MODIFICATION OF FRYING OIL AND BATTER FOR FAT UPTAKE REDUCTION IN DEEP-FRIED CHICKEN PRODUCTS: AN OVERVIEW

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Abstract:

The expanding global demand for deep-fat fried chicken products is primarily driven by their highly desired and distinctive sensory qualities, accessibility, and affordability. However, one major worry voiced by consumers and stakeholders is its high-fat content. The high levels of dietary fat in deep-fried foods raise the risk of noncommunicable illnesses such as obesity, coronary heart disease, diabetes, and so on. In response to the need to reduce the fat content of chicken products, oleogel research has been active in recent decades, yielding several oleogels with desirable qualities such as heat resistance, oxidative stability, and high oil binding capacity. Recently, the use of oleogel as a frying medium has grown in favor. Several studies have found that using oleogel as a frying medium can lower the fat content of deep-fried chicken products. In addition, the amount of literature on the utilization of fiber in food products has also increased dramatically. For example, citrus peel fiber (CPF), a byproduct of juice manufacturing, has gained popularity for its great health-promoting benefits, fat-reduction characteristics, and water-binding capacity. The purpose of this review is to explore the potential of oleogel as a frying medium and the usage of CPF as a functional component in chicken products to reduce fat absorption. Furthermore, this review will discuss current results concerning oleogel and CPF, with an emphasis on anticipating the combined viewpoint of oleogel and CPF in producing deep-fried chicken products.

Keywords: Citrus Peel Fiber; Deep Frying; Fat Uptake; Oleogel

1. Introduction

The apparent availability of digestible elements such as amino acids, fatty acids, vitamins, and minerals makes chicken meat and its products vital in contributing to human health growth and development. In recent years, global chicken meat production has increased significantly, with production exceeding 100 million metric tons in 2023 (Statista, 2023). Consumption of chicken-based products is rising as chicken meat production increases. Because most well-known chicken items go through an oil-dependent frying procedure, the fat content of the final products is likely to be more substantial. Fat is necessary for the general acceptability of products but has also been linked to an increase in noncommunicable diseases (NCDs) such as obesity, heart disease, and diabetes (Adrah et al., 2022). In this regard, reducing fat portions in food products, especially deep-fried chicken products, has become urgent. Numerous studies have been conducted and put in progress to find innovative ways to control and minimize oil uptake during frying (Adrah et al., 2021; Liberty et al., 2019).

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One of the endeavors that recently came to the top of interest among researchers is the application of oleogel technology for its peculiarity in reducing fat uptake in final products. In the oleogel system, liquid oil is converted to semi-solid gels (Adrah et al., 2021). Oleogelators facilitate the conversion of liquid oil to solid-like gel conversion. During the frying process, the oleogel system forms networks that help to entrap and retain oil molecules. However, the oleogel system's efficacy depends on the type of oleogelator used and their network shape, size, number, interactions between the network, and thermal stability (Adrah et al., 2022). Another significant recent trend in the field of food processing is the addition of fibers in different food settings as functional ingredients. The addition of fiber, especially citrus peel fiber (CPF), has been previously reported to be effective in reducing the fat content of food products such as sausages and frankfurters (Fernández-López et al., 2007; Song et al., 2016). In summary, the purpose of this review is to provide an overview of the effect of an oleogel system as a frying medium and employ of CPF as a functional ingredient in reducing the fat content in deep-fried chicken products.

2. Fat uptake in deep-fried foods

Immersion frying, commonly referred to as deep frying, stands as one of the oldest and most extensively employed food preparation unit processes. The practice of deep-frying is believed to have originated in the Mediterranean region, primarily due to the widespread availability and use of olive oil (Andrikopoulos et al., 2002). In recent years, there has been a notable trend in the deep-frying of various processed foods. The significance of fried foods in the food industry cannot be overstated, as they enjoy widespread popularity among consumers and are produced and consumed on industrial and commercial scales in massive quantities. One critical consideration in the realm of deep-fat fried products is the substantial amount of fat absorbed during the frying process. In certain instances, this can exceed 40% of the overall product weight, raising important concerns regarding the nutritional profile of deep-fried products. The oil's cost, stability, location, oxidation resistance, and fried food products decide which frying oil to use. Highly unsaturated vegetable oils have a short frying life and food shelf life due to their vulnerability to oxidation at high temperatures (150°–200°C). On the other hand, saturated fatty acids (SFAs)-rich oils and partially hydrogenated oils offer improved frying stability. Heating promotes oxidative and thermal deterioration of oil during high-temperature frying, creating oxidized and polymerized molecules with increased polarity and altering the nutritional qualities of dietary fat and fried food (Gadiraju et al., 2015). Deep-frying involves the transmission of heat and mass, changes in the product's structure, and a temperature differential between the core and the crust. Oil absorption in fried foods results from these mechanisms. According to studies (Bouchon, 2009; Kassama and Ngadi, 2016), oil absorption is linked to frying temperature and duration. Other variables, such as sample pretreatment and structural changes in the test samples, might be accused of the varied results. Oil absorption is a complicated process that has yet to be fully understood. Several variables, including the starting product structure, the interchanges between the frying medium and the product, and the qualities of the oil, make it difficult for scientists to grasp this phenomenon.

3. Oleogelation for fat uptake reduction

Various methods have been studied to limit oil absorption into food during frying, which is a significant nutritional aspect of deep-frying owing to its health consequences. The frying medium significantly impacts the incorporation of fat into food during deep-frying. Using oleogelation as a frying medium could help to reduce oil absorption while also boosting nutritional value and lowering calorie intake. Oleogels are lipophilic liquid and solid mixes that may entrap bulk oil to create a thermo-reversible, three-dimensional gel network at low concentrations (less than 10% of weight) of solid lipid components (oleogelator) (Adrah et al., 2022). Waxes are oleogelators that contain n-alkanes, fatty acids, fatty alcohols, alcohols, and esters of pentacyclic triterpenoids and sterol esters. With a high melting temperature, these chemical components of waxes make them hydrophobic. These wax esters are generally made up of plants, insects, marine animal derivatives, and petroleum. Plant-based waxes have sparked a lot of interest in oleogel research during the last decade due to their availability, natural origin, and regulatory acceptance. Natural plant waxes such as candelilla (*Euphorbia antisyphilitica*), carnauba (*Copernicia prunifera*), and rice bran wax are employed in food studies (Silva et al., 2023). Plant-based waxes have good gelation properties and can gel liquid oils at concentrations as low as 1–4%. Even though oleogels include a considerable amount of liquid (oil), the system has solid fat properties (Siraj et al., 2015). Oleogels immobilize liquid edible oils in a 3D network produced by an oleogelator, replacing them with a better alternative to traditional saturated fatty acid (SAFA)-based lipids. Several compounds have been found that can shape oils rich in (poly) unsaturated fatty acids. The chemical composition, network development, and interactions, as well as the macroscopic characteristics of the various oleogels, differ significantly. For over two decades, oleogels have been a focus of food research, but commercial applications are sparse.

The study of the viability of employing oleogel as a frying medium for muscle food items has recently received much interest. In a study by Adrah et al., (2022), carnauba wax was used to structure canola oil into oleogels, and the ability to reduce fat uptake while deep-frying chicken breast samples was assessed. Compared to samples fried in canola oil (15.10%), chicken samples fried in 5% and 10% oleogels recorded a lower fat-uptake (8.53% and 9.15% respectively). There are several previously established mechanisms available for fat uptake in deep-frying (**Fig 1**). These mechanisms have been found connected to the use of oleogel frying, which limits fat absorption in the final products. For instance, oleogel deep-frying can help to reduce the impact of cooling phase effects. During the cooling phase, the absorption of oil starts after the product has been removed from the frying medium. Water vapor condenses as it is released from the frying medium, lowering the vapor pressure of the pores in the crust (Ananey-Obiri et al., 2018). The decrease in pressure causes oil to flow into these pores. As a result, a balance between adhesion forces and oil drainage during the cooling phase is required for oil absorption. Oleogel is highly viscous and heavy due to the presence of hydrocolloids (oleogelator) in the matrix. The hydrocolloid action helps to retain the vapor pressure and reduces the migration of oil towards crust pores. On the other hand, normal cooking oils are less viscous and light. Therefore, when there is low vapor pressure of the pores in the crust, oil starts to flow into these pores easily. The microstructure of the crust formed during deep-frying may be studied to assess oil absorption and distribution. Therefore, the product's surface characteristics (crust) and the frying medium's viscosity are the key parameters determining oil absorption. To control oil absorption during the cooling phase, superheated hot air or steam is used to blast the surface oil, or an adsorbent paper is used to soak the oil from the fried product's surface. For the surface-active agent mechanism, oleogel also plays an important role. Deep-frying causes a sequence of chemical processes that cause oil quality to deteriorate (Gertz, 2014). Typical reactions that occur during the frying result in the formation of a variety of chemicals. The link between glycerol and fatty acids is cleaved by hydrolytic processes initiated by adulterating the oil phase with water. The formation of free fatty acids, monoglycerides, and diglycerides is accelerated by increasing the frying temperature. These polar chemicals and surface-active substances (mono- and diglycerides) boost the frying medium's foaming propensity, which speeds up the hydrolytic process. The creation of these degradative chemicals influences the oil-food contact, lowering surface tension between the two components. Excessive oil absorption occurs when the surface tension is low, and the contact duration is extended. The production of surfactants impacts heat transmission at the oil-food contact. Continuous heat transfer to the food induces drying at the food surface and increases water migration to the food's exterior. Some studies support the surface-active agent mechanism involving low fat-uptake during deep-frying. Because the oleogel frying medium is highly viscous as a result of oleogelation, the oil takes longer to move inward. Furthermore, the oleogel deep frying medium has previously been demonstrated to provide a continuous and smooth surface with small pores. Thus, small pores combined with a uniform surface will aid in lowering fat-uptake by acting as a barrier to oil moving inward (Adrah et al., 2022; Lim et al., 2017).

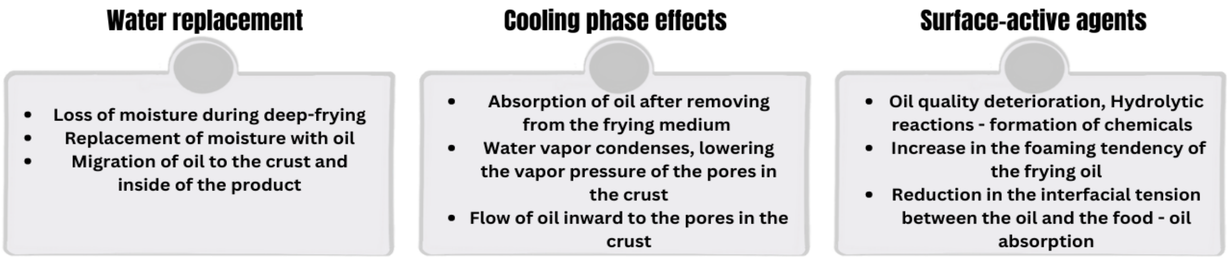

Figure 1: A brief overview of the three mechanisms of fat-uptake during deep-frying (Mellema, 2003)**.**

4. Citrus peel fiber for fat uptake reduction

Consumers' desire for healthy food has prompted the industry to review the nutrient quality of product portfolios to offer products with lower fat content by incorporating functional ingredients and enhancing other technological properties. One of the major fruit crops in the world, citrus, is thought to produce more than 170 million tons annually. However, a significant issue in the food industry is a citrus byproduct after juice production. Each year, it generates waste (>1.5 million tons) that is thrown away and pollutes the environment (Montgomery, 2004). Peels (albedo and flavedo), seeds, fruit pulp, and essential oils comprise most of the citrus waste, and their disposal raises environmental issues. In this competition, numerous efforts have been made in various fields, suggesting the versatile use of citrus waste.

Citrus peel fiber comprises soluble (pectin) and insoluble (cellulose, hemicellulose) components, depending on how soluble they are in the water. The prevention and treatment of obesity, atherosclerosis, coronary heart disease, and diabetes are greatly aided by soluble fiber. Additionally, most insoluble fiber undergoes fermentation in the large intestine, which helps the development of healthy intestinal microbiota. As a result, the use of fibers derived from citrus sources in food products has garnered interest in recent years. For example, it is a texture enhancer in meat products like sausages, minced fish (surimi), and frankfurters due to its superb fat-binding and water-binding properties (Sharaf Eddin et al., 2020). Some academics have investigated the health benefits of fiber. Their findings imply that soluble fibers are connected with lower cholesterol levels and glucose adsorption in the colon, but insoluble fibers are involved with intestinal control (Theuwissen and Mensink, 2008). Furthermore, Gallaher and colleagues (Gallaher et al., 1992) claimed that dietary fiber reduced total cholesterol and low-density lipoprotein (LDL) levels in plasma through bile acid excretion. Dietary fiber can have a significant impact on the diversity, richness, and composition of the microbiome by offering a wide range of substrates for fermentation processes carried out by microbe species that have the enzyme machinery required to break down complex molecules. While there are various forms of dietary fiber, each of which is broken down, there are numerous microbiota species classified as fiber fermenters in the large intestine. Consuming more dietary fiber changes the nutritional niches in the colon, which enables these bacteria to multiply. People with low-fiber diets typically have less diverse microbial populations. As the reduced dietary fiber is likely to be substituted in the diet by animal protein and fat, people with a diet rich in animal protein and fat are likely to harbor bacteria that thrive on amino acids and lipids (Cronin et al., 2021). Thus, given the health benefits of fibers, it is critical to incorporate fibers into food products, particularly popular products such as deep-fried products, to improve overall fiber consumption.

A recent study developed low-fat (10% fat) frankfurters with varying amounts (0, 1, 2, and 3 %) of citrus fiber. The results indicated that citrus fiber could significantly reduce the cooking loss of low-fat frankfurters from 12.69% to 4.71%. Unlike control, frankfurters formulated with reduced fat and citrus fiber contained substantially less fat. The overall fat content of the sausages was close to the target range of 20 to 10%. Among the various samples, those containing 3% citrus fiber had the least amount of fat (Song et al., 2016). Although citrus fiber has been successfully applied to numerous food products, its application to chicken meat-based products remains limited. Few studies have examined the incorporation of citrus-derived fiber into chicken products. For example, chicken patties were developed by substituting citrus peel fiber for fat at 1.0%, 2.0%, and 3.0%. As the fiber concentration increased, the fat content decreased (Chappalwar et al., 2021).

To support the premise of employing CPF to reduce absorption, it is necessary to discuss its ability to accomplish water binding and fat binding. Citrus fiber is mostly made up of pectin, cellulose, and hemicellulose. Because cellulose has a certain capability for expanding in water, it can absorb more moisture. Due to its branching, typically amorphous, and non-crystalline structure, hemicellulose also has a high water-binding capacity. As a result, the CPF has a stronger water-binding ability when added to food products (Wen et al., 1988). However, the proportion of fat uptake in relation to the qualities of the fiber additions must be stated. According to a recent study, the sample with the highest amount of water-soluble fibers had the lowest fat uptake value. This suggests that soluble fibers can lower the product's oil uptake. One possible explanation is that soluble fibers can form a gel network that raises the viscosity of the product's aqueous phase, hence limiting oil penetration into the product's core (Galanakis et al., 2010). To boost CPF's application in deep-fried chicken products, CPF can be added to the batter mix. The CPF can then be applied to the product's surface through battering. One theory suggests that when fiber is applied in batter coating, its hydrophilic properties may bind with water molecules on the food surface, thus limiting moisture loss during frying. As a result, the confined mobility of moisture molecules impedes the absorption of oil molecules by the product, thereby reducing the fat content (Ching et al., 2021; Song et al., 2016).

Based on our review, the integration of CPF application in the batter mix, coupled with the utilization of oleogel as a frying medium, demonstrates the potential to effectively decrease the fat content of deep-fried chicken products. The rationale behind this approach lies in the idea that the presence of CPF on the food's surface facilitates the retention of moisture within, consequently limiting the ingress of oil during the frying process. Furthermore, the high viscosity and three-dimensional network-forming capability of oleogel contribute to the reduction of oil absorption into the product. We recommend implementing these two strategies to achieve the desired reduction in fat levels for fried chicken products. Nonetheless, it is crucial to exercise particular caution and thoroughly comprehend the sensory and nutritional attributes of the final product to ensure consumer acceptance and nutritional adequacy.

5. Conclusion

This review supports the concept of using oleogel for deep-frying chicken. It also discussed the fat-lowering properties of citrus peel fiber. According to our literature search, lowering the final fat content of chicken products may be accomplished by combining oleogel frying and CPF during the production process. Researchers can use the integrated approach to produce low-fat fried food products and explore additional quality aspects owing to the development of oleogel technology and the rising demand for healthier foods.

References:

Adrah, K., Adegoke, S. C., Nowlin, K., & Tahergorabi, R. (2022). Study of oleogel as a frying medium for deep-fried chicken. *Journal of Food Measurement and Characterization*, *16*(2), 1114–1123. https://doi.org/10.1007/s11694-021-01237-6

Adrah, K., Ananey-Obiri, D., & Tahergorabi, R. (2021). Sweet potato starch and a protein-based edible coating minimize the fat-uptake in deep-fat fried chicken. *CyTA - Journal of Food*, *19*(1), 440–447. https://doi.org/10.1080/19476337.2021.1914736

Ananey-Obiri, D., Matthews, L., Azahrani, M. H., Ibrahim, S. A., Galanakis, C. M., & Tahergorabi, R. (2018). Application of protein-based edible coatings for fat uptake reduction in deep-fat fried foods with an emphasis on muscle food proteins. *Trends in Food Science & Technology*, *80*, 167–174. https://doi.org/10.1016/j.tifs.2018.08.012

Andrikopoulos, N. K., Dedoussis, G. V. Z., Falirea, A., Kalogeropoulos, N., & Hatzinikola, H. S. (2002). Deterioration of natural antioxidant species of vegetable edible oils during the domestic deep-frying and pan-frying of potatoes. *International Journal of Food Sciences and Nutrition*, *53*(4), 351–363. https://doi.org/10.1080/09637480220138098

Ansorena, D., Guembe, A., Mendizábal, T., & Astiasarán, I. (2010). Effect of Fish and Oil Nature on Frying Process and Nutritional Product Quality. *Journal of Food Science*, *75*(2), H62–H67. https://doi.org/10.1111/j.1750-3841.2009.01472.x

Bouchon, P. (2009). Chapter 5 Understanding Oil Absorption During Deep-Fat Frying. In *Advances in Food and Nutrition Research* (Vol. 57, pp. 209–234). Elsevier. https://doi.org/10.1016/S1043-4526(09)57005-2

Chappalwar, A. M., Pathak, V., Goswami, M., Verma, A. K., & Rajkumar, V. (2021). Efficacy of lemon albedo as fat replacer for development of ultra-low-fat chicken patties. *Journal of Food Processing and Preservation*, *45*(7). https://doi.org/10.1111/jfpp.15587

Ching, L. W., Zulkipli, N. ‘Afifah M., Muhamad, I. I., Marsin, A. M., Khair, Z., & Anis, S. N. S. (2021). Dietary management for healthier batter formulations. *Trends in Food Science & Technology*, *113*, 411–422. https://doi.org/10.1016/j.tifs.2021.03.054

Cronin, P., Joyce, S. A., O’Toole, P. W., & O’Connor, E. M. (2021). Dietary Fibre Modulates the Gut Microbiota. *Nutrients*, *13*(5), 1655. https://doi.org/10.3390/nu13051655

Donfrancesco, C., Lo Noce, C., Brignoli, O., Riccardi, G., Ciccarelli, P., Dima, F., Palmieri, L., & Giampaoli, S. (2008). Italian network for obesity and cardiovascular disease surveillance: A pilot project. *BMC Family Practice*, *9*(1), 53. https://doi.org/10.1186/1471-2296-9-53

Fernández-López, J., Viuda-Martos, M., Sendra, E., Sayas-Barberá, E., Navarro, C., & Pérez-Alvarez, J. A. (2007). Orange fibre as potential functional ingredient for dry-cured sausages. *European Food Research and Technology*, *226*, 1–6.

Gadiraju, T., Patel, Y., Gaziano, J., & Djoussé, L. (2015). Fried Food Consumption and Cardiovascular Health: A Review of Current Evidence. *Nutrients*, *7*(10), 8424–8430. https://doi.org/10.3390/nu7105404

Galanakis, C. M., Tornberg, E., & Gekas, V. (2010). Dietary fiber suspensions from olive mill wastewater as potential fat replacements in meatballs. *LWT - Food Science and Technology*, *43*(7), 1018–1025. https://doi.org/10.1016/j.lwt.2009.09.011

Gallaher, D. D., Locket, P. L., & Gallaher, C. M. (1992). Bile Acid Metabolism in Rats Fed Two Levels of Corn Oil and Brans of Oat, Rye and Barley and Sugar Beet Fiber. *The Journal of Nutrition*, *122*(3), 473–481. https://doi.org/10.1093/jn/122.3.473

Gertz, C. (2014). Fundamentals of the frying process. *European Journal of Lipid Science and Technology*, *116*(6), 669–674.

Kassama, L. S., & Ngadi, M. (2016). Relationship between Oil Uptake and Moisture Loss during Deep Fat Frying of Deboned Chicken Breast Meat. *Advances in Chemical Engineering and Science*, *06*(04), 324–334. https://doi.org/10.4236/aces.2016.64033

Liberty, J. T., Dehghannya, J., & Ngadi, M. O. (2019). Effective strategies for reduction of oil content in deep-fat fried foods: A review. *Trends in Food Science & Technology*, *92*, 172–183.

Lim, J., Jeong, S., Oh, I. K., & Lee, S. (2017). Evaluation of soybean oil-carnauba wax oleogels as an alternative to high saturated fat frying media for instant fried noodles. *LWT*, *84*, 788–794. https://doi.org/10.1016/j.lwt.2017.06.054

Mellema, M. (2003). Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends in Food Science & Technology*, *14*(9), 364–373. https://doi.org/10.1016/S0924-2244(03)00050-5

Minihane, A. M., & Harland, J. I. (2007). Impact of Oil used by the Frying Industry on Population Fat Intake. *Critical Reviews in Food Science and Nutrition*, *47*(3), 287–297. https://doi.org/10.1080/10408390600737821

Montgomery, R. (2004). Development of biobased products. *Bioresource Technology*, *91*(1), 1–29. https://doi.org/10.1016/S0960-8524(03)00154-8

Sharaf Eddin, A., Adegoke, S., Issa, A. T., Wilson, C., & Tahergorabi, R. (2020). Physicochemical Changes of Surimi Gels with Addition of Different Particle Sizes of Citrus Peel Fiber. *Journal of Aquatic Food Product Technology*, *29*(10), 1029–1040. https://doi.org/10.1080/10498850.2020.1829229

Silva, R. C. D., Ferdaus, Md. J., Foguel, A., & Da Silva, T. L. T. (2023). Oleogels as a Fat Substitute in Food: A Current Review. *Gels*, *9*(3), 180. https://doi.org/10.3390/gels9030180

Siraj, N., Shabbir, M. A., Ahmad, T., Sajjad, A., Khan, M. R., Khan, M. I., & Butt, M. S. (2015). Organogelators as a Saturated Fat Replacer for Structuring Edible Oils. *International Journal of Food Properties*, *18*(9), 1973–1989. https://doi.org/10.1080/10942912.2014.951891

Song, J., Pan, T., Wu, J., & Ren, F. (2016). The improvement effect and mechanism of citrus fiber on the water-binding ability of low-fat frankfurters. *Journal of Food Science and Technology*, *53*(12), 4197–4204. https://doi.org/10.1007/s13197-016-2407-5

Statista. (2023). *Chicken meat production worldwide from 2012 to 2023*. https://www.statista.com/statistics/237637/production-of-poultry-meat-worldwide-since-1990/

Theuwissen, E., & Mensink, R. P. (2008). Water-soluble dietary fibers and cardiovascular disease. *Physiology & Behavior*, *94*(2), 285–292.

Wen, L. f., Chang, K. c., Brown, G., & Gallaher, D. d. (1988). Isolation and Characterization of Hemicellulose and Cellulose from Sugar Beet Pulp. *Journal of Food Science*, *53*(3), 826–829. https://doi.org/10.1111/j.1365-2621.1988.tb08963.x