# Evaluation of olive oil quality grade using a portable battery operated sensor system

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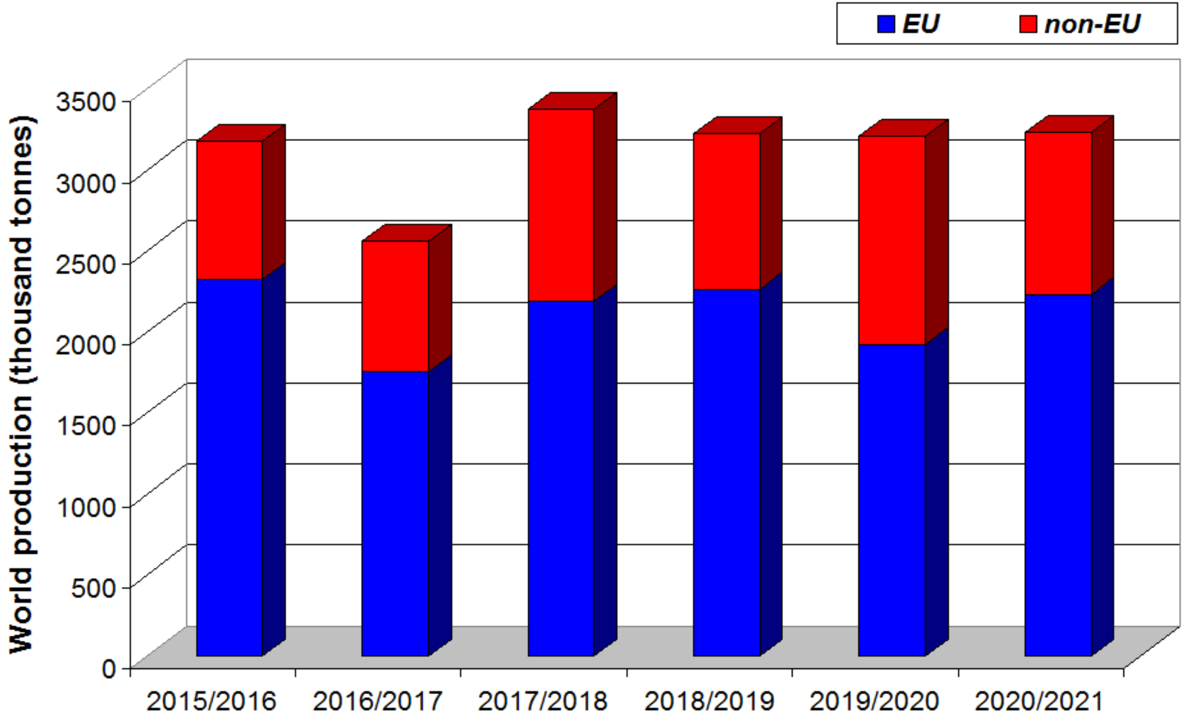
# Olive oil health benefits

**EVOO is responsible for many health benefits** associated to Mediterranean diet as it is a fundamental ingredient of this diet.

- Reduction of microbial activity
- Anti-tumor properties
- Benefits for blood pressure
- Prevent diabetes
- Prevent osteoporosis
- Prevent neurodegenerative diseases
- Anti-inflammatory properties
- Benefits for the digestive system
- Prevent oxidative stress

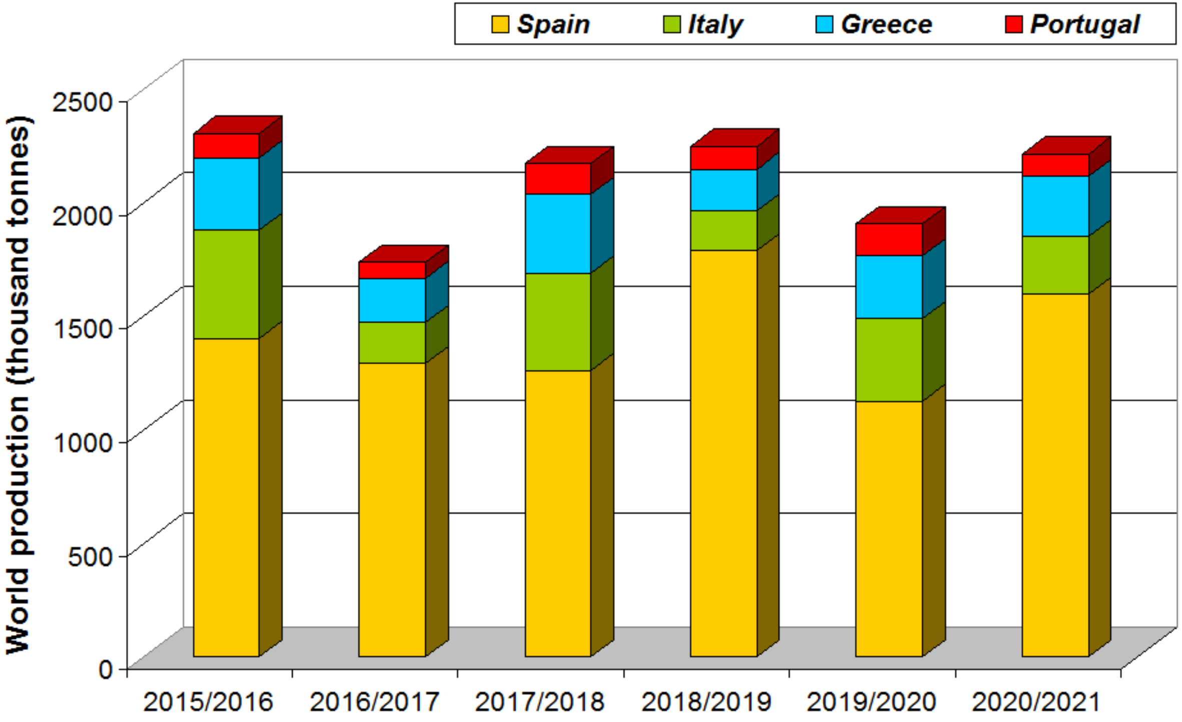
# Olive oil market in the world




**European Union (EU) is the largest olive oil producer** in the world (about 66% of the world production).
EU is also the biggest olive oil consumer (1.5 million tonnes) and exporter (570000 tonnes).

**Source:** *International Olive Council*

# Olive oil market in the European Union




**Spain is the biggest olive oil producer in EU and** Italy is the second biggest producer.

**Spain: 66%**
**Italy: 15%**
**Greece: 13%**
**Portugal: 5%**

**Source:** *International Olive Council*

# Olive oil quality

**Olive oil** is graded to different categories according to quality parameters:

1) **Physico-chemical characteristics**

- **Free acidity (FA):** amount of fatty acids no longer linked to their parent triglyceride molecules. It is affected by the olive quality and production process. It does not change significantly during storage.
- **Peroxide index (PI):** indicator of the oil primary oxidation. If storage conditions are not adequate, oil oxidation takes place and degrades the product quality.

2) **Organoleptic characteristics**

- **Sensory analysis** to check the absence of organoleptic defects.

# Olive oil quality

Based on the values of the different quality parameters, virgin olive oil can be classified into the following categories:

- **Extra Virgin Olive Oil (EVOO)**: FA < 0.8%, PI < 20 meq $O_2$ / kg oil. From an organoleptic point of view, it has no defects and is fruity.
- **Virgin Olive Oil (VOO)**: FA < 2%, PI < 20 meq $O_2$ / kg oil. It may have organoleptic defects at very low level.
- **Lampante Olive Oil (LOO)**: FA > 2% and/or PI > 20 meq $O_2$ / kg oil. It has no fruity characteristics and substantial organoleptic defects. Lampante olive oil is not intended to be marketed at retail stage.

# Measurement of free acidity and peroxide index

The **reference techniques** to measure olive oil free acidity and peroxide index are **manual titration procedures**.

- The analysis must be carried out by trained personnel in a laboratory.
- Chemicals used in the titration must be properly disposed according to regulations.
- Small production centers, that can not afford an internal laboratory for quality analysis, must ship the samples to an external laboratory with high costs and long response time.

# Objective of the research project

The objective of the research project is the development of an **electronic instrument for the evaluation of quality grade of olive oil**. The instrument must have the following characteristics.

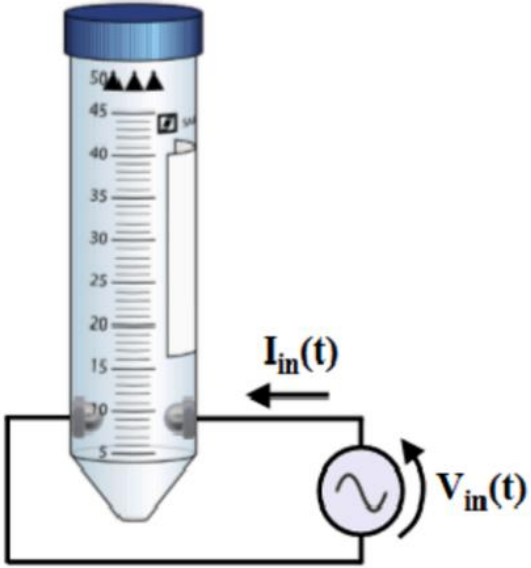
- It must be **portable** and **powered by batteries** to allow **in-situ measurements** in the production centers (oil mills and packaging centers).
- It must be **simple to use**. No particular skills for the operators.
- The measurement must be **quick**.
- **No toxic compounds** must be used.

# Working principle of the proposed technique

The working principle of the proposed technique is based on the **measurement of the electrical characteristics** of an emulsion between an **hydro-alcoholic solution** (60% ethanol, 40% distilled water) and the **olive oil** under test.

The **emulsion** is prepared by mixing **15 mL of hydro-alcoholic solution** and **1 mL of the olive oil** under test.

The emulsion is stored in a 50 mL Falcon vial modified to feature **a couple of stainless steel electrodes** (6 mm diameter, spaced by 12 mm).



# Working principle of the proposed technique

- **Preliminary measurements** have been carried out in a **controlled laboratory environment** on four olive oil samples with different levels of free acidity.

- The emulsion is stored in a thermal chamber with **operative temperature 20 °C.**

- The emulsion electrical characteristics have been analyzed by Electrical Impedance Spectroscopy (EIS) in the **frequency range 20 Hz – 2 MHz** using a commercial impedance analyzer.

# Working principle of the proposed technique

- From an electrical point of view, **the emulsion can be modeled as the parallel of an electrical conductance $G_m$ and an electrical capacitance $C_m$.**

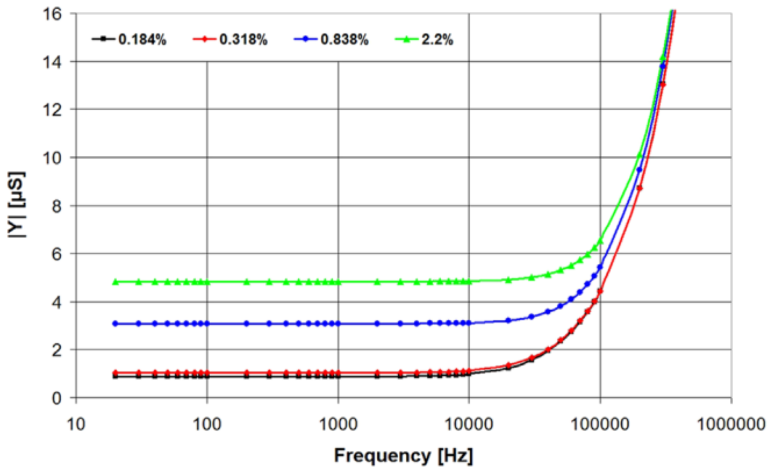
- The sensor impedance is **dominated by $G_m$ at low frequency** (< 10 kHz) and **by $C_m$ at high frequency** (> 100 kHz).

- The **electrical capacitance $C_m$ is function of the oil dielectric properties** and is **not affected by the oil quality parameters** (free acidity and peroxide index).

- The **electrical conductance $G_m$** of the emulsion **is function of the oil quality characteristics.**

# Working principle of the proposed technique

- In the case of fresh olive oil samples, characterized by a peroxide index < 20, the emulsion $G_m$ is function of the olive oil free acidity.




- Samples featuring higher values of free acidity are also characterized by higher values of the emulsion $G_m$.

- In the case of oxidized olive oil samples, the presence of non-volatile compounds (such as aldehydes, ketones and hydrocarbons) also contributes to the increase of the emulsion $G_m$.

# Design of the portable sensor system

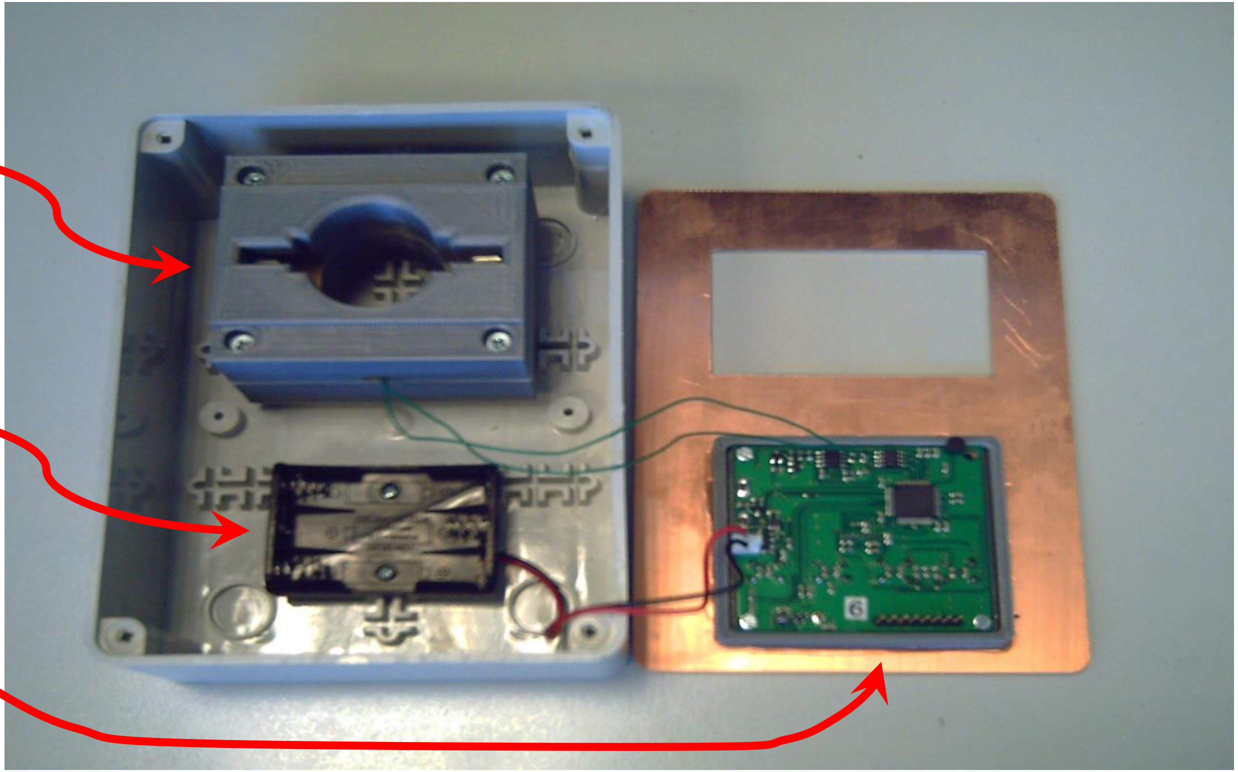

- The portable sensor system has **small size** (11 x 15 x 5 cm), **light weight** (350 g), can be powered by **USB or battery** (3 AAA alkaline batteries) and makes measurements in **about 30 seconds**.

# Design of the portable sensor system

Slot to host the modified Falcon vial

Battery container

Electronic board

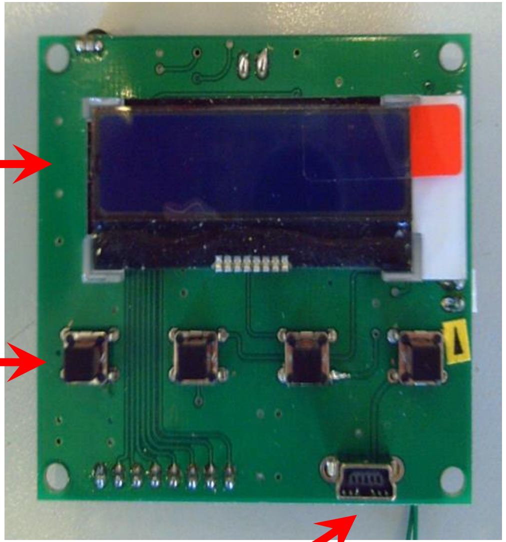


# The electronic board of the sensor system

LCD screen

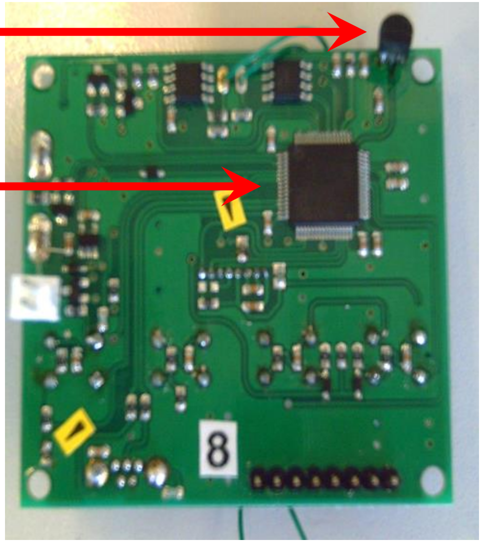
4 user buttons

USB port



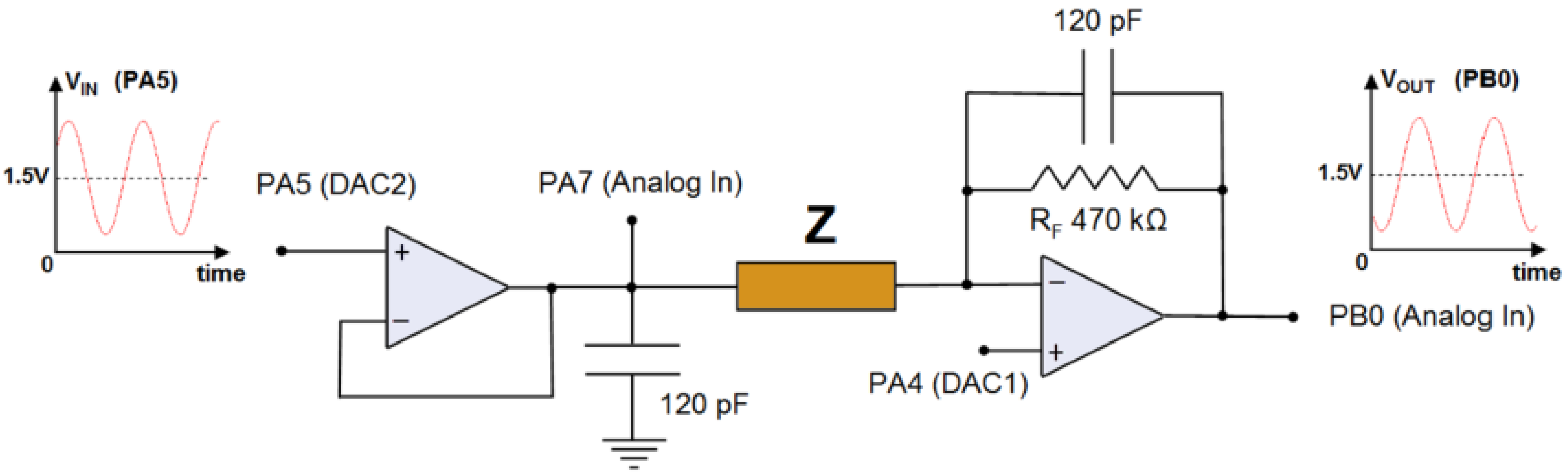
Temperature sensor

STM32 µcontroller



Ad hoc designed analog circuits for impedance measurement

# The electronic board of the sensor system



# The electronic board of the sensor system

- The sinusoidal voltage signal **$V_{IN}$(t) (1.5 V offset, 1 V amplitude, 200 Hz)** is generated using the microcontroller integrated **12-bit DAC** (Digital-to-Analog converter) and applied to the sensor electrodes.

- The sensor current is converted to a voltage **$V_{OUT}$(t)** with a I/V converter.

- The voltage signals **$V_{IN}$(t) and $V_{OUT}$(t)** are **acquired** with the **12-bit ADC** (Analog-to-Digital converter) integrated inside the microcontroller.

- The voltage signals **$V_{IN}$(t) and $V_{OUT}$(t)** are **processed** and the sinewave parameters ($V_{M,IN}$, $V_{M,OUT}$, φ) are calculated.

- The emulsion conductance is calculated as $$G_m = \frac{1}{R_F} \times \frac{V_{M,OUT}}{V_{M,IN}} \times \cos(\varphi)$$

# Compensation of the temperature effect

- The **portable sensor system** has been designed for **in-situ measurements** in a production environment where the **temperature can not be controlled**.
- A **compensation algorithm** has been developed to estimate the emulsion conductance at 23.5 °C (**$G_{m,23.5°C}$**) from the emulsion conductance at the environmental temperature (**$G_{m,T}$**) and the temperature value **(T)**.
- The **compensation algorithm** has been implemented with the microcontroller.

$$G_{m,23.5°C} = \frac{G_{m,T} + 0.0026 \times (T - 23.5)}{1 + 0.0219 \times (T - 23.5)}$$

# Validation of the sensor system

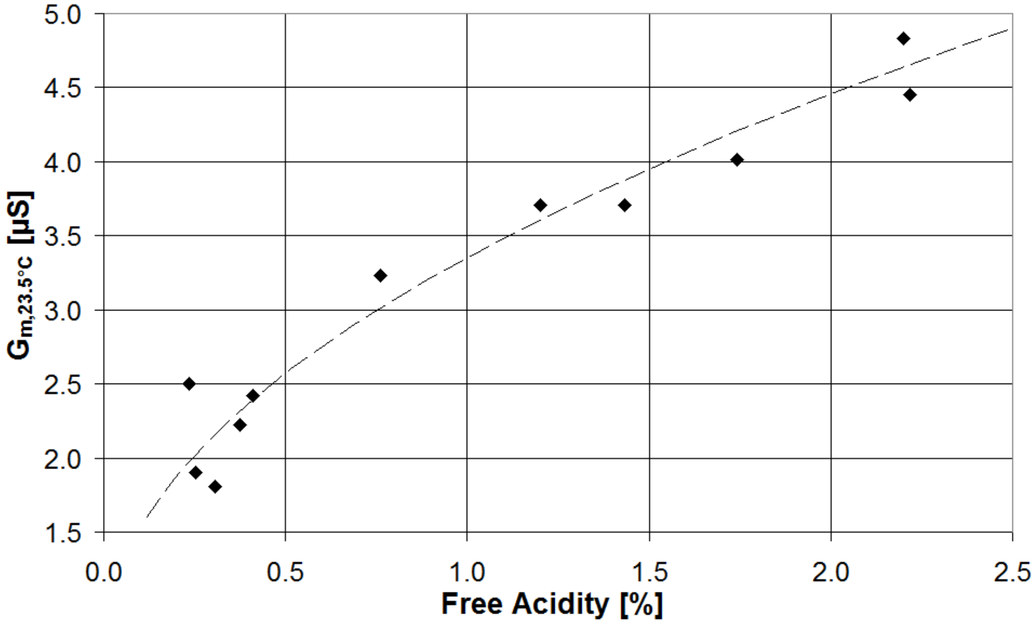
- Tests have been carried out on a set of **17 olive oil samples** (6 EVOOs, 3 VOOs and 8 Lampante olive oils).

- A **subset of 11 samples (fresh olive oils featuring a peroxide index < 20)** has been tested and a **correlation with the sample free acidity is found.**

- In the case of **full set of 17 olive oil samples**, the emulsion **$G_m$ is affected by both the oil free acidity and the oxidation level**, thus a threshold value for $G_m$ can be set to **discriminate EVOOs from lower grade olive oils.**

# Tests on fresh olive oil samples

- A correlation exists between $G_{m,23.5°C}$ and the sample **free acidity**.

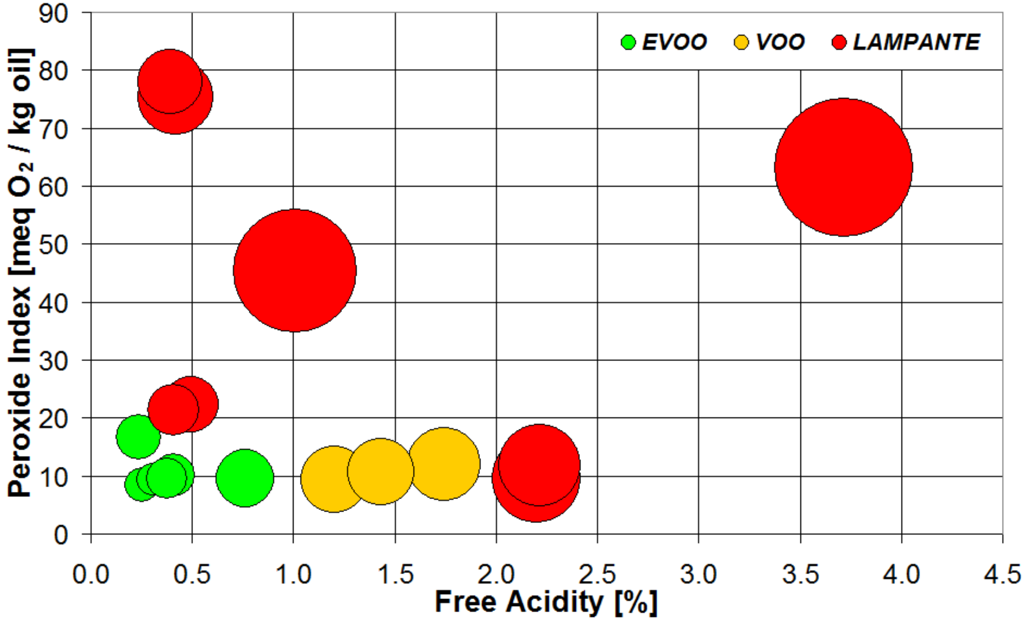



$$FA = \left(\frac{G_{m,23.5°C} - \alpha}{\beta}\right)^2$$

$$\alpha = -0.6856 \qquad \beta = 2.6662$$

# Tests on the full set of olive oil samples

- The value of $G_{m,23.5°C}$ is affected by both **free acidity** and **oxidation level**.




- The circle diameter represents $G_{m,23.5°C}$.
- **EVOO** can be discriminated from lower grade oils by setting a **conductance threshold** $G_{m,23.5°C,TH}$ **= 2.7 µS**.
- $G_{m,23.5°C} < G_{m,23.5°C,TH} \rightarrow \mathrm{EVOO}$

# References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# Thanks for your attention