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Review Article

Health Benefits of Rotating Edible Vegetable Oils for Nutritional Balance and Disease Prevention

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Abstract

Dietary fats are essential in the physiological well-being and determine lipid metabolism, inflammation, and cardiovascular threat. As one of the primary sources of dietary fats, edible vegetable oils are very different in fatty acids makeup and bioactive compounds. Constant use of one kind of oil can result in the imbalance of the essential fatty acids, in the ratio between the omega-6 and the omega-3, which can lead to metabolic and inflammatory diseases. Rotational consumption of edible vegetable oils, which are alternating between various oils, e.g., mustard, olive, sunflower, groundnut, rice bran, and flaxseed, has been suggested as a useful nutritional approach to a balanced fatty acid intake, better oxidative stability, and better health outcomes. This is because this review gives a clear summary on the biochemical background, functional health advantages, practicality and future outlook on the rotational application of edible oils as a means of promoting the health of the population.

Keywords: Edible Oils; Fatty Acids; Omega-6/Omega-3 Balance; Oxidative Stability; Cardiovascular Health; Nutritional Strategies

Introduction

Fatty acids are important macronutrients that supply energy, help the absorption of fat-soluble vitamins (A, D, E, and K), and have crucial roles in cell membrane integrity and hormonal balance [1]. Edible vegetable oils are major sources of fatty acids in human diet, which determine cardiovascular, metabolic, and inflammatory health outcomes [2]. Their composition also differs significantly

based on their botanical source, mode of processing and storage and thus the proportions of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) [3,18].

Historically, most groups of people are inclined to use one form of oil in their daily cooking like sunflower, soybean or groundnut oil. Nonetheless, the presence of one of the oils can disrupt the optimal balance of omega-6 and omega-3 fatty acids, which may raise the likelihood of inflammation, insulin resistance, and cardiovascular diseases [4,5]. The current diet is generally rich in omega-6 fatty acids, which leads to an unbalanced composition of n-6: n -3 ratio to a point of 15-20: 1 when a ratio of 5:1 is considered healthy [6,19,20].

One of the solutions to correct these nutritional imbalances has been put forward through organizing periodic rotation of edible vegetable oils using two or more different types of oils as a simple and sustainable dietary behavior. In such a way, it becomes possible to balance the intake of SFAs, MUFAs, and PUFAs and prevent the threat of overeating any type of fatty acid [7]. As an example, the use of MUFA-rich oils like olive or groundnut oil as an alternative to PUFA-rich oils (such as sunflower or flaxseed oil) can be helpful when it comes to improving lipid profiles and antioxidant status [8,21].

Moreover, every oil has different bioactive compounds including tocopherols, phytosterols, and polyphenols, which further offer extra protection against oxidative stress and persistent inflammation [9]. Rotating oils also limits the existence of thermal degradation and oxidation products that do build up when the same oil is used repeatedly to cook at high temperatures [10,22].

It is against this background that rotational consumption of edible vegetable oils offers a holistic approach to nutritional factors of establishing balance of fatty acids, cardiovascular and metabolic wellness, and prevention of oxidative and inflammatory injury. The purpose of the review is to provide a summary of the biochemical foundation, health advantages, and regulatory opinions pertaining to the edible oil rotation usage to give a sound piece of evidence to guide the populace on health and nutrition management.

Fatty acid composition and health implications

Vegetable oils fitted in food are complicated blends of triglycerides which differ in their ratios of saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs). This variation in the composition of fatty acids defines the nutritional value, oxidative stability, and the effect of each oil on the human body [3]. The ratio of these types of fatty acids is especially important in cardiovascular and metabolic homeostasis maintenance [23].

Saturated fatty acids (SFAs)

Saturated fats, which are found mostly in oils that grow in the tropics including coconut and palm oil, are very stable during cooking and frying. Nevertheless, when consumed in excess, SFAs may raise the low-density lipoprotein cholesterol (LDL-C), thus making one more susceptible to cardiovascular problems (1). However, moderate levels of SFA consumption, when used in alternation with unsaturated fats, helps in energy, as well as cellular balance [2,24,25].

Monounsaturated fatty acids (MUFAs)

The MUFA consists of 19 carbon fatty acids that contain only one unsaturated bond. Monounsaturated Fatty Acids (MUFAs) The MUFA is a type of fatty acid with only 1 unsaturated bond. Olive, groundnut, sesame, and canola oils contain MUFAs, especially oleic acid. The high-content MUFA diets lead to improved lipid profiles due to the reduction of LDL-C and triglycerides, as well as the increase in high-density lipoprotein cholesterol (HDL-C) [3]. The frequent substitution of MUFA-containing oils with regular use has been associated with enhanced insulin sensitivity and endothelial activity that contribute to the decreased risk of metabolic syndrome and type 2 diabetes [11,26,27].

Polyunsaturated fatty acids (PUFAs)

Polyunsaturated fatty acids (PUFAs) are another type of fatty acid typically found in the brain, particularly the brain stem, and various body parts. Polyunsaturated Fatty Acids (PUFAs) Polyunsaturated fatty acids (PUFAs) constitute another form of fatty acids commonly present in the brain (especially, the brain stem) and other parts of the body. PUFAs contain omega-6 (linoleic acid) and omega-3 (alpha-linolenic acid) fatty acids that are required to form cell membranes and are the biomolecules of eicosanoids [12]. The oils of the sunflower, safflower, and soybean contain a high amount of omega-6 PUFAs, and the oils of mustard, flax and canola are interesting sources of omega-3 PUFAs [5]. Although PUFAs are useful in reducing serum cholesterol, a large amount of omega-6 compared to omega-3 can stimulate inflammation and oxidative

stress [7]. The alternative use of oils of different PUFA profiles can be used to sustain a desirable omega-6/omega-3 ratio against chronic diseases [28,29].

Minor components and bioactive molecules

In addition to fatty acids, vegetable oils also have bioactive compounds that include tocopherols (vitamin E), phytosterols and polyphenols, offering antioxidant and anti-inflammatory effects [8]. An example is olive oil, which is supplemented with hydroxytyrosol, and rice bran oil, which is supplemented with γ-oryzanol and tocotrienols, which reduce the uptake of cholesterol and oxidative stress [6]. Frequent rotation of oils that are high in various bioactives promotes the general intake of nutrients and antioxidant defense.

Health implications of fatty acid balance

The balanced fatty acid composition of cardiovascular and hepatic and metabolic health requires the use of rotational oil. It has been found that 10 to 20 percent of the risk of coronary heart diseases could be lowered even when part of dietary SFAs are substituted with diets that contain MUFAs and PUFAs [2]. Also, omega-3 fatty acids of mustard or flaxseed oil lower inflammatory cytokines including TNF-alpha and C-reactive protein [9]. Thus, the combination of and rotation of oils with complementary fatty acid and antioxidant profiles will guarantee maximum lipid metabolism, less oxidative load, and long-term well-being.

Mechanisms supporting rotational use of edible vegetable oils

Nutritional and health effects of edible vegetable oils are not only related to the composition of fatty acids, but also associated with their oxidative stability, content of bioactive compounds and their metabolic pathway effects. Rotational consumption of edible oils, i. e. alternating between oils with high MUFAs, PUFAs, and bioactives have a number of biochemical and physiological benefits. This section describes the key ways that rotational oil consumption promotes human health.

Maintenance of fatty acid homeostasis

Various oils give different proportions of saturated, monounsaturated and polyunsaturated fatty acids. The persistent intake of the same oil can upset lipid homeostasis, especially by raising the levels of omega-6 fatty acids in the diet at the expense of omega-3s, leading to the synthesis of pro-inflammatory eicosanoid prostaglandin E 2 and leukotriene B 4 [4].

Since oils have a balanced intake of fatty acids, the optimal ratio of n-6:n-3 (=5:1) that keeps membrane fluidity, vascular activity, and anti-inflammatory balance [2] is achieved through rotational use of oils. Indicatively, regular rotation of sunflower or safflower oil (containing omega-6) with mustard or flax seeds oil (containing omega-3) can help stabilize serum lipids and stop the inflammatory cascades [7,30].

Enhancement of oxidative stability and reduction of thermal degradation

Every edible oil has a specific smoke point and oxidative stability index, and it defines how it is resistant to rancidity and degradation during heating. Oils with high concentrations of PUFAs are subject to oxidation resulting in peroxides and aldehyde that could cause damage to lipids and proteins [10]. Frying oils Rotating oils: It is best to fry in thermally stable oils like groundnut, rice bran, or olive, and low-heat cooking in oils rich in PUFA (canola or flax) [13]. The practice is useful in maintaining nutritional integrity and guarding against oxidative stress in vivo.

Regulation of lipid metabolism and cholesterol homeostasis

Rotation in oil consumption affects the lipid metabolism by regulation of hepatic enzymes like HMG-CoA reductase and lipoprotein lipase [3]. Oils rich in MUFA improve reverse cholesterol transport whereas PUFA-enriched oils suppress the hepatic triglyceride production [1]. Phytosterols and 7-oryzanol are found in mustard and rice bran oils and that they competitively block intestinal cholesterol absorption, resulting in low serum LDL-C levels [8,31].

Inflammatory and endothelial pathways modulation

The fatty acid structure has a direct influence on endothelial functioning and inflammatory signaling. Omega-3 fatty acids of oils like mustard and flaxseed are precursors of anti-inflammatory eicosanoids and resolvins and decrease the expression of C-reactive protein and TNF-alfa [9]. However, the opposite exhibits a rise in pro-inflammatory mediators derived in arachidonic via too much omega-6 PUFAs. Regular rotation provides a balanced consumption of them both with a preservation of endothelial nitric oxide production and inhibition of vascular inflammation [5,32].

Synergy of antioxidants and nutrients

Rotating oils improve dietary antioxidant and minor bioactive diversity, which prevent lipid peroxidation. Hydroxytyrosol and phenolics can be found in olive oil, tocotrienols and 8 -Orzanol in rice bran oil, and lignans, including sesamin, in sesame oil—all of which have a synergistic effect on redox balance and lipid oxidation resistance [8]. Periodic fluctuation in such oils orients the constant supply of assorted antioxidants, vitamins (with a predominance of E and K) and phytochemicals which as a collective help raise the defensive processes within the cell.

Microbiota of the gut and regulation of metabolism

According to the latest findings, the metabolic and microbial diversity of the gut undergoes changes based on the composition of dietary fats [14]. The oils containing omega-3 are beneficial in increasing the growth of the Lactobacillus and Bifidobacterium species, thereby raising the gut barrier integrity and lowering systemic inflammation. Rotational oil use has diverse lipid substrates that may sustain a diverse microbiome, which leads to better digestion, immune responses, and energy metabolism

Health advantages and practical applications of rotating the use of edible vegetable oils

By means of rotating intake of edible oils, the human diet is subjected to a variety of fatty acids, antioxidants, phytosterols, and bioactives that contribute to metabolic homeostasis and lowers the risk of the disease. Rather than depending on one oil, alternating among oils with diverse lipid profiles is not only synergistically health-beneficial but it maximizes cardiovascular, metabolic, and immune functions.

Cardiovascular health benefits

The type and the quality of dietary fats eaten are closely associated with cardiovascular disease (CVD) risk. Constant intake of omega-6-enriched oils (e.g., sunflower, safflower) may increase LDL oxidation and inflammation, but the addition of MUFA-enriched oils (e.g., olive, mustard, flaxseed) makes serum cholesterol and triglycerides lower [1,3]. The combination of these oils through rotating will provide a positive lipid profile, balance LDL-C and HDL-C levels, and reduce the total cholesterol/HDL ratio [5]. Frequent alternation also enhances endothelial activity, reduces blood pressure and addresses oxidative stress related to atherogenesis [9]. As an example, olive and rice bran oils have cardioprotective properties as they are rich in phenolics and 8-oryzanol, which increase the bioavailability of nitric oxide and decrease vascular inflammation [8,33,34].

Metabolic and glycemic regulation

The quality of dietary fat affects the insulin sensitivity and glucose metabolism. Oil that is rich in MUFAs like olive and groundnut oil enhance the insulin receptor signaling and uptake of glucose in the peripheral tissues [2]. On the other hand, oils containing omega-3 such as, flax and mustard lower hepatic lipogenesis and increase secretion of adiponectin, which promotes higher glycemic control [7]. Alternation of these oils helps to avoid hepatic accumulation of fat and the regulation of PPAR-g and AMPK pathways that are important in energy balance. Frequent intake of oils with PUFA is also helpful in terms of keeping metabolic flexibility and preventing a non-alcoholic fatty liver disease (NAFLD) [15,35].

Anti-inflammatory and antioxidant effects

Chronic diseases like diabetes, CVD and cancer are all inflamed and affected by oxidative stress. Flax seed oil or mustard oil contains omega-3 fatty acids that prevent the production of pro-inflammatory cytokines (TNF- 2, IL-6) and sesame, olive, and rice bran oils contain antioxidant phenolics, lignans and tocotrienols that counteract the effects of reactive oxygen (ROS) [8-10].

Neuroprotective and cognitive benefits

The consumption of PUFA and MUFA plays an important role in the composition and activity of the brain lipids. Flaxeed and canola oils that are rich in omega-3 provide α-linolenic acid (ALA) that is used to produce DHA, which is critical in maintaining the fluidity of neuronal membranes and neuronal synaptic communications [12]. Turning these oils with olive oil or groundnut oil which is rich in MUFA helps in maintaining cognitive performance by decreasing neuroinflammation and oxidative stress [14]. Also, sesame and rice bran oils contain antioxidants potentially useful in preventing neurodegenerative processes associated with Alzheimer disease through suppressing amyloid-B aggregation [15].

Weight management and lipid utilization

Lipid metabolism and satiety are influenced by the variety in the fatty acid structure of the oils. Alternating between use ensures that metabolic enzymes are not adapted to one fatty acid profile, which facilitates the fatty acid oxidation and uses of energy [7].

Oils rich in Omega-3- and MUFA stimulate thermogenesis and regulate leptin sensitivity and hence healthy weight maintenance. In addition, the use of alternating oils minimizes the danger of lipid peroxidation and chronic inflammation caused by obesity and enhances the general metabolic strength [2,36].

Immunomodulatory benefits

Dietary fats determine the immune functioning with their impact on the synthesis of cytokines, lymphocyte growth and eicosanoid synthesis. A proper balance of omega-6 and omega-3 PUFAs, which is achieved by the use of rotated oils, is the optimal way of generating immune responses and minimizing exposure to infection [5].

Innate immunity is also enhanced by bioactives like tocotrienols and phytosterols present in rice bran and sesame oils that regulate the functions of the macrophage and T-cell [8]. Therefore, the alternate use of oils facilitates the maintenance of pro- and anti-inflammatory immunity that is essential in ensuring homeostasis of immune system [37].

Industrial, regulatory, and safety

Edible vegetable oils that are used in a rotational manner have become a promising nutrition practice to promote health and prevent chronic diseases. Nevertheless, the safety, regulatory and industrial considerations of the practice should be critically taken into consideration so that the practice is not only healthy but also technologically viable.

Safety and quality aspects

The oxidative stability, fatty acid composition and the handling of the edible oils during cooking and storage are the key parameters which dictate their safety. Recurrent heating of Oils with high amounts of PUFAs may result into lipid peroxidation and production of harmful substances like aldehydes, polymers, and trans fats [10]. These by-products are linked with endothelial dysfunction, hepatotoxicity as well as carcinogenicity [13]. Rotation reduces the risk of continuous exposure to thermally-unstable oils by permitting the use of more stable oils (ex: rice bran, olive, groundnut) to do high-temperature cooking. Regular checking of oil degradation by acid value, peroxide value and total polar compounds (TPC) is vital in monitoring of safety. FSSAI and WHO/FAO suggest disapproving oil when TPC is more than 25% of the entire content [13,16].

Regulatory framework

Internationally, quality parameters are established by the Codex Alimentarius Commission and European Food Safety Authority (EFSA), such as fatty acid composition standards, peroxide value standards, and other food contaminants such as glycidyl esters and 3-MCPD [17]. These systems promote consumer education and traceability, which is an assurance that oil practices that are rotated will not undermine nutritional safety or infringe labeling regulations.

Technological and industrial concerns

In the industrial field, the oil blending and rotation are in line with sustainable production and diet diversification strategies. The food industry is adopting the use of blended oils to enhance the nutritional properties of the saturated or MUFA-rich oils with the oxidative stability of PUFA-rich oils [7]. As an example, rice bran and safflower oil blends or mustard and sunflower oil blends show better oxidative resistance and lipid balance [8]. The improvement of the microencapsulation, antioxidant fortification and cold-press extraction methods has also increased the stability of the oils, shelf life and safety [15]. The industry is also inclining towards having sustainable sources and traceability systems to curb adulteration and to have authenticity, which are critical elements in preserving consumer confidence.

Consumer knowledge and education

Regardless of regulatory frameworks, people do not yet understand the health effects of oil reuse, and the positive aspects of rotational use. Teaching consumers on the appropriate oil to use in particular cooking techniques e.g. olive oil or groundnut oil to use in sauting and mustard/flax seed oil to use in dressing can greatly enhance the quality of dietary fats. Such national campaigns as Eat right India [13] support the idea of moderation and rotation in oil consumption in order to balance the intake of omega-6 and omega-3 and to avoid excessive consumption of trans fats.

Sustainability and environmental effect

Using rotational practices helps foster sustainability by encouraging the diversification of different oil sources and avoiding the over-reliance on one oilseed crop such as palm or soybean. It also promotes agro-biodiversity, lessens the reliance on imports, and increases the utilization of local oilseeds [16]. From an environmental perspective, the use of cold-pressed and

less processed oils also helps decrease energy consumption and carbon emissions generated from the subsequent refining and hydrogenation [38].

Challenges and future directions

The health and dietary benefits of the rotational use of edible vegetable oils is evident. However, there are still some scientific, regulatory, and technological hurdles that must be overcome in order for this practice to be adopted on a wider scale.

Lack of consumer awareness and dietary practices

The limited knowledge of consumers can be very harmful. It can be a problem when a consumer does not recognize the different edible oils and how each can affect their health. There are families that use only a single cooking oil for every meal, ignoring the oil's fatty acid profile and how often it spoils. This lack of diversified oil use can also be due to misleading marketing which calls cooking oils "heart-healthy" or "cholesterol-free" and, therefore, discourages consumers from switching their oils. To avoid the health problems that can occur from eating left over oils, future oil use community campaigns and public nutrition education should focus on the rotation of oils, particularly to balance the omega 6 and omega 3 fatty acids.

Variability in nutrient composition and adulteration

Different cultivars, processing, and storage conditions contribute to the variability in the fatty acid profile, antioxidants, and oxidative stability of edible oils [8]. Moreover, the inadequate substitution of less valued oils (like olive and sesame oil) further compromises the adulterated oil's nutritive value and safety [17]. Developing new analytical techniques, including NMR, GC–MS fingerprinting, and isotopic analysis, is a promising pathway to guarantee the authenticity and traceability of oils in the marketplace [15].

Standardization of rotational guidelines

Currently, there are no universally accepted guidelines for how often, in what amounts, or for how long to rotate oil in diets. Most evidence is based on observation, and there have been few randomized clinical trials to assess long-term effects of using rotational oils [7]. Future research should aim to create evidence-based dietary models that consider local eating habits, cooking styles, and disease risk factors to improve rotation strategies. Working together, nutritionists, food scientists, and policy-makers are crucial to forming recommendations that fit specific regions.

Industrial and economic constraints

Industrially, there are several challenges. Producing and distributing different types of oil can be expensive, and it is not always easy to keep quality consistent when blending. Small oil producers often do not have the equipment needed for refining and fortifying their products, which can result in uneven quality. Investments in cold-press and small-scale oil extraction technologies and the promotion of blended oil formulations can help make rotational practices more economically viable

Research gaps and technological innovations

Despite the few clinical studies that glorify the merits of individual oils, there is a paucity of clinical evidence on individual oils versus rotational-oil ingestion. Further research needs to examine:

- The long-term outcomes of rotation on lipid metabolism and inflammation.
- Dietary interactions with gut microbiota.

Effects of rotational use on gene-expression of lipid and glucose metabolism.

- Innovation of smart oils blends or microencapsulated formulations that are targeted at certain cooking temperatures and nutritional results [8].

Artificial intelligence and nutrigenomics could also be used to customize the choices of oil rotation in the case of a specific person, in accordance with his or her metabolic profile.

Policy integration and sustainability goals

This can be done by aligning the rotational oil utilisation with sustainable food systems and agro-biodiversity initiatives which will diminish the reliance on imported oils including palm and soybean. Increased native oilseeds (mustard, sesame, flaxseed, groundnut) should be promoted and blended oil procured by the country on national nutrition programmes. This would empower local economies as well as encouraging dieting variation and community health [16].

Conclusion

Edible vegetable oils rotational use is a growing nutritional approach, which incorporates science, tradition, and sustainability.

Rather than relying on the use of one type of oil, switching among those with varying amounts of fatty acids and antioxidants will lead to a healthy balance of nutrients and avoid the consequences of being constantly exposed to a particular lipid profile. This is a beneficial strategy towards a healthy cardiovascular system, optimal cholesterol, enhanced metabolic well-being as well as shielding against oxidative and inflammatory stress. The frequent use of different oils, e.g., olive, mustard, rice bran, sesame, groundnut, and flaxseed, may offer a wide range of essential fatty acids, vitamins, and bioactive compounds that synergize to facilitate a healthy body. It also minimizes the risks of reheating and over use of unstable oils. On top of health, rotational use of oil signifies a sensible and locally adjustable type of nutrition. It can build food security by promoting the growth of oilseeds and the consumption of oil products in a mindful way and contribute to the health agenda of the population. When people are more aware, do more research and receive an education the rotational use of edible oils can become an easy yet effective move towards a more balanced, healthy life.

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