, higher total phenol  
250 content results in lower values of measured  $D_{\text{OUT}}$ . Measurements on a set of 10 olive oil samples  
251 result in a linear correlation between  $\text{Log}_{10}(D_{\text{OUT}}/4096)$  and total phenol content ( $Y = -4.978 \cdot 10^{-4} \cdot X$   
252  $-4.7 \cdot 10^{-3}$ ).

253 In Fig. 6 (b)  $D_{\text{OUT}}/4096$  is plotted vs. time for 3 samples featuring different values of peroxide value  
254 and, as can be seen, more oxidized samples exhibit lower values of  $D_{\text{OUT}}$ . Measurements on a set of  
255 7 olive oil samples result in a linear correlation between  $D_{\text{OUT}}/4096$  and the peroxide value ( $Y =$   
256  $8.532 \cdot 10^{-3} \cdot X + 0.893$ ).

257 The linear regression equations have been used to compare the estimated values of both peroxide  
258 value and total phenol content with those obtained with the reference methods and the calculated

259 determination coefficient  $R^2$  differs by less than 1.6% between the two measuring systems. In  
260 particular, in the case of peroxide value,  $R^2 = 0.901$  and  $0.887$  for the bench-top set-up and the  
261 embedded system, respectively; while with total phenol content  $R^2 = 0.932$  and  $0.922$  for the bench-  
262 top set-up and the embedded system, respectively. The agreement between the two measuring  
263 systems is very good.

264

#### 265 **4. Conclusions**

266 A novel technique to measure peroxide value and total phenol content in olive oil has been  
267 presented that is based on optical density measurements of a suitable reagent inoculated with the  
268 olive oil of interest. The technique, suitable to be realized in the form of a low-cost, embedded  
269 electronic system, has been tested using an experimental set-up built with bench-top  
270 instrumentation and the results show that it can estimate with good accuracy the peroxide value ( $R^2$   
271  $= 0.883$ ) and the total phenol content ( $R^2 = 0.895$ ) of olive oil in less than 10 minutes.

272 The proposed technique has been implemented in an electronic board to realize a portable  
273 embedded system; the results obtained with such an instrument have been compared with those  
274 coming from the bench-top set-up and an excellent agreement has been found.

275 The portable embedded system could be applied for fast and *in-situ* olive oil quality control and to  
276 assess the shelf-life without the need of trained personnel. Furthermore, it could be useful for a first  
277 evaluation of the total phenol content of virgin olive oils in case of interest of a producer to report  
278 on the label the olive oil claim, according with the EU Regulation 432/2012, stating that “Olive oil  
279 polyphenols contribute to the protection of blood lipids from oxidative stress”, but admitted only if  
280 at least 5 mg of hydroxytyrosol and its derivatives (e.g. oleuropein complex and tyrosol) are  
281 contained in 20 g of olive oil.

282

283

284

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288

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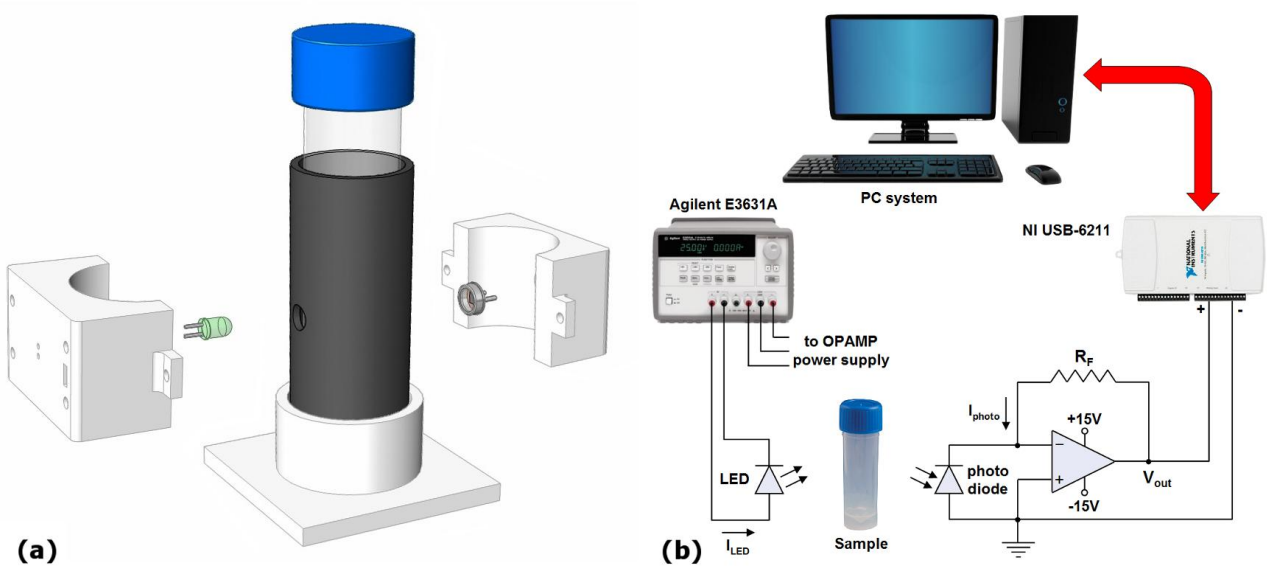
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**Fig. 1.** The sensor used for the experiments of the present work (a) and the experimental set-up built with bench-top instrumentation used for the measurements (b).

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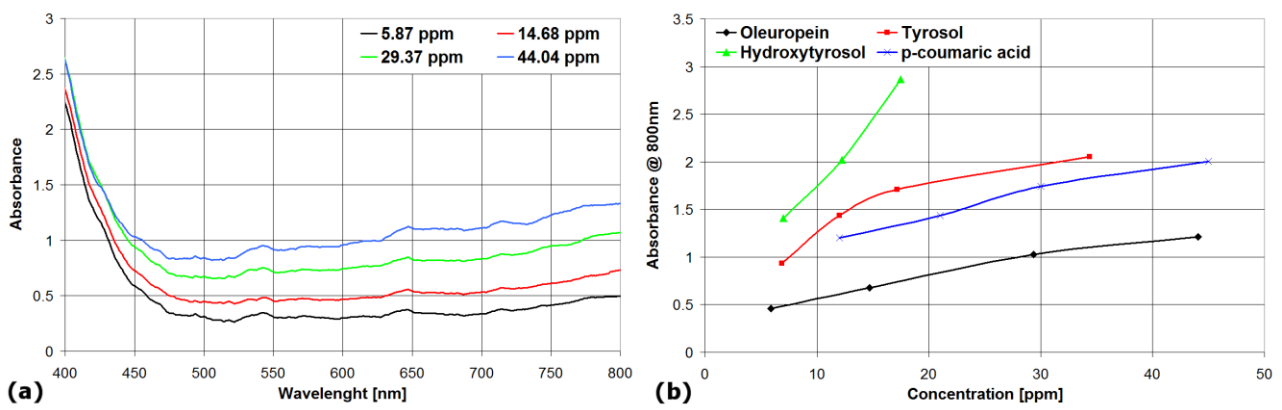
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440 **Fig. 2.** Measured absorbance vs. wavelength in the range 400 – 800 nm for different concentrations  
441 of oleuropein (a) and measured absorbance at 800 nm plotted vs. phenol content for different  
442 phenolic compounds (b).

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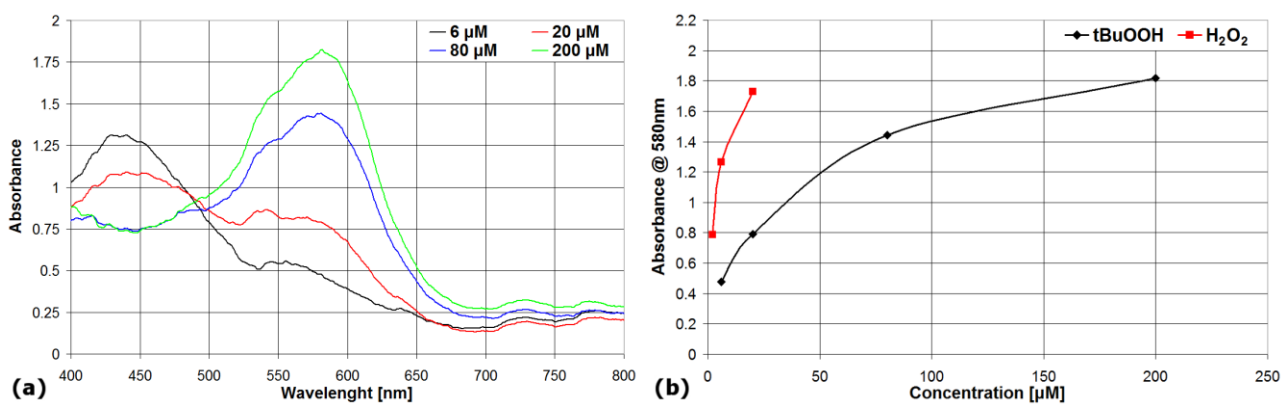
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**Fig. 3.** Absorbance plotted vs. wavelength in the range 400 – 800 nm for different concentrations of tert-butyl hydroperoxide (a) and measured absorbance at 580 nm plotted vs. concentration for tert-butyl hydroperoxide as well as vs. hydrogen peroxide (b).

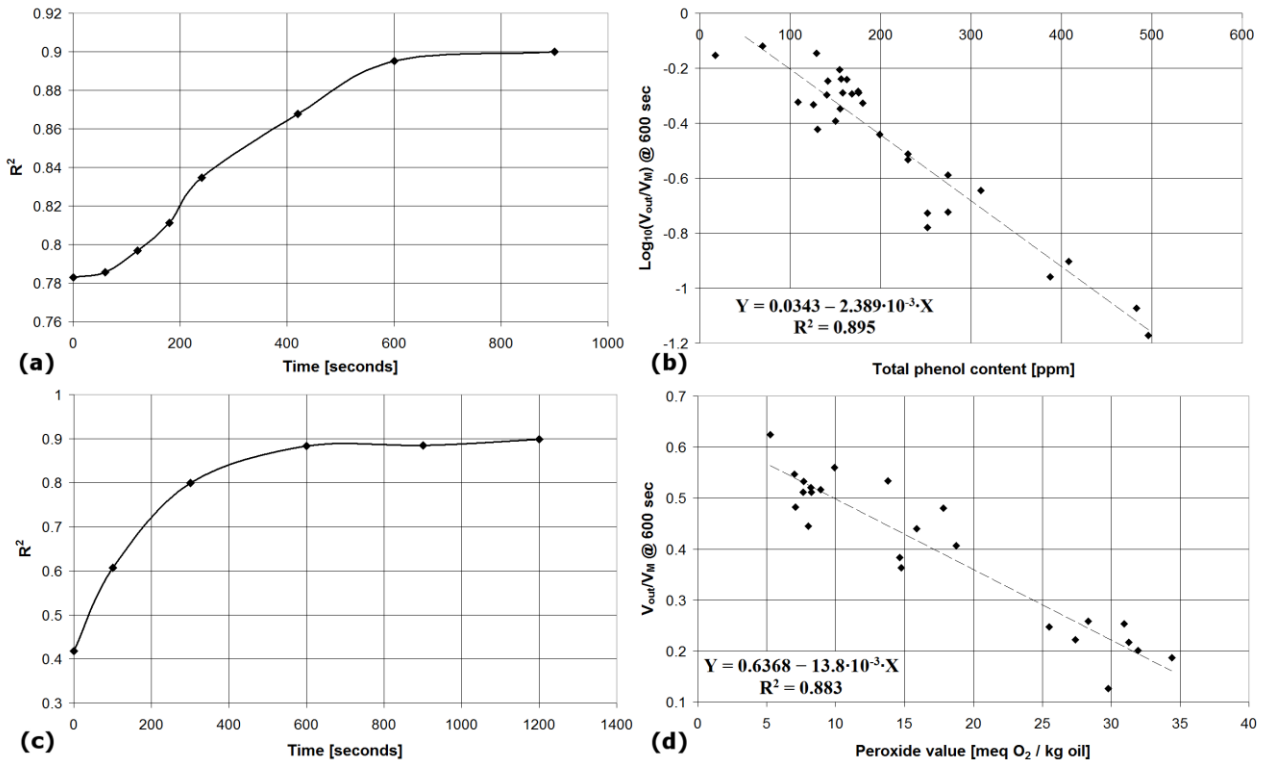
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480 **Fig. 4.** Coefficient of determination  $R^2$  plotted vs. time for the total phenol content (a) and peroxide  
481 value (c). Scatter plot and linear regression line calculated for 600 seconds for total phenol content  
482 (b) and peroxide value (d).

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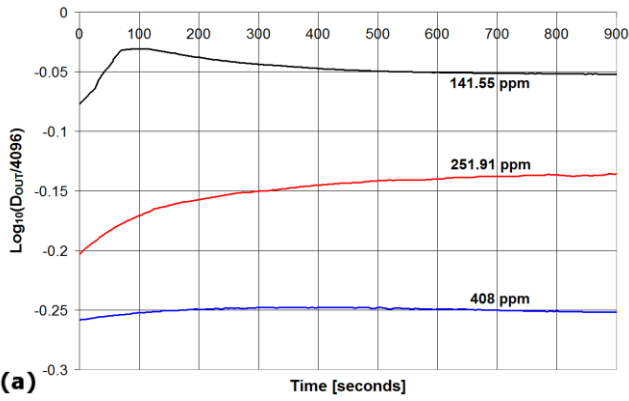


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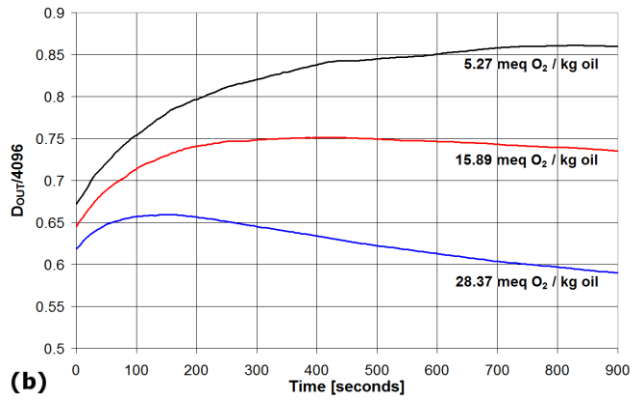
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**Fig. 6.** Data measured with the designed electronic board for different oil samples vs. time in the case of total phenol content (a) and peroxide value (b).

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