Natural Plant-Derived Oils in Modern Industry

Dr. Francesca Bruni, researcher at the CDR Chemical Lab "Francesco Bonicolini"

P2614

Introduction

Natural plant-derived oils represent a strategic category of bio-based lipids increasingly adopted across cosmetic, nutritional, pharmaceutical and functional food industries. The progressive transition from petroleum-derived mineral oils to renewable plant lipids reflects both regulatory pressure and consumer demand for sustainable, biologically active ingredients.

Unlike mineral oils, which are chemically inert hydrocarbon mixtures, natural oils are biologically complex matrices capable of providing structural functionality together with bioactive properties. Their compatibility with biological membranes, metabolic pathways and dermal lipid structures makes them particularly suitable for high-value applications.

In modern industrial formulations, plant oils are no longer considered simple carriers or excipients. They function as active ingredients capable of modulating skin barrier repair, oxidative balance, lipid nutrition and drug bioavailability. Their industrial relevance extends across cosmetics and personal care, functional foods, nutritional supplements and pharmaceutical preparations.

Chemical Composition

The functional behavior of natural oils is determined by their biochemical architecture, which differs significantly from that of mineral oils. Vegetable oils are composed primarily of triglycerides, typically representing approximately 98 percent of the total composition. The remaining fraction, commonly referred to as the unsaponifiable fraction, although quantitatively minor, contains compounds of high biological and technological value. This fraction includes phytosterols, phenolic acids, tocols such as tocopherols and tocotrienols, and carotenoids. Phytosterols contribute to membrane stabilization and are widely recognized for their cholesterol-lowering properties when incorporated into functional foods. Phenolic acids such as caffeic, ferulic and p-coumaric acids provide antioxidant activity by scavenging reactive oxygen species. Tocols act as lipid-soluble antioxidants that protect unsaturated fatty acids from oxidative degradation, thereby extending shelf life and preserving nutritional integrity. Carotenoids contribute both pigmentation and protective activity against photooxidative damage.

The fatty acid profile further defines industrial performance. Oils rich in monounsaturated fatty acids, such as oleic acid, generally exhibit higher oxidative stability, whereas those containing elevated levels of polyunsaturated fatty acids offer enhanced nutritional benefits but require stricter stability control.

Extraction and processing methods significantly influence final quality. Mechanical cold pressing preserves the integrity of the unsaponifiable fraction, whereas solvent extraction and aggressive refining steps may reduce bioactive content in favor of improved color and oxidative stability.

Properties and Applications

The multifunctional nature of plant-derived oils allows their integration across multiple industrial sectors.

In pharmaceutical applications, natural oils are widely used as solubilizing vehicles for poorly water-soluble active pharmaceutical ingredients. They enhance oral bioavailability in soft gel capsules and oral solutions and serve as lipid components in parenteral nutrition emulsions. Highly refined oils such as soybean, olive or sesame oil are selected based on pharmacopoeial standards and purity requirements. Their fatty acid composition directly influences metabolic tolerance and stability.

In cosmetics and personal care, plant oils act as emollients, barrier-repair agents and active treatments. Oils with low comedogenic potential, such as almond or grapeseed oil, are preferred for facial formulations, while more saturated oils provide occlusive protection in products designed for dry or compromised skin. Their antioxidant fraction contributes to anti-aging performance and oxidative stress mitigation.

In functional foods and nutritional supplements, specific oils are selected for their lipid profile and bioactive compounds. Extra virgin olive oil is internationally recognized as a functional food due to its high monounsaturated fatty acid content and phenolic fraction, both associated with cardiovascular and anti-inflammatory benefits.

Industrial applications frequently require stability optimization. Processes such as hydrogenation modify melting behavior and oxidative resistance, while controlled esterification generates tailored emollients with improved sensory properties and reduced greasiness.

Given their chemical complexity and susceptibility to oxidation and hydrolysis, natural oils require rigorous analytical control. Monitoring parameters such as **Free Fatty Acids**, **Peroxide Value**, **Anisidine Value** and **Iodine Value** is essential to ensure safety, shelf life and compliance with regulatory standards. Modern analytical systems designed for rapid quality assessment allow manufacturers to maintain consistent performance while minimizing solvent use and sample preparation.

Monitoring Oil Oxidation: Critical Parameters for Quality Control

Oil oxidation, commonly referred to as **rancidity**, is an unavoidable but controllable degradation process that directly affects the quality, safety and commercial value of edible and functional oils. Oxidation begins with the formation of **hydroperoxides** as **primary products** and progresses toward **secondary compounds** such as **aldehydes**, **ketones** and other **carbonyl derivatives** responsible for rancid odor and flavor. Since oils are continuously exposed to oxygen, light, heat, moisture and trace metals during processing and storage, strict analytical monitoring is essential to limit deterioration and economic losses.

Among the most widely adopted parameters for oxidation assessment are **Peroxide Value** (PV), **Anisidine Value** (AV) and **Totox Value**. PV measures hydroperoxides formed in the early stages of oxidation and provides an index of initial lipid degradation. However, as oxidation progresses, hydroperoxides decompose into secondary products, causing PV to decrease despite worsening quality. For this reason, AV is used to quantify aldehydic secondary oxidation compounds, particularly 2-alkenals and 2,4-dienals, which are directly associated with rancid sensory characteristics. To obtain a more comprehensive evaluation of oxidative status, the Totox value is calculated as AV + 2PV, offering an integrated indicator of both primary and secondary oxidation stages.

From an industrial perspective, oxidation leads to refining losses, reduced shelf life, and compromised product acceptability in food, feed and cosmetic applications. Therefore, continuous control of PV, AV and **Totox** throughout processing and storage is indispensable to ensure product stability, regulatory compliance and economic sustainability.

Traditional Official Titration Methods vs. Rapid Photometric Analysis

The official determination of oxidation and acidity parameters in oils, such as Peroxide Value, Anisidine Value, and Free Fatty Acids, is traditionally performed using standardized titration methods described in **AOCS** and **ISO protocols**. These procedures typically require large solvent volumes, glassware preparation, reagent standardization, blank corrections and careful endpoint detection. In addition, operators must handle flammable organic solvents, corrosive acids and bases, and light-sensitive reagents. The analytical workflow can be time-consuming, often requiring significant sample preparation and laboratory expertise to ensure reproducibility and compliance.

In contrast, the **CDR FoodLab®** system applies a photometric analytical approach using pre-vialed reagents and micro-quantities of sample. The method eliminates the need for solvent preparation, reflux steps or manual titration, significantly reducing analysis time and operator variability. Results are obtained within minutes, enabling real-time decision-making during raw material acceptance, processing and storage. The reduced use of hazardous chemicals enhances operator safety and lowers environmental impact. Moreover, the small sample volume minimizes interference from oil color and matrix complexity, ensuring reliable measurements even in dark or highly pigmented oils.

From an operational perspective, while official titration methods remain the regulatory reference, rapid photometric systems provide a practical, industry-friendly alternative for routine quality control, allowing processors to maintain continuous monitoring with improved efficiency, safety and cost control.

Feature	Traditional Official Methods (Titration)	CDR FoodLab® System
Methodology	Iodometric titration for **Peroxide Value**, acid–base titration for **Free Fatty Acids**, spectrophotometric method for **Anisidine Value** according to AOCS/ISO standards.	Photometric analysis with pre-calibrated methods and spectrophotometric reading.
Regulatory Status	Reference methods defined by AOCS, ISO, ASTM and EN standards.	Methods aligned with official reference procedures for routine quality control and process monitoring.
Reagents & Solvents	Requires preparation and handling of hazardous chemicals such as glacial acetic acid, isooctane, potassium hydroxide and standardized titrants.	Ready-to-use, pre-filled reagents. No preparation of large solvent volumes and no handling of bulk hazardous chemicals.
Analysis Time	Lengthy procedure involving reagent standardization, blank correction and manual titration steps.	Rapid analysis with results available within minutes.
Sample Preparation	Requires accurate weighing, solvent dissolution and controlled reaction conditions.	Minimal or no sample preparation required.
Sample Volume	Standard analytical quantities with significant solvent consumption.	Microquantities of sample required.
Matrix Interference	End-point detection may be affected by oil color or operator subjectivity.	Minimal matrix interference due to small sample volume and objective optical reading.
Equipment Requirements	Laboratory glassware, burettes, reflux systems and controlled lab environment required.	Compact instrument suitable for laboratory and production environments.
Operator Skill Level	Requires trained laboratory personnel experienced in titration techniques.	Designed for routine industrial use, no highly specialized personnel required.
Safety & Environmental Impact	Involves flammable solvents, corrosive acids and alkaline solutions, higher chemical waste generation.	Improved operator safety, reduced chemical handling and lower environmental impact.
Operational Application	Suitable for official compliance testing and external laboratory certification.	Ideal for real-time monitoring, raw material acceptance and in-process control.

Bibliography

American Oil Chemists' Society (AOCS). (n.d.). *Official Method Cd 8b-90: Peroxide Value, Acetic Acid–Isooctane Method*. Champaign, IL, USA: AOCS Press.

American Oil Chemists' Society (AOCS). (n.d.). *Official Method Cd 18-90: p-Anisidine Value*. Champaign, IL, USA: AOCS Press.

American Oil Chemists' Society (AOCS). (n.d.). *Official Method Ca 5a-40: Free Fatty Acids*. Champaign, IL, USA: AOCS Press.

Gunstone, F. D. (2011). *Vegetable Oils in Food Technology: Composition, Properties and Uses*. Wiley-Blackwell.