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# Vegetable Oil Fractionation: Technological Methods, Applications, and Future Perspectives

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**Abstract**

Vegetable oil fractionation is a technology used to modify the physicochemical properties of oils and to obtain optimized fractions for different industrial applications. This process allows the separation of fractions with different melting points, such as stearin and olein, depending on their triglyceride composition. Fractionation methods are divided into three main categories: dry (direct), solvent, and detergent (surfactant-assisted) fractionation. The dry fractionation method is widely preferred because it is environmentally friendly and economical.

In the fractionation process, parameters such as cooling rate, crystallization temperature, mixing speed, and time play a critical role. These parameters are controlled by statistical experiment design, response surface methodology, and artificial intelligence applications. The resulting products have various uses in the food, cosmetics, and pharmaceutical industries. For example, stearin from palm oil is used to produce and shorten margarine, while olein is used as a frying oil.

Technological advances enable more specific and functional oil fractions to be obtained. Research on green technologies such as supercritical $CO_2$ extraction and bio-based solvents continues within the scope of environmental sustainability. In the future, genetic engineering and enzyme technologies are expected to contribute to developing products that do not contain trans fats and have high oxidative stability.

**Keywords**: Vegetable Oil Fractionation, Dry Fractionation, Solvent Fractionation, Oil Crystallization, Palm Oil, Green Technologies, Sustainability

## Vegetable Oil Fractionation

Vegetable oil fractionation is widely used as an essential technological process in the oil industry to modify the physicochemical properties of oils and to obtain optimized fractions for specific applications. This technology enables the separation of fats into fractions with different melting points based on their triglyceride composition, resulting in high-melting stearin and low-melting olein fractions (Kellens et al., 2007). The fractionation process allows for the production of products with broad applications in the food, cosmetics, and pharmaceutical industries (Gibon, 2006).

Fractionation technology is divided into three main categories: dry (direct), solvent, and detergent (surfactant-assisted) fractionation, and studies are using SC-$CO_2$ assisted fractionation (Tamkute et al., 2020) and membrane fractionation (Coutinho et al., 2009) methods. The most commonly preferred method in industrial applications is dry fractionation because it is environmentally friendly and economical (Timms, 2005). This method involves



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cooling the oil in a controlled manner, crystallizing it, and then separating it into solid and liquid fractions through mechanical filtration. In SC-$CO_2$ supported fractionation, it is possible to obtain fractions with different melting points with temperature and pressure changes. Solvent and detergent fractionation are used for specific applications (Defense, 1985).

Optimization of the fractionation process is critical to achieving high-quality and yield products. The control of basic parameters such as cooling rate, crystallization temperature, mixing speed, and time directly affects the properties of the fractions obtained (Zaliha et al., 2004). Advanced methods such as statistical experiment design, response surface methodology (RSM), and artificial intelligence and machine learning techniques have been used in recent years to optimize these parameters (Gonzalez-Fernandez et al., 2019).

Advances in fractionation technology allow more specific and functional oil fractions to be obtained in industrial applications. For example, palm mid fraction (PMF), obtained from multiple fractionations of palm oil, is an essential raw material used in producing cocoa butter equivalent (Smith, 2001). Similarly, milk fat fractions are used in dairy products such as ice cream and cream, improving the textural properties of products (Kaylegian et al., 2007).

The future of fractionation technology is shaped by the development of more efficient and sustainable processes, the discovery of new application areas, and the further improvement of product quality. Environmentally friendly technologies such as supercritical $CO_2$ extraction are being researched to increase the sustainability of fractionation processes (Temelli, 2009), and in recent years there has been a greater focus on this issue. In addition, enzyme technologies and structured lipid production methods are used to develop product formulations that do not contain trans fats (Karabulut et al., 2004). These developments indicate that vegetable oil fractionation will continue to contribute to developing innovative products in the food, cosmetics, and pharmaceutical industries.

**Chemical and Physical Properties of Vegetable Oils**

Vegetable oils are complex lipid structures composed of triglycerides and are characterized by their chemical composition fatty acid profile (Gunstone, 2011). Triglycerides are made up of three fatty acids attached to a glycerol molecule by ester bonds, and this structure determines the physicochemical properties of fats (Shahidi & Ambigaipalan, 2018). Chain length, unsaturation, and isomeric configuration of fatty acids affect essential properties of vegetable oils, such as melting point, viscosity, and oxidation stability (Gunstone & Harwood, 2007).

The fatty acid composition of vegetable oils varies depending on the type of plant, the climatic conditions in which it grows, and genetic factors (Matthäus et al., 2016). For example, olive oil contains a high percentage of oleic acid (C18:1), while sunflower oil is rich in linoleic acid (C18:2) (Boskou, 2015). These differences determine the nutritional value of the oils and their industrial uses. The ratio of unsaturated fatty acids increases the tendency of the oil to remain liquid, while the high level of saturated fatty acids increases the solidification point (Gunstone, 2011).

Among the physical properties of vegetable oils, density, viscosity, refractive index, and melting profile stand out (Shahidi & Ambigaipalan, 2018). These properties vary depending on the triglyceride structure and fatty acid composition of oil. For example, long-chain saturated fatty acids increase the viscosity of oil, while polyunsaturated fatty acids increase the fluidity (Gunstone & Harwood, 2007). The refractive index is used as an indicator of the purity and chemical structure of the oil and is usually positively correlated with the degree of unsaturation (Boskou, 2015).

The oxidative stability of vegetable oils is closely related to the amount of unsaturated fatty acids and their antioxidant content (Shahidi & Zhong, 2010). Polyunsaturated fatty acids are



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more susceptible to oxidation and can shorten their shelf life. However, natural antioxidants, such as tocopherols and polyphenols, increase oxidative stability (Matthäus et al., 2016). For example, the high oxidative stability of olive oil is attributed to its oleic acid content and the presence of antioxidants such as polyphenols and tocopherol (Boskou, 2015).

The crystallization behavior of vegetable oils plays an essential role in the food industry and is related to the polymorphic structure of the oil (Sato, 2001). The crystal structure of triglycerides shows three basic polymorphic forms, α, β', and β. Transitions between these forms affect the textural properties and workability of the oil (Marangoni et al., 2012). For example, the tendency of cocoa butter to crystallize in its β-crystalline form determines chocolate's characteristic brittleness and melting properties (Sato, 2001). Recently, studies with cocoa butter have found crystallization in different polymorphic forms. In this direction, the importance of the fractionation technique has emerged for use in new applications (Mirzaee Ghazani & Marangoni, 2021).

The thermal properties of vegetable oils are studied using techniques such as differential scanning calorimetry (DSC), which reveal their melting-crystallization profiles (Tan & Che Man, 2000). These profiles vary depending on the triglyceride composition and polymorphic structure of oil. The thermal behavior of oils is critical in formulating and processing food products (Marangoni et al., 2012).

The rheological properties of vegetable oils encompass viscosity and flow behavior and affect the textural properties of food products (Rao, 2013). The rheological behavior of oils depends on temperature, shear velocity, and crystal structure. For example, the rheological properties of palm oil play an essential role in producing margarine and shortening (Gunstone, 2011).

The surface-active properties of vegetable oils determine their capacity to form and stabilize emulsions (McClements & Gumus, 2016). Polar lipids, such as mono- and diglycerides, accumulate at the oil-water interface, increasing the stability of emulsions. This property is critical in formulating emulsion-based food products such as mayonnaise and salad dressings (Gunstone & Harwood, 2007).

The chemical reactivity of vegetable oils depends on the presence and location of unsaturated bonds (Shahidi & Zhong, 2010). Chemical modifications such as hydrogenation, interesterification, and epoxidation alter physical and functional properties of oils. For example, the partial hydrogenation process raises the solidification point of liquid oils and increases their oxidative stability, but it can also form trans-fatty acids (Gunstone, 2011).

The nutritional value of vegetable oils is associated with essential fatty acids and fat-soluble vitamins (Shahidi & Ambigaipalan, 2018). Essential fatty acids, such as linoleic acid (omega-6) and α-linolenic acid (omega-3), are critical to human health. In addition, fat-soluble vitamins such as vitamin E (tocopherols) and vitamin K are essential components of vegetable oils and positively affect health with their antioxidant properties (Matthäus et al., 2016).

**Fractionation Techniques**

Fractionation techniques of vegetable oils are essential to modify the physicochemical properties of oils and obtain optimized fractions for specific applications. These techniques allow fats to be separated into fractions with different melting points based on their triglyceride composition (Kellens et al., 2007). Dry (direct), solvent (solvent), and detergent (surfactant-supported) fractionation techniques are determined as the main fractionation techniques, and dry fractionation is considered the most widely used and environmentally friendly method. This technique involves cooling the oil in a controlled manner, crystallizing it, and then separating it into solid (stearin) and liquid (olein) fractions by mechanical filtration (Timms, 2005). The dry fractionation process is widely used, especially in the palm oil industry, allowing valuable



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products such as palm olein and stearin to be obtained (Zaliha et al., 2004). The advantage of this method is that it does not require chemicals, and product loss is minimal.

Solvent fractionation involves dissolving the oil in an organic solvent (usually hexane or acetone) and subjecting it to controlled crystallization and filtration processes (Defense, 1985). This method provides a sharper separation than dry fractionation and is particularly effective in separating triglycerides with a high melting point. Solvent fractionation produces cocoa butter equivalents and prepares specialty oils (Smith, 2001). However, it carries environmental and safety concerns due to the use of solvents.

Detergent fractionation is a technique carried out using surfactants in an aqueous medium. After controlled crystallization, the oil is emulsified and separated by centrifugation (Gibon, 2006). Detergent fractionation is especially preferred in processing lauric acid-based oils and allows high-purity fractions to be obtained. However, there may be difficulties in waste management due to the use of water and detergents.

The efficiency of the fractionation process and the quality of the fractions obtained depend on optimizing the crystallization conditions. Parameters such as cooling rate, stirring intensity, and crystallization temperature affect crystal morphology and size (Marangoni et al., 2012). For example, slow cooling rates often form more significant and homogeneous crystals, improving filtration efficiency. In addition, the formation of desired polymorphic forms can be encouraged by using the grafting technique (Sato, 2001).

Advanced fractionation techniques include supercritical fluid extraction and membrane technology. Supercritical $CO_2$ extraction is a method in which $CO_2$ is used as a solvent under high pressure and is particularly effective in separating thermally sensitive components (Reverchon & De Marco, 2006). On the other hand, Membrane technology separates oil fractions by techniques such as nanofiltration and pervaporation (Coutinho et al., 2009).

Characterization of the products obtained from the fractionation process uses various analytical techniques. Differential scanning calorimetry (DSC) is widely used to determine the thermal properties of fat fractions (Tan & Che Man, 2000). X-ray diffraction (XRD), on the other hand, is used to analyze crystal structure and polymorphic forms (Dewettinck et al., 2004). Furthermore, gas chromatography (GC) and high-performance liquid chromatography (HPLC) techniques determine fatty acid and triglyceride compositions.

Recent advances in fractionation technology include the applications of artificial intelligence and machine learning in process control and optimization. These approaches enable real-time monitoring and optimization of the fractionation process, improving product quality and process efficiency (Gonzalez-Fernandez et al., 2019). In addition, in line with the principles of green chemistry, work continues to develop environmentally friendly solvents and energy-efficient systems.

Fractionation techniques have wide applications in the food, cosmetics, and pharmaceutical industries to improve the functional properties of vegetable oils and obtain value-added products. For example, palm oil fractions are used in the formulations of products such as chocolate, margarine, and ice cream (Gunstone, 2011). On the other hand, cocoa butter fractions have a wide range of uses in food and industrial applications, especially in chocolate production, improving melting properties and providing moisturizing and softness in cosmetics (Beckett, 2008; Barel et al., 2009). These features make these products indispensable with their quality-enhancing effects. In addition, fractionation techniques are essential in developing products that do not contain trans fats and have a low saturated fat content.


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## Equipment and Technologies Used in Fractionation

The equipment and technologies used in the fractionation of vegetable oils vary depending on the physicochemical properties of the oils and the desired end product characteristics. Dry fractionation systems are the most commonly used method, including specially designed crystallizers and filtration equipment (Kellens et al., 2007). Crystallizers usually consist of double-walled and agitated tanks equipped with cooling systems to control precise temperature. These systems optimize controlled oil cooling and crystal formation (Timms, 2005). Filtration equipment is critical in separating crystallized oil into solid and liquid fractions. Membrane filter presses and vacuum filtration systems are widely used on an industrial scale (Gibon, 2006). Membrane filter presses operate under high pressure to provide adequate separation, while vacuum filtration systems are preferred for more sensitive applications. In recent years, dynamic filtration technologies have also been developed, increasing efficiency and shortening processing time (Calliauw et al., 2010).

The equipment used for solvent fractionation differs from dry fractionation. These systems include solvent recovery units, crystallizers, and filtration equipment. In solvent fractionation systems, specially designed heat exchangers cool and crystallize the oil-solvent mixture (Defense, 1985). The filtration process usually involves centrifugal separators or unique filter systems. Solvent recovery units are critical to the economic and environmental sustainability of the process (Smith, 2001).

Detergent fractionation systems include emulsion, crystallization, and phase separation equipment. In these systems, high-shear rate mixers are used for emulsion formation, while specially designed crystallizers provide controlled cooling and crystal growth (Gibon, 2006). Disc centrifuges or decanters are usually used for phase separation. This equipment works efficiently, ensuring the effective separation of the aqueous phase, oil phase, and crystalline fraction (Kellens et al., 2007).

Among the advanced fractionation technologies, supercritical fluid extraction systems require specialized equipment such as high-pressure pumps, extraction columns, and pressure-reducing valves (Reverchon & De Marco, 2006). These systems operate at temperatures and pressures above the critical point of $CO_2$ and provide precise separation of fractions. Supercritical $CO_2$ extraction is particularly effective in separating thermally sensitive components and is considered an environmentally friendly method (Temelli, 2009).

Membrane technology is gaining more and more attention in the fractionation of vegetable oils. Membrane-based separation techniques, such as nanofiltration and pervaporation, are being developed as an alternative to traditional methods (Coutinho et al., 2009). These systems use selectively permeable membranes to separate fat fractions based on molecular size or polarity differences. Membrane technology is promising due to its energy efficiency and environmental friendliness (Rangaswamy et al., 2021).

Advanced analytical and control systems are used to optimize and control fractionation processes. Analytical instruments such as differential scanning calorimetry (DSC) and X-ray diffraction (XRD) are used for real-time monitoring of the crystallization process and evaluation of product quality (Tan & Che Man, 2000; Dewettinck et al., 2004). In addition, process control systems enable precise control of critical parameters such as temperature, pressure, and mixing speed.

Artificial intelligence and machine learning techniques have recently been used to optimize fractionation processes. Through analyzing and modeling process data, these technologies enable the automatic adjustment of process parameters and product quality prediction (Gonzalez-Fernandez et al., 2019). Within the Industry 4.0 concept framework, sensor


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technologies and Internet of Things (IoT) applications enable remote monitoring and control of fractionation equipment (Tiwari et al., 2021).

Energy efficiency and sustainability are becoming increasingly important in the design of fractionation equipment. Heat recovery systems, energy-efficient motors, and insulation technologies are widely used to reduce the energy consumption of fractionation plants (Shahidi & Ambigaipalan, 2018). In addition, bio-based solvents and new fractionation technologies developed in line with the principles of green chemistry aim to reduce the industry's environmental footprint (Chemat et al., 2012).

**Optimization of Fractionation Process Parameters**

Optimization of the fractionation process parameters of vegetable oils is critical to obtaining high-quality and yield products. The basic parameters of the fractionation process include cooling rate, crystallization temperature, mixing speed, and time. The optimization of these parameters varies depending on the triglyceride composition of the oil and the desired end-product properties (Kellens et al., 2007).

The cooling rate has a direct effect on crystal formation and growth. Slow cooling rates usually create more significant and homogeneous crystals, while rapid cooling forms small and irregular crystals. Zaliha et al. (2004) investigated the effect of cooling rate on palm oil fractionation and determined that the optimal cooling rate is in the range of 0.05-0.3°C/min. In this range, it was observed that the quality parameters such as iodine value and cloud point of the obtained olein improved.

Crystallization temperature is an important parameter that affects the polymorphic structure and amount of crystals formed. The optimal crystallization temperature for each type of oil differs. For example, for palm oil, this temperature is generally reported to be in the range of 18-22°C, while for cocoa butter, it is reported to be in the range of 26-28°C (Timms, 2005; Mirzaee Ghazani & Marangoni, 2021). Differential scanning calorimetry (DSC) analysis is widely used in determining the optimal crystallization temperature (Tan & Che Man, 2000).

Mixing speed and time are other important parameters that affect crystal formation and growth. High mixing speeds promote the formation of tiny crystals, while low speeds allow for the formation of larger crystals. Calliauw et al. (2010) studied the effect of mixing speed on the fractionation of palm olein and determined that the optimal mixing speed is 15-30 rpm. In this range, it has been observed that the obtained fractions give the best results regarding physicochemical properties and yield.

Optimization of fractionation time is essential for process efficiency and product quality. Long fractionation times often result in better separation while increasing energy consumption and operating costs. Gibon (2006) stated that the optimal time for palm oil fractionation varies between 4-8 hours, and this time should be adjusted depending on the initial composition of the oil and the desired end product properties.

The grafting technique is another important parameter used in optimizing the fractionation process. Adding preformed crystals can accelerate the formation of desired polymorphic forms and shorten the process time. Sato (2001) studied the effect of the grafting technique on cocoa butter crystallization and showed that it promotes the formation of $\beta_V$ crystals. This technique is widely used to optimize the tempering process in chocolate production.

Techniques such as statistical experiment design and response surface methodology (RSM) are widely used in optimizing the fractionation process. These approaches allow us to analyze the interactions of different process parameters and determine optimal conditions. Defense (1985)



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used these techniques in palm oil fractionation to model the effects of cooling rate, crystallization temperature, and mixing rate on the iodine value and yield of olein.

Artificial intelligence techniques such as artificial neural networks and genetic algorithms have been used to optimize fractionation process parameters in recent years. Thanks to their ability to model complex and nonlinear relationships, these techniques can give more effective results than traditional optimization methods. Gonzalez-Fernandez et al. (2019) examined the use of artificial neural networks in olive oil production and showed that these techniques can be successfully applied in process optimization.

Advanced analytical techniques are used for online monitoring and real-time optimization of the fractionation process. Techniques such as Fourier transform infrared spectroscopy (FTIR) and near-infrared spectroscopy (NIR) allow for real-time monitoring of the crystallization process and dynamic adjustment of process parameters (Verstringe et al., 2012). This approach helps to reduce energy consumption and waste generation while improving the consistency of product quality.

Sustainability and energy efficiency are becoming increasingly crucial in optimizing fractionation process parameters. Heat recovery systems, energy-efficient motors, and insulation technologies are widely used to reduce the energy consumption of fractionation plants. In addition, new fractionation technologies developed in line with the principles of green chemistry aim to reduce the environmental footprint of industry (Chemat et al., 2012).

**Feature of products obtained as a result of fractionation of vegetable oils**

The products obtained from the fractionation of vegetable oils have different physicochemical and functional properties than the starting material and find wide application in the food, cosmetics, and pharmaceutical industries. The fractionation process allows fats to be separated into fractions with different melting points based on their triglyceride composition, resulting in high-melting stearin and low-melting olein fractions (Kellens et al., 2007).

Palm stearin, obtained from palm oil fractionation, is widely used in producing margarine and shortening due to its high melting point (44-56°C) and fat content. Since palm stearin tends to form a β' crystal form, it provides the desired texture and plasticity in products (Smith, 2001). On the other hand, palm olein fraction is preferred as frying oil due to its low melting point (19-23°C) and high oxidative stability. Palm super olein, on the other hand, has an even lower melting point (13-15°C) and can be used as a liquid oil in cold climates (Gibon, 2006).

Cocoa butter equivalents (CBE) are one of the essential products of fractionation technology. CBEs, which are obtained by blending fractionated fats such as palm oil medium fraction (PMF), shea butter, and illipe oil, show triglyceride composition (POP, POS, SOS) and melting profile similar to cocoa butter (Lipp & Anklam, 1998). These products are used as a partial substitute for cocoa butter in the chocolate industry, reducing product costs and increasing the thermal resistance of chocolate (Jahurul et al., 2013).

Products obtained due to the fractionation of coconut oil are widely used in cosmetics and personal care products. The high-melting coconut stearin fraction (32-36°C) is used as a building agent in skin creams and lotions, while the low-melting olein fraction (20-24°C) is preferred as a moisturizing agent in hair care products (Timms, 2005). These fractions show more specific functional properties than the original coconut oil and allow for more controlled use in product formulations.

Fractionation of olive oil allows the liquid fraction to have a high oleic acid content and the solid fraction to have a high stearic and palmitic acid content. The liquid fraction has a lower cloud point and viscosity, making it suitable for cold climates. On the other hand, the solid


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fraction can be used in producing margarine and shortening because of its high melting point and oxidative stability (Contiñas et al., 2008). These fractions, while preserving the nutritional properties of olive oil, allow for different areas of application.

The fraction with high oleic acid content obtained due to the fractionation of sunflower oil is preferred in industrial applications due to its oxidative stability. This fraction provides a longer shelf life when used as a frying oil and minimizes the formation of trans fats (Grompone, 2011). The fraction with low linoleic acid content has a higher melting point and can be used in margarine production.

The fractionation of soybean oil allows a solid fraction with a high stearic acid content and a liquid fraction with a high linoleic and linolenic acid content. The solid fraction can produce margarine and shortening but does not contain trans fats. In contrast, the liquid fraction can develop functional food products enriched with omega-3 and omega-6 fatty acids (List et al., 1995). These fractions expand the use of soybean oil and allow for more specific applications.

The physicochemical properties of the products obtained from fractionation differ significantly according to the starting material. For example, the iodine value of the palm stearin fraction (21–48 g $I_2$/100 g) and cloud point (44–56°C) are significantly different from that of the original palm oil (iodine value: 50–55 g $I_2$/100 g, cloud point: 31–35°C) (Zaliha et al., 2004). These differences allow the fractions to be used in specific applications and allow for more precise adjustments to product formulations.

The fractionation process can also affect the nutritional value of oils. For example, palm olein, obtained by fractionation of palm oil, contains more unsaturated fatty acids than the original palm oil and maybe more nutritionally advantageous (Sundram et al., 2003). Similarly, the liquid fraction obtained from the fractionation of olive oil may contain a higher proportion of oleic acid and phenolic compounds, which may increase its antioxidant capacity (Contiñas et al., 2008). With the development of fractionation technology, products with more specific properties can be obtained by applying multiple fractionation processes. For example, palm mid fraction (PMF), obtained from various fractionations of palm oil, is an essential raw material used in producing cocoa butter equivalent. PMF is rich in POP (1,3-dipalmitoyl-2-oleoyl-glycerol) triglycerides (>65%), providing the desired crystallization and melting properties in chocolate products (Calliauw et al., 2010). Such advanced fractionation techniques allow higher value-added products to be obtained in industrial applications.

**Areas of application**

Products obtained from the fractionation of vegetable oils have a wide range of applications in the food industry. Palm oil fractions are widely used, especially in producing margarine and shortening. Palm stearin, due to its high melting point and tendency to form a β' crystal form, provides the desired texture and plasticity in margarines (Smith, 2001). Palm olein, on the other hand, is preferred as a frying oil due to its low melting point and high oxidative stability (Gibon, 2006). Using these fractions helps reduce the trans fat content while improving the functional properties of the products.

The chocolate industry is an important application area of fractionated fat products. Cocoa butter equivalents (CBE) are obtained by blending fractionated oils such as palm oil medium fraction (PMF), shea butter, and illipe oil. These products are used as a partial substitute in chocolate production, showing triglyceride composition and melting profile similar to cocoa butter (Jahurul et al., 2013). Using CBEs increases the thermal resistance of chocolate, reduces costs, and expands product diversity.

The dairy industry is another important application area of fractionated fat products. Milk fat fractions are used in ice cream, cream, and cheese, improving their textural properties and



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melting profile. High melting point milk fat fractions increase the melting resistance of ice cream, while low melting point fractions provide a creamy texture (Kaylegian et al., 2007). While these applications improve the functional properties of dairy products, they allow the development of products suitable for consumer preferences.

Bakery products are another area where fractionated oils are widely used. Palm stearin and palm olein fractions produce cakes, biscuits, and crackers, improving the texture, flavor, and shelf life of products. In particular, due to its high-fat content, palm stearin provides the desired brittleness and crunch in pastries (Nor Aini & Miskandar, 2007). These applications help optimize production costs while improving the quality of bakery products.

The cosmetics and personal care products industry is an important application area of fractionated fat products. Coconut oil fractions are widely used in skin creams, lotions, and hair care products. The high-melting stearin fraction is used as a building agent in skin creams, while the low-melting olein fraction is preferred as a moisturizing agent (Timms, 2005). These fractions show more specific functional properties than the original oil, allowing more controlled use in product formulations.

The pharmaceutical industry is another area of application of fractionated oil products. High-purity oil fractions are used as carrier systems in drug formulations. For example, palm oil fractions are used in controlled-release systems and liposome formulations, increasing drug efficacy and bioavailability (Obitte et al., 2010). These applications contribute to developing new and effective formulations in the pharmaceutical industry. Industrial applications are an increasing use of fractionated oil products. Sunflower oil fractions with high oleic acid content are used as bio-based lubricants and hydraulic fluids. These products show higher biodegradability and lower toxicity than petroleum-based alternatives (Grompone, 2011). In addition, palm oil fractions are used as raw materials in biodiesel production, contributing to the development of renewable energy sources.

The animal feed industry is another application area of fractionated oil products. Oil fractions with high energy content are used as an energy source in animal feed. In particular, palm oil fractions are widely used in ruminant and poultry feeds, improving animal growth performance and feed conversion rate (Palmquist, 2009). These applications offer more effective and economical solutions in animal nutrition.

The textile industry is another area where fractionated oil products are used. Coconut oil fractions with a high lauric acid content are used to produce textile softeners. While these products give softness and flexibility to fabrics, they also provide antistatic properties (Ataman Chemicals, 2025). In addition, palm oil fractions are used as emulsifiers in the formulations of textile dyes, improving dye performance.

The paint and ink industry is an ever-increasing application area of fractionated oil products. Soybean oil fractions with high linoleic acid content are used to produce alkyd resins, allowing the development of environmentally friendly paint formulations. These products reduce volatile organic compound (VOC) emissions while increasing the durability and gloss of the paint (Lligadas et al., 2013). In addition, palm oil fractions are used as a carrier system in ink formulations, improving print quality.

**Problems Encountered in Vegetable Oil Fractionation and Solution Suggestions**

Vegetable oil fractionation is a necessary process to modify the physicochemical properties of oils and obtain optimized fractions for specific applications. However, various problems are encountered in this process, and continuous research is being carried out to solve these problems.



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Crystallization control is one of the most significant challenges encountered in fractionation. Obtaining the appropriate crystal size and morphology directly affects the separation efficiency of the fractions. Slow cooling rates generally produce more critical and homogeneous crystals, while rapid cooling forms small and irregular crystals (Kellens et al., 2007). To solve this problem, controlled cooling profiles and grafting techniques are used. Grafting optimizes the crystallization process by promoting the formation of desired polymorphic forms (Sato, 2001).

Filtration efficiency is another major problem encountered in the fractionation process. Filtration becomes difficult, especially in high-viscosity oils and small crystal sizes. This problem is being solved by developing filtration equipment and optimizing process conditions. Modern technologies that improve filtration efficiency include membrane filter presses and dynamic filtration systems (Calliauw et al., 2010).

Striking a balance between the purity and yield of fractions is another challenge in industrial applications. Stringent process conditions applied to obtain high-purity fractions often reduce yields. Multi-stage fractionation techniques and optimized process parameters solve this problem (Gibon, 2006). Furthermore, artificial intelligence and machine learning techniques are increasingly used in process optimization (Gonzalez-Fernandez et al., 2019).

Oxidative stability is a significant problem encountered in fractionated fat products. Fractions with an exceptionally high content of unsaturated fatty acids are more susceptible to oxidation. To solve this problem, methods such as using natural and synthetic antioxidants, processing under inert gas, and appropriate packaging techniques are applied (Shahidi & Zhong, 2010). Furthermore, developing oil varieties with high oleic acid content is another strategy in which genetic engineering approaches are used to increase oxidative stability.

Environmental sustainability is an increasingly important issue in fractionation operations. In particular, the ecological effects of organic solvents used in solvent fractionation methods are of concern. To solve this problem, environmentally friendly technologies such as supercritical $CO_2$ extraction are being developed (Temelli, 2009). In addition, various strategies are implemented to minimize and recycle process waste. Energy efficiency is another major challenge in fractionation processes. Crystallization and filtration processes cause high energy consumption. To solve this problem, heat recovery systems, energy-efficient motors, and insulation technologies are used (Shahidi & Ambigaipalan, 2018). In addition, techniques such as process integration and pinch analysis are applied to optimize energy consumption.

Consistency of product quality is another challenge in fractionation processes. Variations in raw material composition and fluctuations in process conditions can cause inconsistencies in product quality. Advanced process control systems and real-time analytical techniques are used to solve this problem. Techniques such as Fourier transform infrared spectroscopy (FTIR) and near-infrared spectroscopy (NIR) allow real-time monitoring of the crystallization process and dynamic adjustment of process parameters (Verstringe et al., 2012). Cost optimization is a significant challenge in fractionation operations on an industrial scale. The equipment and operating costs required to obtain high-quality fractions affect product prices. To solve this problem approaches such as process intensification and continuous production systems are applied. In addition, evaluating by-products and their transformation into value-added products are strategies used for cost optimization (Gunstone, 2011).

Developing product formulations that do not contain trans fats has presented new challenges in fractionation technology. As an alternative to conventional hydrogenation processes, combinations of fractionation and interesterification are used. However, these approaches also bring new technical challenges. To solve this problem, new enzyme technologies and structured lipid production methods are being developed (Karabulut et al., 2004).


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As a result, vegetable oil fractionation remains an essential technology in the oil industry. Research and development studies in this field continue in line with developing technologies and increasing consumer demands. The optimization of fractionation technology and the discovery of new areas of application will contribute to the development of innovative products in the food, cosmetics, and pharmaceutical industries.

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