ISSN 0973 - 6379

JOURNAL OF LIPID SCIENCE AND TECHNOLOGY

Volume - 55-56 | No. 1-4 | January - December 2023 & 2024

Published by
Oil Technologists' Association of India

Editorial Board

Journal of Lipid Science and Technology

Volume 55-56 No. 1-4 January - December 2023 & 2024

CONTENTS

The views and opinions expressed in this journal are those of the contributors. Oil Technologists' Association of India does not necessarily concur with the same. All correspondence should be addressed to the Honorary Editor in Chief, Journal of Lipid Science and Technology, Head Quarter, OTAI Building, HBTU, Nawabganj, Kanpur-205002. email: editorinchief-jlst@otai.org

Annual Subscription: Rs 2000 (India)/ US $ 100 (Overseas).

Burgeoning demand of research in lipid Science and Technology

Dear Readers,

In recent years, lipid research has witnessed significant advancements that continue to deepen our understanding of the complex roles lipids play in both health and disease. Once primarily considered as structural components of cell membranes or energy reservoirs, lipids are now appreciated for their dynamic involvement in signaling, inflammation, and gene expression regulation. As our knowledge evolves, it is increasingly clear that the lipidome-a complex array of lipid species and their metabolites-interacts intricately with cellular pathways, shaping diverse biological processes.

One of the most exciting areas of lipid research is the field of lipidomics, which has expanded our toolkit for exploring lipid structures, functions, and dynamics on an unprecedented scale. High-throughput lipidomic analyses allow us to map lipid alterations in various diseases, from metabolic disorders to neurodegenerative diseases, cancers, and cardiovascular diseases. This expanding knowledge base is propelling lipidomics into translational medicine, where lipids are potential biomarkers and therapeutic targets.

Lipid research is also shedding light on the role of lipids in cellular signaling and the immune response. The inflammatory properties of certain lipid mediators, such as eicosanoids and resolvins, are well-recognized, but recent discoveries of additional lipid mediators provide new insights into how cells respond to stress, infection, or injury. Lipids such as sphingolipids and phosphoinositides are emerging as key regulators of cellular signaling, providing new avenues to understand immune responses and inflammation pathways in greater detail. These findings are particularly timely, as the global health burden of chronic inflammatory diseases is on the rise.

The therapeutic potential of lipid-based treatments is also an area of growing interest. While statins and lipid-lowering agents have long been part of our arsenal against cardiovascular disease, novel lipid-based approaches, including lipid nanoparticles and omega-3 fatty acids, are expanding therapeutic possibilities. Lipid nanoparticles, in particular, have proven their efficacy in delivering mRNA vaccines, showcasing the versatility of lipid-based delivery systems. As our understanding of lipid metabolism and signaling pathways matures, we are poised to see lipid-targeted therapies addressing a range of diseases beyond cardiovascular health.

Despite these exciting advances, lipid research faces challenges. The complexity of the lipidome and the variability of lipid profiles across tissues and individuals demand sophisticated analytical techniques and computational tools. Moreover, the context-specific roles of lipids require researchers to interpret lipid alterations carefully, considering factors like cell type, disease stage, and environmental influences.

Moving forward, collaborations across disciplines-linking biochemistry, pharmacology, clinical research, and bioinformatics-are essential for translating lipid discoveries into tangible health benefits. This journal is dedicated to supporting such interdisciplinary endeavors, providing a platform for innovative research that will undoubtedly continue to shape the future of lipid science.

In this era of unprecedented opportunity, lipid research stands at the forefront of biomedicine, with the potential to unravel key mechanisms in health and disease and to guide the development of novel, lipid-centered therapeutic strategies. Let us continue to expand the boundaries of lipid science and contribute to a future where lipids play a central role in advancing human health.

Dr HB Singh
Editor-in-Chief

Innovations and challenges in oilseed processing

Dear Editor,

The oilseed processing industry plays a pivotal role in global food security, agriculture, and economic development. As demand for vegetable oils and plant-based protein continues to surge, this sector is evolving rapidly to meet both market needs and environmental challenges. Advances in processing technologies, sustainability practices, and the diversification of end-products are transforming the landscape of oilseed processing.

One significant area of progress is in the efficiency of oil extraction methods. Traditional solvent extraction processes are being complemented or even replaced by greener technologies, such as supercritical fluid extraction and enzyme-assisted extraction. These methods not only enhance oil yield and quality but also reduce the environmental impact associated with solvent use and waste production. The implementation of these technologies, however, often comes with increased initial costs and the need for specialized equipment and expertise. Striking a balance between economic feasibility and environmental responsibility remains a pressing challenge for the industry.

The valorization of oilseed by-products is another promising development. Residues such as seed cakes, typically used for animal feed, are increasingly recognized for their potential in nutraceuticals, biofuels, and biodegradable materials. Research into the protein, fiber, and bioactive compounds present in oilseed by-products is opening new opportunities for diversified products that can add value to oilseed processing. Developing efficient methods to isolate and purify these valuable compounds will be essential to maximize the potential of oilseed by-products and minimize waste.

Furthermore, as the industry seeks to adapt to shifting consumer preferences, there is a growing emphasis on transparency, quality, and sustainability. To maintain consumer trust, processors are investing in traceability systems and certification programs that ensure products are ethically and sustainably sourced. Sustainable practices in cultivation, such as minimizing pesticide use and optimizing water resources, are not only beneficial for the environment but are also becoming key drivers for product differentiation in a competitive market.

Looking forward, continued collaboration between academia, industry, and regulatory bodies will be critical to overcoming technical and economic barriers in oilseed processing. In particular, investments in research and development are needed to make novel processing techniques more accessible and cost-effective for processors of all sizes.

Thank you for the opportunity to share these reflections on the evolving landscape of oilseed processing. As we navigate these challenges and embrace innovation, we are confident that the oilseed processing industry can continue to contribute to a sustainable and resilient global food system.

CS Joshi
Director, FARE Labs
csjoshi@farelabs.com

1. Campaign calls on Norwegian government to ban fish oil sourced from Africa, limit salmon-farming growth (*published in Food Safety and Health, July 5, 2024*)

A group of non-governmental organizations, including Oceana and Greenpeace, are calling on the Norwegian government to ban imports of African fishmeal. In a 2nd July letter sent to Norwegian government officials, including Norway Prime Minister Jonas Gahr Støre, the letter requests the government more stringently regulate the country's salmon-farming industry. Specifically, the NGOs are requesting the industry be limited in its growth so it "remains within planetary boundaries," adhere to full disclosure of suppliers from source fisheries through aquafeed suppliers, and institute an "immediate ban on the sourcing of fish oil from food-insecure regions, including Northwest Africa."

"We are writing to urge the Norwegian government to take rapid action to regulate Norway's salmon-farming industry in light of new findings highlighting its huge and growing appetite for wild-caught fish from food-insecure countries in the Global South," the letter said.

The 39 organizations signing the letter include Feedback Global, Coalition for Fair Fisheries Arrangements, Naturvernforbundet, Ocean Rebellion, Sea Shepherd, Living Ocean Society, Aquatic Life Institute, Don't Cage Our Oceans, WildFish, Seas at Risk, and the Environmental Justice Foundation, the latter of which recently published numerous studies exposing sustainability issues in West Africa's fishing sector.

A separate study commissioned in 2023 by the Global Roundtable on Marine Ingredients, an initiative co-founded by the IFFO - The Marine Ingredients Organization and the Sustainable Fisheries Partnership, found the fishmeal and fish oil industry in West Africa has mainly supported export market growth, leaving domestic seafood markets with dwindling amounts of fish available for human consumption, environmental degradation, and decreased income for fishers and factory workers.

"The fishmeal industry is a serious threat to food security and the future of fisheries in West Africa," Greenpeace Africa Senior Ocean Campaign Manager Aliou Ba said in a press release. "This industry plunders our marine resources to feed intensive aquaculture in Asia and Europe, where local populations need it for their own food. It is time that the fish of the poor stopped feeding the fish of the rich."

The letter claims the ingredients in fish oil that is then used by the Norwegian salmon-farming industry could provide up to 4 million people in Africa with a year's supply of fish sufficient to meet their nutritional needs. Around 2 million metric tons of wild fish caught in countries like Mauritania and Senegal are used for fishmeal and fish oil production, including anchovy, sardine, sprat, herring, and sandeels.

"What some in Norway view as a corporate success story has come at the expense of communities and fish populations in the Global South," the groups said. "A significant share of the fish oil Norwegian farmed salmon companies use is imported from Northwest Africa, depriving up to 4 million people in the region of fish to meet their annual nutritional needs. This is fueling a modern-day food imperialism, which, in addition to entrenching global inequity and food insecurity, is extremely inefficient: Norway's annual output of farmed salmon is 27 percent lower than the volume of wild fish required to produce the fish oil used in Norwegian farmed salmon feed."

The four largest aquafeed and fish oil producers – Mowi , Skretting, Cargill, and BioMar – supply nearly all the feed used in Norwegian salmon farming and all source fish oil from Northwest Africa, according to the letter. The number of fishmeal and fish oil plants in West Africa has increased from five to 49 in the past 10 years, it said.

"The Norwegian salmon industry is gobbling up fish from some the world's most food-insecure regions, decimating fish populations, devastating livelihoods, and driving malnutrition," Feedback Global Executive Director Carina Millstone said. "The Norwegian government must take rapid action now to regulate its extractive salmon industry and prevent further destruction."

The Norwegian government's support of its aquaculture sector "stands in stark contrast to Norwegian development policy, which has identified food security and the fight against hunger as a priority area, notably in Sub-Saharan Africa," the letter said.

2. BVO No Longer Authorized for Food Use by FDA *(published in Food Safety Magazine, July 2, 2024)*

Effective August 2, 2024, the US Food and Drug Administration (FDA) has revoked its authorization of the use of brominated vegetable oil (BVO) in food due to studies showing the potential for adverse health effects to humans. The compliance date is one year after the effective date, by which point companies must reformulate, relabel, and deplete their inventories of BVO-containing products.

Conducted in collaboration with the U.S. National Institutes of Health (NIH), the study that prompted FDA to revoke its authorization of BVO in food showed damaging effects on the thyroid. Specifically, scientists conducted a 90-day dietary exposure study in Sprague Dawley rats and analyzed tissue distribution of the main metabolites. Male and female rats aged six weeks were fed diets containing varying amounts of BVO by weight. Statistically significant increases were observed in the serum bromide in the high-dose group of both sexes; as well as in the incidence of thyroid follicular cell hypertrophy in the two highest dose groups of males and in the high-dose group of females. An increase in thyroid stimulating hormone (TSH) serum was observed in the high-dose group for both sexes, as well as a decrease in serum T4 in the high-dose males. A clear dose-response was observed in di- and tetra-bromostearic acid levels in the heart, liver, and inguinal fat.

The findings of the NIH study expand upon previous observations in rats and pigs that oral exposure to BVO is associated with increased tissue levels of inorganic and organic bromine, and that the thyroid is a potential target organ of toxicity.

FDA has regulated BVO as a food additive since the agency removed it from the list of Generally Recognized As Safe (GRAS) substances in 1970. As authorized, it was used in small amounts to keep the citrus flavoring from floating to the top in some beverages, and manufacturers were required to list BVO, or the specific type of BVO such as brominated soybean oil, in the ingredients list if it was used. In the present day, few beverages in the U.S. contain BVO. FDA's revocation of its regulation authorizing BVO for use in food is the result of its efforts to strengthen systematic post-market chemical reassessment, following a recent uptick in state legislative action to regulate food additives. BVO is one of the food additives banned by the 2023 *California Food Safety Act*, and is the target of similar pieces of legislation pending in other states.

3. The prospects of coconut oil in the biodiesel economy *(published in Philippine Daily Inquirer, August 23, 2024)*

The adoption by the International Maritime Organization of the "2023 IMO Strategy on Reduction of GHG (greenhouse gasses) Emissions from Ships" opens a new and highly promising business opportunity for the shipping industry, particularly those involved in the logistics and fuel side. Specifically, shipping companies can partner with agriculture companies who can venture into the production of biodiesel from coconut oil to cut dependence on fossil fuel, while obtaining carbon credits in the process.

Scientists, including experts in the Philippine Coconut Authority (PCA), have long known that coconut oil can be converted into high-grade biodiesel. In the book "Biofuels from Philippine Plants" that was published by the Asia-Pacific Biofuels Corp., it was reported that "copra has 63 to 68 percent oil, no more than 6 percent water, and a free fatty acid content of less than 1 percent." Moreover, the book says: "Coconut oil, cracked at high temperatures, can yield nearly 50 percent motor fuel and diesel oil …" Coconut oil could thus be a very good candidate from this viewpoint, and could become a major player in biodiesel supply in developing tropical countries like the Philippines.

On Oct. 4, 2023, the Marcos administration declared its goal of planting 100 million coconut trees by 2028. A budget of P2.4 billion is being asked to improve national coconut production, including the massive replanting to produce 8.4 million seedlings. The new trees are to be planted mostly in the Visayas and Mindanao regions.

When the coconut products that result from this massive replanting program are processed, a large portion of the output can be set aside for non-food use, such as producing biodiesel to fuel the Philippine transport industry from buses to container ships. While imported fossil diesel is seen to continue dominating the domestic fuel market for transport, the emerging bio processing technologies and climate change incentives could lead to a gradual replacement program in favour of biodiesel.

With the replanting program, it is estimated that the Philippines can easily double its production of 1.6 million tons of coconut oil per year. This doubling of output could result in the Philippines producing more hydrotreated vegetable oil, portions of which could be shared with the transport industry as 100 percent “green” fuel. On the shipping side alone, there will be opportunities to shift to the use of biodiesel. Building biodiesel storage tanks in foreign ports could be the next step.

There have also been interesting numbers on the ability of 100 million coconut trees to sequester carbon emissions, which means obtaining more carbon credits. According to the PCA, 100 million coconut trees will require 700,000 hectares planted at 143/trees per hectare. Each hectare of mature coconut trees sequesters 12.81 tons tCO2e (carbon dioxide equivalent) per hectare per year. Using this assumption, 700,000 ha can sequester close to 9 million tons tCO2e per year. Assuming one ton of tCO2e is worth $33 based on the Singapore carbon market, close to $300 million worth of tCO2e could be sequestered per year.reHuge corporations like Bayer, GSK, SAP, Standard Chartered, Unilever, among others, are in a position to advance carbon credit financing, according to carbon traders. They could perhaps be joined by large Philippine agribusiness and infrastructure companies to serve as a platform for a sustainable biodiesel industry in the country.

4. Breakthrough in cost-effective production of cultivated meat *(by Pranjal Malewar published in Tech Explorist, August 21, 2024)*

Cellular agriculture aims to supply the increasing market for animal products. However, because present production technology produces low yields, economic projections prevent the scalability of cultivated meat. A new study from a multidisciplinary team at the Hebrew University of Jerusalem and the cultivated meat industry reported a pioneering new method for producing cultivated meat. This new continuous manufacturing process addresses the key challenges of scalability and cost, potentially making cultivated meat accessible to everyday consumers and contributing to a more sustainable and ethical food system. Scientists used tangential flow filtration (TFF) to continuously manufacture cultivated meat, producing biomass of up to 130 billion cells per litre and yielding 43% weight per volume.

The process was carried out continuously over 20 days, enabling daily biomass harvests. The study also presents a growth medium with no animal components and costs only $0.63 per litre. This medium is designed to support chicken cells’ high-density, long-term culture. Put differently, this continuous manufacturing approach could make farmed meat production more affordable and simpler, making it more accessible to general consumers. The study shows that continuous manufacturing enables cultivated meat production at a fraction of current costs without resorting to genetic modification or mega-factories. This technology brings us closer to making cultivated meat a viable and sustainable alternative to traditional animal farming.

This study is a significant advance in the economic feasibility of cultivated meat. Using empirical data, scientists conducted a techno-economic analysis of a hypothetical 50,000-liter production facility. Based on analysis, the cost of production of cultivated chicken could be reduced to $6.20 per pound. Dr Elliot Swartz, Principal Scientist at Cultivated Meat, The Good Food Institute, emphasized the significance of the study’s findings, stating, *”This important study provides numerous data points that demonstrate the economic feasibility of cultivated meat. The study confirms early theoretical calculations that serum-free media can be produced at costs well below $1/L without forfeiting productivity, a key factor for cultivated meat achieving cost-competitiveness.” “Empirical data is the bedrock for any cost model of scaled cultivated meat production, and this study is the first to provide real-world empirical evidence for key factors that influence the cost of production, such as media cost, metabolic efficiency, and achievable yields in a scalable bioprocess design.”*

Other authors noted, *”Various other factors would affect the final market price of cultivated meat; this research underscores the potential of continuous manufacturing to significantly lower production costs, making cultivated meat more accessible to consumers and competitive with conventional meat products.”* Along with promising cellular agriculture in meeting the global demand for animal products, this study aligns with broader environmental and ethical objectives by reducing reliance on traditional livestock farming.

This technological innovation may significantly impact food security, safety, and animal welfare to meet the needs of a world population that is becoming increasingly impacted by climate change. The study's implications for humanity's future are likely to spark intense interest from a wide range of academic fields and the media.

5. Engineering Lipid Nanoparticles for Enhanced MSUD Treatment (*Reviewed by Lexie Corner,* August 23, 2024 in AZO Nano)

A ground-breaking study by researchers at the University of Pennsylvania and Moderna has shown that repeated mRNA therapy can significantly improve survival and reduce leucine levels in a mouse model of maple syrup urine disease (MSUD). This promising approach, which utilizes lipid nanoparticle-encapsulated mRNA, offers hope for patients with this rare genetic disorder. The study has been published in *Human Gene Therapy*. When the researchers, headed by James Wilson, MD, Ph.D., of the University of Pennsylvania's Perelman School of Medicine, assessed a lipid nanoparticle-based treatment strategy, they considered all potential genetic mutations that can cause MSUD.

The investigators stated, "Repeated intravenous delivery of lipid nanoparticle-encapsulated mRNAs encoding hBCKDHA, hBCKDHB, and hDBT increased survival and body weight, and decreased serum leucine levels in a hypomorphic MSUD mouse model that survives until weaning without clinical intervention. Repeated administration of LNP-encapsulated mRNAs may represent a potential long-term universal treatment approach for MSUD."

In another recent study from Dr Wilson's lab, researchers discovered a novel family of adeno-associated virus (AAV) variants with favorable biodistribution properties. These variants may be useful for targeting tissues other than the liver, like the heart.

Capsid engineering efforts aim to reroute in vivo AAV biodistribution away from the liver toward disease-relevant peripheral organs to improve both the safety and cost of AAV gene therapy. When compared to wild-type AAV9 in mice, one recently discovered variant showed a ten-fold increase in cardiac RNA expression and a six-fold decrease in liver RNA expression.

6. Health Impact of Processing Contaminants in Supplementary Foods for Food-Insecure Regions *(Food Safety Magazine Editorial Team, August 26, 2024)*

The Food and Agriculture Organization of the United Nations (FAO) recently published a report on food safety in the context of limited food availability, which specifically covers dietary exposure to toxic fatty acid esters from supplementary foods provided by humanitarian organizations to treat malnutrition.

Lipid-based nutrient supplements (LNS) and ready-to-use therapeutic food (RUTF) are fortified foods designed to prevent and treat malnutrition in children, and although they are often delivered to regions experiencing food insecurity by humanitarian organizations, LNS and RUTF are often produced locally. Before consumption or use in products like LNS and RUTF, all edible oils must be refined to remove undesirable substances and create a palatable, shelf-stable product—a process that can lead to the formation of heat-induced contaminants such as 3-monochloropropane-1,2-diol (3-MCPD) fatty acid esters and glycidol fatty acid esters (GEs). High levels of these chemicals are typically observed in refined palm oil, which is commonly used in the manufacture of LNS/RUTF products.

In 2018, the EU set maximum limits for GEs expressed as glycidol in infant formula and foods for special medical purposes intended for infants and young children, as well as vegetable oils and fats intended for consumer use or as an ingredient in food. These regulations were expanded in 2020 to include free 3-MCPD and its fatty acid esters in the same products, and in 2024, the limits for 3-MCPD were lowered. Currently, the only existing *Codex Alimentarius* standard for 3-MCPD regards liquid condiments containing acid-hydrolyzed vegetable proteins, while no Codex standards are available for GEs.

According to a recent risk assessment of 3-MCPD and fatty acid esters in nutrient supplements and therapeutic food, the lifetime average daily dose (LADD) would not exceed the EU provisional maximum tolerable daily intake (PMTDI) of 2.4 micrograms per kilogram (ìg/kg) body weight, given that the total 3-MCPD equivalent concentrations in LNS/RUTF did not exceed 382 ìg/kg. The estimated increase in incremental lifetime cancer risk (ILCR) attributable to GEs exposure from LNS/RUTF would not exceed one case in 100,000, if GE concentration in the products does not exceed 164 ìg/kg.

The risk assessment estimates were based on 12 months of exposure to RUTF as the sole source of nutrition, which is considered an extreme scenario. Any LNS/RUTF exposure period of less than 12 months would increase the tolerated concentrations for both 3-MCPD and GEs.

Overall, even though FAO's risk assessment of 3-MCPD and GEs in LNS/RUTF estimated a level of exposure that is of low concern to public health, FAO urges manufacturers of LNS/RUTF to strive for process improvements to limit exposure to these contaminants as much as possible.

7. Role of Prenatal Fish Consumption on Autism Diagnosis *(Published in Drexel News, September 3, 2024)*

The Food and Drug Administration (FDA), the Environmental Protection Agency (EPA) and the Dietary Guidelines for Americans recommend that pregnant people eat at least two to three servings (about eight to 12 ounces) of a variety of seafood a week to obtain the important nutrients that aid in the baby's brain development. However, prenatal fish consumption in the U.S. is generally low.

Led by researchers from Drexel University's A.J. Drexel Autism Institute, Harvard Medical School and Harvard Pilgrim Health Care Institute, a recent study aimed to examine associations of prenatal fish consumption and omega-3 supplement use with autism diagnosis and broader autism-related traits in children. The NIH Environmental Influences on Child Health Outcomes (ECHO) program sponsored research was recently published in *The American Journal of Clinical Nutrition*.

"Studies examining how both prenatal fish consumption and omega-3 supplement use are associated with autism spectrum disorder (ASD) and related traits are lacking," said Kristen Lyall, ScD, an associate professor in the A.J. Drexel Autism Institute and co-author of the study.

The study results showed a continuation of previous work that suggests that prenatal fish consumption, but not omega-3 supplement use, may be associated with a lower likelihood of both autism diagnosis and related traits. Lyall and co-author Emily Oken, MD, a professor in Harvard Medical School and Harvard Pilgrim Health Care Institute, added that given the low fish intake in the United States general population and the rising autism prevalence, these findings suggest the need for better public health messaging regarding guidelines on fish intake for pregnant individuals.

"This study provides yet more evidence for the safety and benefit of regular fish consumption during pregnancy," said Oken. "Other proven benefits include lower risk for preterm birth and improved cognitive development. Pregnant people should aim to consume a variety of fish types at least twice weekly."

The study also showed that the associations of fish intake and lower autism prevalence were somewhat stronger for female children. However, the associations did not show a dose-response pattern, suggesting a possible threshold effect of fish intake or the role of other nutrients in fish. Additionally, intake of supplements containing fish oil/omega-3 fatty acids during pregnancy was not associated with autism diagnosis or autism-related traits.

Researchers examined maternal fish consumption of 10,800 pregnant people, enrolled in 23 ECHO research sites, and omega-3/fish oil supplement use of 12,646 pregnant participants, at 35 ECHO research sites, for associations with clinician-diagnosed autism and parent-reported autism-related traits measured by parents or caregivers with the Social Responsiveness Scale (SRS)-Second Edition. Information on fish consumption and omega-3 supplement use was collected from pregnant participants between 1999 to 2020.

Analysis of the ECHO Cohort data found that around a quarter of the pregnant participants reported no fish intake during pregnancy. Even fewer participants reported taking omega-3 supplements.

Lyall and Oken said that the study suggests the need for continued public health efforts to encourage fish intake during pregnancy, accounting for types of fish with the lowest risk of toxicants (like mercury), and that the study supports the role of prenatal diet in autism-related outcomes in children.

8. Lipid biomarkers in children with obesity linked to future cardiometabolic risks *(Reviewed, University of Copenhagen – The Faculty of Health and Medical Sciences, September 20, 2024)*

Scientists from the University of Copenhagen have detected lipid biomarkers in children and teenagers with obesity that indicate an increased risk of developing type 2 diabetes, liver and heart disease as adults. A one-year lifestyle intervention lowered the levels of these lipid biomarkers, which demonstrates the importance of early intervention for children with obesity. The study is published in the prestigious journal Nature Medicine.

The number of children and teens with obesity is increasing worldwide, with over 250 million expected to be affected by 2030. It is a major public health crisis, as children with obesity risk developing insulin resistance, fatty liver, and high blood pressure, which may lead to diseases such as cardiovascular disease, type 2 diabetes and liver disease, later in life.

Scientists think these diseases can be triggered by changes in the body's lipids – a wide range of fats and oils in the body including triglycerides and cholesterol that serve many purposes including energy storage and cellular signalling. But it is still not well understood how lipid species change in children with obesity, and how they are linked to early cardiometabolic complications.

Now, scientists at the University of Copenhagen have discovered that lipid species linked to cardiometabolic disease in adults are strongly associated with cardiometabolic risk factors in children and teenagers with obesity. The findings could pave the way for tests that serve as an early warning system for cardiometabolic disease.

"Our study shows that the impact of cardiometabolic associated lipid species emerges early in life in children with obesity, particularly affecting liver function and glucose metabolism. These risk lipid species could potentially be explored further as biomarkers for diagnosing or predicting cardiometabolic risk in children at high risk, offering new insights for early detection and intervention," says Postdoc Yun Huang from the Novo Nordisk Foundation Center for Basic Metabolic Research at the University of Copenhagen, and co-first author of the study in Nature Medicine.

The scientists made their discoveries by drawing on the HOLBAEK Study biobank of more than 4,000 children with and without obesity. at the Children's Obesity Clinic at Holbaek Hospital. Together with scientists at Steno Diabetes Center Copenhagen, they harnessed powerful mass spectrometry technology to map hundreds of individual lipid species, each with distinct structures and functions, providing a detailed picture of lipid metabolism. By analyzing the differences in the lipid profiles of 958 children with overweight or obesity and 373 who had normal weight, they gained deep insight into obesity altered lipid profiles and their link to cardiometabolic risk, and the ability to detect excessive fat in the liver.

To see how the lipid profiles of the children and teenagers would respond to a lifestyle intervention, 186 participants who underwent a one-year obesity management program at the Children's Obesity Clinic were examined before and after the treatment. The clinic is an accredited European Centre for Obesity Management that practices the Holbaek Obesity Treatment method, which comprises a range of lifestyle recommendations. Eighty-three percent of participants reduced their weight, and the scientists discovered that levels of harmful lipids had clearly reduced alongside the weight loss. These changes in lipid species play a role in explaining the link between weight loss and improvements in cardiometabolic traits.

This study reinforces the need to treat childhood obesity far more seriously, as it increases the risk of developing a range of diseases that lower quality of life. Thankfully, we have shown that early intervention can reverse the risk and allow children and teenagers the possibility of living long disease-free lives as adults.

Navigating the future of oilseed processing in a climate-conscious era

D Mathur
Director, FARE Labs Pvt Ltd, Gurugram
dmathur@farelabs.com

In an industry rooted in maximizing agricultural value, oilseed processing faces both an exciting transformation and a mounting responsibility in the era of climate change. The evolving demands from both consumers and regulators for sustainability, innovation, and transparency challenge the oilseed processing industry to rethink its approaches while continuing to deliver high-quality, functional products. For an industry steeped in tradition, the path forward lies in embracing technological advancements that enhance efficiency, reduce environmental impact, and maximize the potential of every component of the oilseed.

One of the primary shifts needed is a greater adoption of green extraction technologies. Traditional methods, like solvent extraction, are highly effective but come with environmental and health concerns due to the solvents used. Techniques like enzyme-assisted and supercritical CO_2 extraction offer safer, more sustainable alternatives, though they require significant initial investment and adaptation. The challenge, therefore, is to ensure these techniques are scalable and economically feasible for small and large processors alike. Collaboration between industry and research institutions will be essential in advancing these technologies and creating frameworks that facilitate their wider adoption.

Value addition of its by-products also presents a significant opportunity. Oilseed processing generates substantial residual materials, often entrusted to animal feed. However, advancements in protein extraction and isolation of bioactive compounds open new avenues for creating high-value products for food, nutraceuticals, and even biofuels. For example, proteins and fibers from oilseed residues can serve in plant-based food innovations, meeting the rising consumer demand for sustainable protein sources.

Moreover, as the oilseed industry seeks to align with sustainable practices, carbon footprint reduction and energy efficiency must be prioritized. Many companies are now adopting energy-efficient machinery, waste heat recovery systems, and even exploring renewable energy sources for processing. Such practices not only reduce operational costs in the long term but also enhance the industry's public image—a crucial factor as consumers increasingly scrutinize the environmental impact of the products they consume.

Transparency in sourcing and production is another area ripe for improvement. Certification programs and traceability technologies allow consumers to understand the origins and environmental impact of their products. For processors, these tools create opportunities to differentiate their products based on sustainability, fostering consumer trust in a competitive market.

In conclusion, the future of oilseed processing lies at the intersection of technology and sustainability. By investing in green extraction, maximizing the potential of by-products, enhancing energy efficiency, and building transparent supply chains, the industry can continue to thrive in a climate-conscious world. As stakeholders across the supply chain work together, the oilseed processing industry has the potential not only to meet but to lead in setting sustainable standards for the food and agriculture sectors.

Bio-nanopesticides: A promising approach for the management of pests and diseases in oilseed crops

Balwant S Paliya[1] and **Harikesh B Singh[2*]**

[1]Pharmacology Division, CSIR-National Botanical Research Institute, Lucknow-226001

[2]Somvanshi Research Foundation, 12 Sidhartha Residency-2, Kaushlesh Nagar, Varanasi-221005

*Corresponding Author: hbs1@rediffmail.com; somvanshi.rf@gmail.com

Abstract

The increasing global demand for oilseed crops necessitates effective disease management practices that are both sustainable and environmentally friendly. While traditional chemical pesticides offer a solution, their environmental impact, pest resistance, and threats to non-target organisms emphasize the need for alternative approaches. Bio-nanopesticides, which harness nanotechnology alongside biological pest control agents, present a novel and promising solution. This review provides an overview of different types of bio-nanopesticides, their mechanisms of action, and their comparative advantages over chemical pesticides, particularly for oilseed crop protection.

1. Introduction

In agriculture, pests like insects, pathogens, and weeds cause significant crop yield losses (30–40%). Pesticides, the primary solution, have limited efficiency, with <1% reaching targets. Annually, 3 million tons are applied globally, but most are lost to the environment through leaching, runoff, and degradation (Pimentel, 2009; Zhao et al., 2017).Oilseed crops, including soybean (Glycine max), sunflower (Helianthus annuus), canola (Brassica napus), and others, are essential for producing vegetable oils, animal feed, and biofuels. However, these crops are highly susceptible to pest and wide array of diseases caused by fungi, bacteria, and viruses which leads to significant yield reductions [Bhattacharyya, P et al 2021; Chauhan, R et al 2022].

Phytophthora sojae is a water mold causing root and stem rot in soybean. This pathogen is particularly problematic in poorly drained, saturated soils and can lead to plant wilting and death. Disease management typically involves resistant cultivars and improved drainage; however, pathogen diversity and adaptation reduce the efficacy of resistance over time (Leandro et al., 2018). *Sclerotinia sclerotiorum*, responsible for *Sclerotinia* stem rot in sunflower, affects various host plants and causes yield losses by damaging stems, which leads to plant lodging. This pathogen is challenging to manage due to its prolonged soil persistence through sclerotia (hard fungal structures), which remain viable for years (Bradley et al., 2006). In canola, *Leptosphaeria maculans* causes *Blackleg*, affecting the plant at different growth stages, leading to stem cankers and potential plant death. *Alternaria* blight, caused by *Alternaria brassicae*, affects mustard by creating leaf spots and can significantly reduce photosynthetic activity, weakening plant productivity. Among the most critical diseases are *Phytophthora* root rot in soybean, *Sclerotinia* stem rot in sunflower, blackleg in canola, and *Alternari*a blight in mustard.

Although conventional chemical pesticides have been the mainstay for controlling these diseases, they pose risks, including the development of pathogen resistance, ecological toxicity, and persistence in the environment. Bio-nanopesticides, which leverage biological pest control agents with nanotechnology, provide an effective alternative. The ecofriendly nature of biopesticides has garnered increasing interest from farmers and researchers, leading to a significant expansion in their global market potential. Biopesticides, derived from natural materials like plants and bacteria, offer ecofriendly pest control with minimal harm. According to the US Environmental Protection Agency, they are classified into biochemical, microbial, and plant-incorporated protectants (USEPA, 2008).

Over the past decade, nanotechnology has shown transformative potential in agriculture, especially in pesticide delivery. Nanomaterials' unique properties, such as high surface-to-volume ratios and chemical reactivity, enhance biopesticide formulations by increasing loading capacity, stability, and target affinity while reducing required quantities. Nanoparticles may also serve as bioactive agents (de Oliveira et al., 2014; Singh et al., 2018; Rakshit et al., 2022; Yadav et al., 2018). Thus, the term "nanobiopesticide" highlights its environmentally friendly role in crop protection, stemming from the natural origin of bioactive agents and the biocompatibility of nanomaterials used as active ingredients or carriers.

2. Types of bio-nanopesticides

Bio-nanopesticides can be classified based on their biological active agents, formulation types, and mechanisms of action (Figure 1). Here are the primary categories relevant to oilseed crop disease control:

2.1. Nano emulsion based formulated biopesticides

These formulations use natural agents like plants essential oils, plant extracts, or secondary metabolites from microorganisms. By encapsulating these compounds in nanoparticles, their stability, solubility, and efficacy are enhanced. In the context of biopesticides, nanoformulations enable the efficient delivery of essential oils and plant extracts without relying on organic solvents. To date, nanoformulations of various plant essential oils have primarily been developed as oil-in-water microemulsions or nanoemulsions. Nanoemulsions are more effective due to their smaller droplet size, which improves both the stability and bioavailability of active constituents. When these are nano-emulsified, their bioavailability and penetration into plant tissues improve, making them more effective in combating pathogens. These nano-emulsions are biodegradable and cause minimal harm to non-target species, promoting sustainable pest management.[Anjali et al., 2012; Duarte et al., 2015; Mossa et al., 2018]

2.2. Microbial nanopesticides

Microbial agents such as Bacillus thuringiensis or fungal antagonists can be delivered using nanocarriers, ensuring higher survival rates of the microbes when applied to plants. Bacillus thuringiensis (Bt), Trichoderma viride, Metarhizium spp., Beauveria bassiana, and Nuclear Polyhedrosis Virus (NPV) are key bioproducts in plant protection. Bt, occupying 2% of the insecticidal market, targets specific insect species via strain-specific toxins (e.g., kurstaki, aizawai for lepidopteran larvae; israelensis for mosquitoes). Baculoviruses (NPV, GV) and entomopathogenic fungi like Beauveria spp. and Metarhizium spp. are also effective against pests like Heliothis and Spodoptera. Nanoparticles protect these biocontrol agents from adverse environmental factors, increasing their effectiveness against target pathogens.[49-51]

2.3. Nanocarriers for RNA interference (RNAi)

RNA interference (RNAi) has become a potent tool in pest and disease management, offering a high level of target specificity. Nanocarriers enable the delivery of double-stranded RNA molecules that silence specific genes in pests or pathogens, impeding their ability to grow or infect the plant. This strategy is particularly useful against insects or pathogens resistant to traditional treatments. Due to the low hydrophilicity and net negative charge of dsRNA, cationic nanocarriers have garnered significant research attention. **Das et al. (2015)** demonstrated promising outcomes using chitosan, carbon quantum dots (CQDs), and amine-functionalized silica nanoparticles for dsRNA delivery. **Mitter et al. (2017)** demonstrated the effective delivery of dsRNA using layered double hydroxides (LDHs), enabling plants to resist viruses. This system ensured sustained release, with dsRNA remaining on sprayed leaves even after 30 days. A single application of dsRNA-loaded LDHs provided at least 20 days of protection, including unsprayed new leaves.

3. Mechanism of action of bio-nanopesticides

The effectiveness of bio-nanopesticides stems from their unique mechanisms of action, which include:

- **Enhanced target specificity:** Nanoformulations allow bio-nanopesticides to be tailored to target specific pathogens. For instance, RNAi-based nanocarriers can deliver genetic material that silences essential genes, effectively suppressing pest or pathogen populations without affecting beneficial organisms.

- **Controlled release and stability:** Encapsulation of bioactive agents in nanoparticles facilitates controlled release, maintaining effective concentrations over extended periods. The nanoparticles also protect these agents from environmental degradation, such as UV radiation or hydrolysis, which can significantly decrease the active agent's effectiveness.

- **Improved uptake and distribution:** Nanoparticles increase the solubility and mobility of bioactive compounds, especially those that are hydrophobic, improving their absorption into plant tissues. This allows the active agents to reach systemic pathogens or target pests that inhabit inner plant tissues.
- **Disruption of quorum sensing:** Some bio-nanopesticides inhibit quorum sensing (QS), a cell-to-cell communication process essential for biofilm formation and virulence factor production in bacterial pathogens. By disrupting QS, these bio-nanopesticides prevent pathogens from effectively colonizing and infecting oilseed crops.

4. Advantages of bio-nanopesticides over chemical pesticides for sustainable oilseed crop production

The use of chemical pesticides in agriculture has long been the dominant strategy for pest and pathogen control; however, the adverse environmental and health effects have spurred significant research into more sustainable alternatives. Among these, bio-nanopesticides are emerging as a promising substitute for chemical pesticides, offering numerous advantages such as environmental safety, reduced pest resistance, minimal impact on non-target organisms, cost-effectiveness, and promotion of plant growth and resistance (Table 1). This article explores these advantages in detail, specifically for the sustainable production of oilseed crops, a sector heavily dependent on effective pest management.

4.1. Environmental safety and biodegradability

One of the most compelling advantages of bio-nanopesticides over chemical pesticides is their enhanced environmental safety and biodegradability. Chemical pesticides are known to persist in the environment, leading to contamination of soil and water resources. Persistent organic pollutants (POPs) from chemical pesticides can bioaccumulate and biomagnify through the food chain, posing risks to biodiversity and human health. In contrast, bio-nanopesticides are derived from natural sources, such as plant extracts, microbial metabolites, or organic compounds, which are inherently biodegradable. Nano-encapsulation techniques further enhance the stability and efficacy of bioactive compounds while ensuring that these compounds degrade into non-toxic byproducts. This biodegradable nature minimizes environmental pollution, reduces the risk of bioaccumulation, and prevents contamination of water bodies and ecosystems (Kah et al., 2018). Bio-nanopesticides thus align with the principles of sustainable agriculture, preserving soil health and promoting ecological balance essential for long-term crop productivity.

4.2. Reduced resistance development

A major issue in conventional pesticide use is the development of resistance in pests and pathogens. Chemical pesticides typically target specific biochemical pathways, leading to a high probability of resistance through genetic mutations in the target organisms. This resistance development reduces the effectiveness of pesticides, often necessitating higher doses or more toxic alternatives to control the same pest populations. Bio-nanopesticides, however, offer a multifaceted approach to resistance management. For example, RNA interference (RNAi)-based pesticides delivered via nanoparticle carriers can target essential genes unique to pests or pathogens, making it difficult for them to develop resistance (Zhu et al., 2020). Additionally, bio-nanopesticides can interact with multiple cellular targets, unlike single-target chemical pesticides, reducing the likelihood of resistance. The diverse mechanisms of action and the ability to manipulate the biochemical interactions with pests and pathogens provide bio-nanopesticides a distinct advantage in sustainable pest management strategies for oilseed crops.

4.3. Minimal impact on non-target organisms

Chemical pesticides often cause collateral damage to non-target organisms, including pollinators, soil microbes, and natural pest predators, which play a crucial role in maintaining ecological balance. This non-specific toxicity can lead to a decline in biodiversity, disrupting ecosystem services vital for agriculture, such as pollination and natural pest control. Bio-nanopesticides, however, can be designed for specificity, targeting only specific pests or pathogens. For instance, RNAi-based bio-nanopesticides can be tailored to silence genes essential only to the target pest, leaving non-target organisms unaffected (Joga et al., 2016). Moreover, nano-encapsulation enables controlled release, ensuring that the bioactive compounds are delivered only where needed, minimizing off-target effects. This specificity preserves beneficial organisms, thereby maintaining ecosystem biodiversity and supporting sustainable agricultural practices that enhance oilseed crop productivity.

4.5. Cost-effectiveness and efficiency

The cost-effectiveness of bio-nanopesticides stems from their enhanced stability, controlled release mechanisms, and efficacy at lower doses. Nano-encapsulation protects bioactive compounds from premature degradation due to environmental factors such as sunlight, temperature, and humidity, extending their shelf life and field efficacy (Sharma et al., 2019). This stability enables lower application rates and reduces the frequency of pesticide applications, decreasing labor and material costs. For smallholder farmers, in particular, bio-nanopesticides offer an economically viable solution for pest management in oilseed crops. The reduced dosage and frequency contribute to lower overall production costs, and the sustained release of active ingredients ensures prolonged protection against pests. Additionally, as bio-nanopesticides promote plant health and growth, they may reduce the need for other agricultural inputs, further enhancing their cost-effectiveness.

4.6. Promotion of plant growth and resistance

In addition to pest control, certain bio-nanopesticides exhibit plant growth-promoting properties. For example, chitosan, a naturally occurring biopolymer, has been shown to induce systemic resistance in plants and stimulate growth, making it a valuable bio-nanopesticide component for oilseed crops (Bautista-Baños et al., 2016). Chitosan nanoparticles not only act as antifungal agents but also trigger innate immune responses in plants, enhancing their ability to withstand pathogen attacks and environmental stressors. This dual functionality of bio-nanopesticides, both as pest management agents and as plant growth promoters, makes them highly advantageous. By enhancing plant resilience and yield potential, bio-nanopesticides contribute to increased crop quality and productivity, supporting the overall goal of sustainable agriculture. Enhanced resistance to diseases and pests reduces dependence on external inputs, making bio-nanopesticides an integral component of integrated pest management (IPM) strategies.

5. Applications of bio-nanopesticides in oilseed crop disease management

5.1. Nano-encapsulated azadirachtin in sunflower disease management

Azadirachtin, an active compound extracted from neem, is known for its potent insecticidal and antifungal properties. However, its sensitivity to environmental degradation has limited its effectiveness. Nano-encapsulation of azadirachtin increases its stability and ensures controlled release, making it more effective for field applications. Studies have shown that nano-azadirachtin reduces fungal spore germination and promotes disease resistance in sunflower plants, leading to better crop health and yield (Selvaraj et al., 2021).

5.2. Chitosan nanoparticles in soybean disease control

Chitosan nanoparticles exhibit natural antifungal properties, making them effective in managing diseases in soybean crops. Phytophthora sojae, a significant pathogen in soybean, has shown susceptibility to chitosan nanoparticles, which inhibit pathogen growth and stimulate soybean plant immunity. Beyond pathogen suppression, chitosan nanoparticles promote root and shoot growth, enhancing soybean plant resilience and yield (El Hadrami et al., 2010).

5.3. RNAi nanocarriers targeting fungal pathogens in canola

One of the most advanced applications of bio-nanopesticides is the use of RNAi technology delivered through nanocarriers. This approach has been used to target genes essential for the survival of Leptosphaeria maculans, the pathogen responsible for blackleg disease in canola. RNAi-loaded nanoparticles silence specific

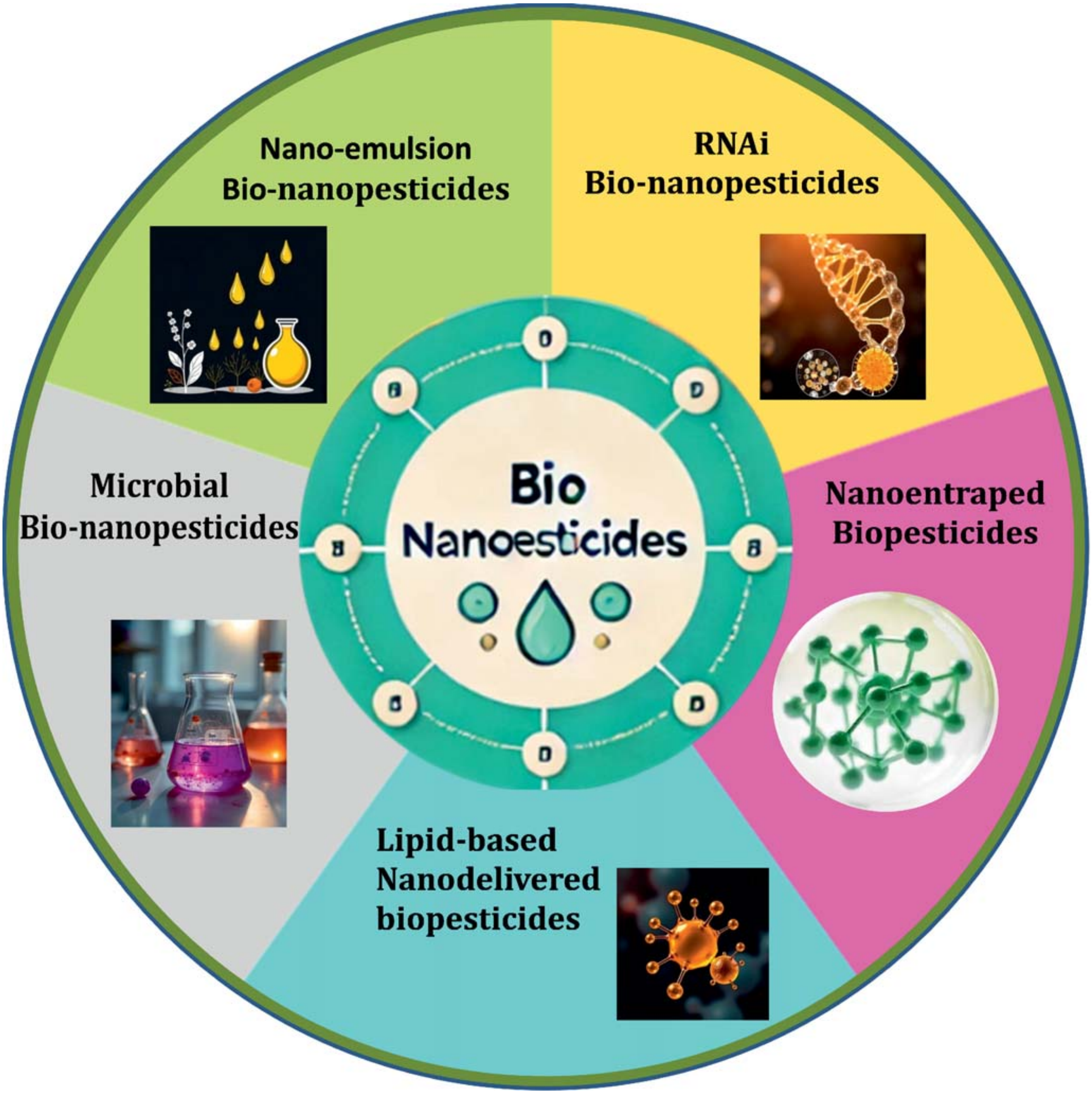


Figure 1. Various types of bio-nanopeticides

Table 1. Applications of different botanical-based bio-nanopesticides in oil seed crops

Bionanopesticide Type	Composition/Carrier	Target Pest/Pathogen	Oilseed crop	Mode of action	References
Nano-encapsulated botanical oils	Essential oils (e.g., neem, eucalyptus) in nanoformulation	Aphids, whiteflies	Mustard, Soybean	Prolonged release and enhanced adhesion on plant surfaces; interferes with pest feeding.	Grewal et al., 2023; Yin et al., 2023
Silver nanoparticles (AgNPs)	Synthesized using plant extracts (e.g., *Ocimum* spp.)	Fungal pathogens (Alternaria, Fusarium)	Groundnut, Sesame	Antifungal activity through reactive oxygen species generation disrupting fungal cells.	MDPI, 2023
Nanoemulsions	Plant-based oils emulsified into nanoscale droplets	Lepidopteran pests	Mustard, Rapeseed	Increased bioavailability and pest mortality via disruption of insect nervous system.	Grewal et al., 2023
Nano-clay-based biopesticides	Layered double hydroxide (LDH) loaded with dsRNA	Virus vectors	Canola, Sunflowe	Silencing genes essential for virus replication and pest survival via RNA interference	Environmental Science: Nano, 2022
Biogenic zinc oxide nanoparticles	ZnO nanoparticles synthesized with herbal extracts	Bacterial blights	Sunflower, Canola	Antibacterial activity by disrupting cell walls and proteins.	MDPI, 2023; Yin et al., 2023
Chitosan nanoparticles	Chitosan coated with active biomolecules (e.g., matrine)	Nematodes, aphids	Soybean	Biodegradable polymer enhances penetration and delays pest resistance development.	Periakaruppan, R et al, 2023

genes critical for fungal growth, resulting in precise pathogen suppression with minimal impact on non-target organisms. The precision of RNAi-based bio-nanopesticides makes them particularly valuable in canola production, reducing the disease burden while preserving environmental and agricultural sustainability (Reddy et al., 2016).

Conclusion

The advantages of bio-nanopesticides over traditional chemical pesticides are evident in terms of environmental safety, reduced resistance development, specificity for target organisms, cost-effectiveness, and dual functionality in promoting plant growth. Their application in oilseed crops such as sunflower, soybean, and canola demonstrates their potential to sustainably manage pests and diseases while enhancing crop productivity. As bio-nanopesticide technology continues to advance, it holds the promise of becoming a cornerstone of sustainable agriculture, aligning with global goals for reduced chemical inputs, biodiversity conservation, and long-term agricultural productivity.

References

1. Anjali, C.H., Sharma, Y., Mukherjee, A., Chandrasekaran, N., 2012. Neem oil (Azadirachta indica) nanoemulsion—a potent larvicidal agent against Culex quinquefasciatus. Pest Manag. Sci. 68, 158–163.

2. Anonymous. US Environmantal Protection Agency 2007, information published at website. Info@healthgood.com.

3. Bautista-Baños, S., et al. (2016). Chitosan as a potential natural compound for controlling fungal diseases. Plant Pathology Journal, 15, 267-275.

4. Bhattacharyya, P., Chattopadhyay, S., & Mukherjee, A. (2021). Bio-nanopesticides: An emerging eco-friendly approach for pest control. Environmental Nanotechnology, Monitoring & Management, 15, 100441. doi:10.1016/j.enmm.2020.100441

5. Bradley, C. A., Lamey, H. A., Endres, G. J., Henson, R. A., Hanson, B. K., McKay, K., ... & Halvorson, M. (2006). Epidemiology and management of Sclerotinia stem rot of sunflower in the North Central region. Plant Disease, 90(6), 568-576.

6. Bravo A, Likitvivatanavong S, Gill SS, Soberón M. Bacillus thuringiensis: A story of a successful bioinsecticide. Insect Biochemistry and Molecular Biology 2011; 41:423-431.

7. Chauhan, R., Abraham, J., & Mallick, M. (2022). Nanotechnology in agriculture: Bio-nanopesticides as an alternative to chemical pesticides. Journal of Nanoscience and Nanotechnology, 22

8. Das, S., Debnath, N., Pramanik, P., et al. (2015). Functionalized nanocarriers for efficient dsRNA delivery: Applications in pest control. Journal of Nanotechnology and Agriculture Research.

9. de Oliveira, J.L., Campos, E.V.R., Bakshi, M., Abhilash, P.C., Fraceto, L.F., 2014. Application of nanotechnology for the encapsulation of botanical insecticides for sustainable agriculture: prospects and promises. Biotechnol. Adv. 32, 1550–1561.

10. Duarte, J.L., Amado, J.R.R., Oliveira, A.E.M.F.M., Cruz, R.A.S., Ferreira, A.M., Souto, R.N.P., Falcão, D.Q., Carvalho, J.C.T., Fernandes, C.P., 2015. Evaluation of larvicidal activity of a nanoemulsion of Rosmarinus officinalis essential oil. Rev. Bras 25, 189–192.

11. El Hadrami, A., et al. (2010). Chitosan in plant protection. Marine Drugs, 8(4), 968-987.

12. Grewal, K., Singh, H. P., & Batish, D. R. (2023). Plant essential oils as biopesticides: Applications, mechanisms, innovations, and constraints. *Plants*, 12(16), 2916.

13. Joga, M. R., et al. (2016). RNA interference for insect pest management: from lab to field. Pest Management Science, 72(4), 643-645.

14. Kah, M., et al. (2018). Nanopesticides: State of knowledge, environmental fate, and exposure modeling. Critical Reviews in Environmental Science and Technology, 48(6), 289-339.

15. Leandro, L. F. S., Robertson, A. E., Mueller, D. S., & Yan, G. P. (2018). Soybean sudden death

syndrome and Phytophthora root and stem rot. Plant Disease, 102(7), 1211-1225.

16. Mitter, N., Worrall, E. A., Robinson, K. E., et al. (2017). Sustained dsRNA delivery for plant virus resistance using layered double hydroxides. Nature Plants, 3(16207).

17. Mossa, A.-T.H., Afia, S.I., Mohafrash, S.M.M., Abou-Awad, B.A., 2018. Formulation and characterization of garlic (Allium sativum L.) essential oil nanoemulsion and its acaricidal activity on eriophyid olive mites (Acari: Eriophyidae). Environ. Sci. Pollut. Res. 25, 10526–10537.

18. Pan, X., Guo, X., Zhai, T., Zhang, D., Rao, W., Cao, F., & Guan, X. (2023). Nanobiopesticides in sustainable agriculture: developments, challenges, and perspectives. *Environmental Science: Nano*, *10*(1), 41-61.

19. Periakaruppan, R., Romanovski, V., Thirumalaisamy, S. K., Palanimuthu, V., Sampath, M. P., Anilkumar, A., ... & Selvaraj, K. S. V. (2023). Innovations in modern nanotechnology for the sustainable production of agriculture. ChemEngineering, 7(4), 61.

20. Pimentel, D., 2009. Pesticides and pest control. In: Peshin, R., Dhawan, A. (Eds.), Integrated Pest Management: Innovation-Development Process. Springer, Dordrecht, pp. 83–87.

21. Rakshit, Amitava,Meena,VS,Sarma, B K, Abhilash, P C, Singh, H.B., Leonardo Fernandes Fraceto ,Singh, A. K., Parihar,Manoj. (Eds). 2022. Advances in Bioinoculants: Biopesticides Vol.II. Elsevier ,p.430.

22. Reddy, P. S., et al. (2016). RNAi-based technology for insect pest control. Environmental Science and Pollution Research, 23(9), 8487-8502.

23. Rosell G, Quero C, Coll J, Guerrero A. Biorational insecticides in pest management. Journal of Pesticide Science. 2008; 33:103-121.

24. Selvaraj, A., et al. (2021). Efficacy of nano-encapsulated azadirachtin in controlling fungal diseases in sunflower crop. Journal of Agricultural Science, 13(2), 57-66.

25. Sharma, A., et al. (2019). Potential of bio-nanopesticides in sustainable agriculture. Journal of Agricultural and Food Chemistry, 67(7), 1672-1683.

26. Singh, H.B., Mishra, S., Leonardo F. Fraceto and Renata de Lima. (Eds.) 2018. Emerging Trends in Agri-nanotechnology: Fundamental and Applied Aspects CABI-UK. ISBN 978-1-78639-144-5, p. 302.

27. Yadav, S. K., Patel, J. S., Kumar, G., Mukherjee, A., Maharshi, A., Sarma, B. K., and Singh, H. B. (2018). Factors Affecting the Fate, Transport, Bioavailability and Toxicity of Nanoparticles in the Agroecosystem. *Emerging Trends in Agri-nanotechnology: Fundamental and Applied Aspects*, Eds. H.B. Singh, Sandhya Mishra, Leonardo Fernandes Faceto and Renata de Lima, CABI, pp. 118-134.

28. Yin, J., Su, X., Yan, S., & Shen, J. (2023). Multifunctional nanoparticles and nanopesticides in agricultural application. *Nanomaterials*, 13(7), 1255.

29. Zhao, X., Cui, H., Wang, Y., Sun, C., Cui, B., Zeng, Z., 2017. Development strategies and prospects of nano-based smart pesticide formulation. J. Agric. Food Chem. 66, 6504–6512.

30. Zhu, X., et al. (2020). Advances in RNAi for control of insect and fungal pests of crops. Plant Physiology, 183(4), 1328-1342.

1. Mediterranean Diet for Cognitive Health:

Following a Mediterranean diet rich in unsaturated fats (like olive oil) has been associated with improved brain health, particularly a thicker cortex, which is vital for cognitive function. This diet may help reduce Alzheimer's risk due to its anti-inflammatory and antioxidant effects. Researchers emphasize that diet can influence Alzheimer's indirectly by impacting other risk factors like heart disease and diabetes *(published in Oils and Fats Update, January 2024).*

2. Monounsaturated Fats in High Oleic Oils:

Oils high in monounsaturated fats, such as high oleic sunflower oil, show promise for cardiovascular health due to their ability to lower LDL cholesterol. Dr Allan Green from Australia points out that highly monounsaturated oils are being developed to provide healthier alternatives to conventional vegetable oils *(published in Oils and Fats Update, January 2024).*

3. Fats' Role in Hormone Regulation:

Research on dietary fats indicates they play an essential role in hormone regulation, influencing metabolism and mood. Diets too low in fat can disrupt hormonal balance, affecting everything from mental health to immune function. Omega-3-rich fish oil and certain plant oils help maintain this balance effectively *(published in Oils and Fats Update, January 2024).*

4. Plant Oils vs. Animal Fats:

Studies consistently support the benefits of replacing animal fats with plant-based oils, particularly for heart health. For example, a recent meta-analysis involving over 56,000 participants found that diets high in unsaturated fats from plants, such as olive oil, were associated with healthier blood lipid profiles, lower cardiovascular disease risks, and reduced type 2 diabetes incidence. Conversely, saturated fats from sources like butter had a negative impact, increasing markers for heart disease and metabolic issues *(published in Nature Medicine 30, 2867-2877, 2024).*

5. Variety in Fat Sources:

Newer research emphasizes that a diet rich in diverse fat types may be more beneficial than focusing on a single source. A large-scale study in Nutrients found that consuming a variety of fats—especially unsaturated fats like monounsaturated (MUFAs) and polyunsaturated fats (PUFAs) found in nuts, seeds, and fatty fish—was associated with longer lifespan and reduced heart disease risks. Saturated fats, particularly from red meat, were more strongly linked to cancer risk *(published in Nutrients 16, 152, 2024).*

6. Brown Fat and Metabolic Health:

Research into brown fat (which burns calories to produce heat) has led to insights on metabolic health. Scientists recently identified a molecular "off-switch" for brown fat that could influence obesity and metabolic conditions. This discovery could open avenues for therapies targeting weight management by regulating brown fat activity *(published in ScienceDaily, 29 April 2024).*

7. Innovations in Lipid Nanoparticles for Drug Delivery:

Lipid nanoparticles (LNPs) have revolutionized the delivery of mRNA vaccines, particularly evident during the COVID-19 pandemic. Researchers are optimizing LNP formulations to enhance stability and immune response. Modified lipids with improved characteristics are being tested for better cellular uptake *(published in Advanced Drug Delivery Reviews, 182, 114094, 2023).*

8. The Role of Lipidomics in Metabolic Disorders:

Lipidomics is gaining traction in identifying biomarkers for metabolic diseases. Ongoing research focuses on how alterations in lipid profiles can indicate the onset of conditions like diabetes and obesity, leading to personalized therapeutic strategies *(published in Trends in Analytical Chemistry, 158, 97-106, 2023).*

9. Re-evaluating Dietary Fats and Cardiovascular Health:

Recent studies are challenging traditional views on saturated fats, suggesting moderate intake may not adversely affect heart health as previously thought. This shift prompts a re-evaluation of dietary guidelines concerning fat consumption *(published in European Journal of Clinical Nutrition, 77(2), 267-280, 2023).*

10. Targeting Lipid Metabolism in Cancer Therapy:

Altered lipid metabolism is a hallmark of cancer cells, making it a potential target for therapy. Research is exploring how manipulating lipid pathways can inhibit tumor growth and promote cancer cell death *(published in Nature Reviews Cancer, 23(1), 55-70, 2023)*

11. Omega-3 Fatty Acids in Mental Health:

Emerging evidence suggests omega-3 fatty acids play a significant role in managing mood disorders. Clinical trials are investigating their efficacy in reducing symptoms of anxiety and depression, highlighting their potential as a supplementary treatment *(published in Psychiatry Research, 320, 1016, 2023).*

12. Lipid-Based Drug Formulations for Enhanced Bioavailability:

Innovations in lipid-based formulations are being explored to improve the bioavailability of poorly soluble drugs. This research focuses on developing self-emulsifying formulations that enhance absorption and therapeutic efficacy *(published in European Journal of Pharmaceutics and Biopharmaceutics, 177, 178-190, 2023).*

13. Impact of Dietary Fats on the Gut Microbiome:

Dietary fats significantly influence gut microbiome composition, which has implications for metabolic health. Recent studies suggest specific types of fats can modulate gut bacteria, affecting overall health and disease susceptibility *(published in Gut Microbes, 15(1), 170520, 2023).*

14. Applications of Phospholipids in Food Technology:

Phospholipids are being utilized in food technology to improve texture, stability, and shelf-life. Research is focusing on their emulsifying properties, which can enhance the sensory qualities and nutritional profiles of food products *(published in Food Research International, 164, 112042, 2023).*

Towards self sufficiency in production and consumption of edible oils by 2030?

Dr P Rethinam

Plantation Crops Management Specialist & Formerly, Director, National research Centre for Oil Palm, Pedavegi; Asst. Director General-Plantation Crops, ICAR, New Delhi; Chairman, Coconut Development Board, Kochi, GOI; Executive Director, Asian and Pacific Coconut Community, Jakarta, Indonesia.

18 Lakshmi Nagar, S.N.Palayam, Coimbatore 641003, Tamil Nadu, India.

Mail : palms02@hotmail.com; dr.rethinam@gmail.com

1. Introduction

Edible Oils are defined as 'food substance, , of whatever origin, source, a composition that is manufactured for human consumption wholly or in part from a fat or oil other than that of milk/ dairy product .Traditionally, Indians have used two broad types of edible oils: the first was 'vegetable' oil obtained from crushing local oilseeds- mustard in northern and eastern India; groundnut in Gujarat, Maharashtra, Karnataka and Andhra Pradesh; sesame and groundnut in Tamil Nadu; and coconut in Kerala – in what was known as "Kachchi-ghanis" (bullock driven cold presses). The second cooking oil medium was 'animal' fat, mainly desi-ghee prepared from milk. India's monthly requirement of edible oil is about 1.9 million tonnes. Of late, palm oil is also being use and gained importance as largest used edible oil in the country.

India is the largest producer of oilseeds in the world, which occupies an important position in the country's economy. The country accounts for 12-15 % of global oilseeds area, 6-7% of vegetable oils production, and 9-10 % of the total edible oil consumption. India is also the bulk importer of edible oil to a tune 16 million tons of which palm oi is the largest quantity spending almost Rs. 70,000 crores. To achieve this economic self-sufficiency, the country had made several attempts like increasing the area under oilseeds, developing new varieties and technologies including drip irrigation to increase the productivity and total production. For implementation of programmes at a faster pace, a Technology Mission on Oilseeds (TMO) was formulated with four micro missions. Besides the nine annual oilseed crops two perennial crops viz coconut and oil palm were included. Aspects related to coconut were taken up by the Coconut Development Board, while that of Oil palm was taken up as Oil Palm Development Programme (OPDP) by the Ministry of Agriculture, Cooperation and Farmers Welfare. TMO slowly underwent dilution as TMOP by adding pulses and then maize etc The Mission headed by a Special Secretary was changed to Additional Secretary level. TMOP came under the name of ISOPAM and later NMOOP. Merger of NMOOP under NFSM: National Mission on Oilseeds & Oil Palm (NMOOP) was launched in 2014-15 and continued up to 2017-18 to augment the availability of vegetable oils and to reduce the import of edible oils by increasing the production and productivity of oilseeds and area expansion of oil palm. While this was going on one side, the edible oil import bill also went up every year since edible oil consumption is income elastic and the people affordability has increased due to income increase. Let us see the production and consumption of global edible oil as well as Indian scenario, examine the various efforts being made to attain self-sufficiency and suggest additional modifications required to reach the goal.

2. World Production of Vegetable Oils

The total world production of vegetable oils more than doubled between 2000 and 2017, to 191 million MT in 2017. This is 99 million MT more than produced during 2000.The production of major vegetable oils from 2012-13 to 2019-2020 is presented in Table 1 and the percentage contribution by various countries are depicted in Fig.1 and 2.

Table1.Production of major vegetable oils worldwide from 2012-13 to 2019-20, by type (in million MT)

Year	Palmoil	Soybean	Rapeseed	Sunflower seed	Palm Kernel	Peanut	Cotton seed	Coconut	Olive	Total
2012-13	56.38	43.10	25.69	12.90	6.72	5.47	5.22	3.62	2.50	161.60
2013-14	59.34	45.13	27.26	15.52	7.13	5.67	5.17	3.38	3.19	171.79
2014-15	61.64	49.06	27.63	14.91	7.39	5.54	5.13	3.37	2.54	177.21
2015-16	58.92	51.56	27.34	15.40	7.18	5.43	4.25	3.34	3.13	176.55
2016-17	65.34	53.82	27.55	18.19	7.83	5.71	4.38	3.41	2.61	188.84
2017-18	70.58	55.09	28.06	18.53	8.53	5.91	5.09	3.67	3.27	198.73
2018-19	74.02	55.64	27.68	19.34	8.87	5.86	4.97	3.74	3.25	203.37
2019-20	72.27	56.32	27.30	21.20	8.73	6.05	5.12	3.62	3.12	203.73

Source:Statista 2021

Globally, palm oil production is the highest and made tremendous progress compare the second largest production of soyabean followed by Rape seed and sunflower oil. Even during 2023-24 the same trend is seen (Fig 1 s).

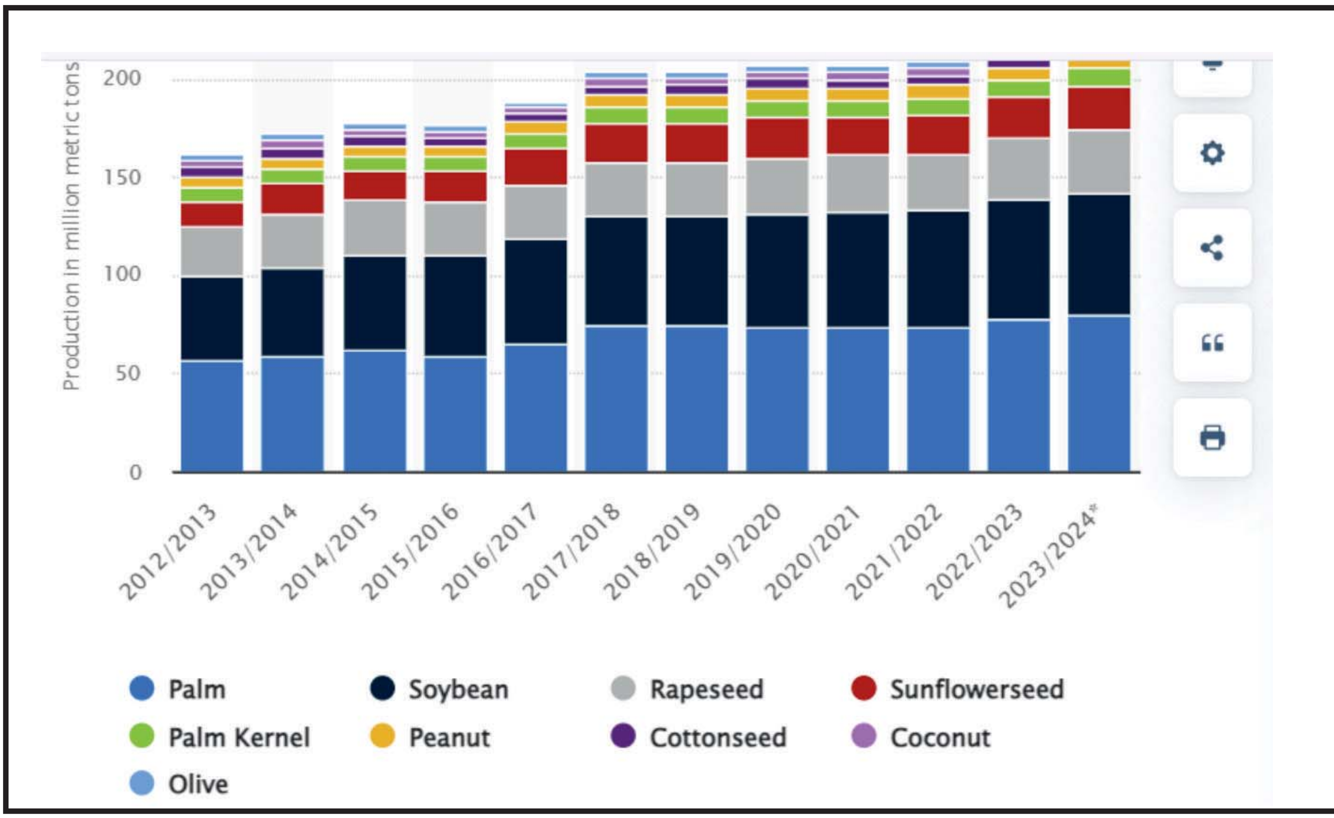


Fig.1 .Production of major vegetable oils worldwide from 2012/13 to 2023/2024, by type *(in million metric tons)*

The production of vegetable oil is dependent on the crushing of oilseeds and the production of perennial tropical oil plants, particularly, palm oil. The global palm oil production has exceeded the production of other edible oils in the last decade. The global production of vegetable oil during 2019-20 was 203.73 million MT, wherein palm oil had the highest volume of production at 72.27 million MT (i.e.,35.5 %) followed by soybean oil at 56.32 millin MT(i.e.,27.6%).

The production trend of Palm oil during 2018-19 and 2019-20 is depicted in Fig.3.

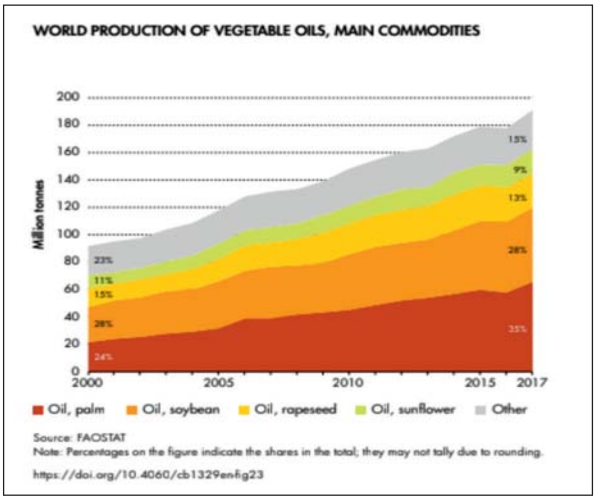


Fig.2.World production of vegetable oil

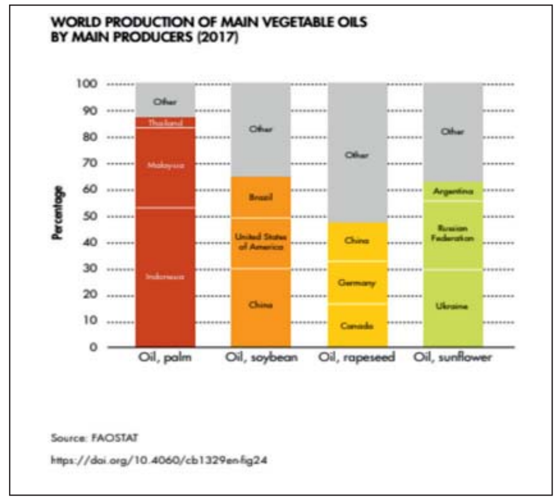
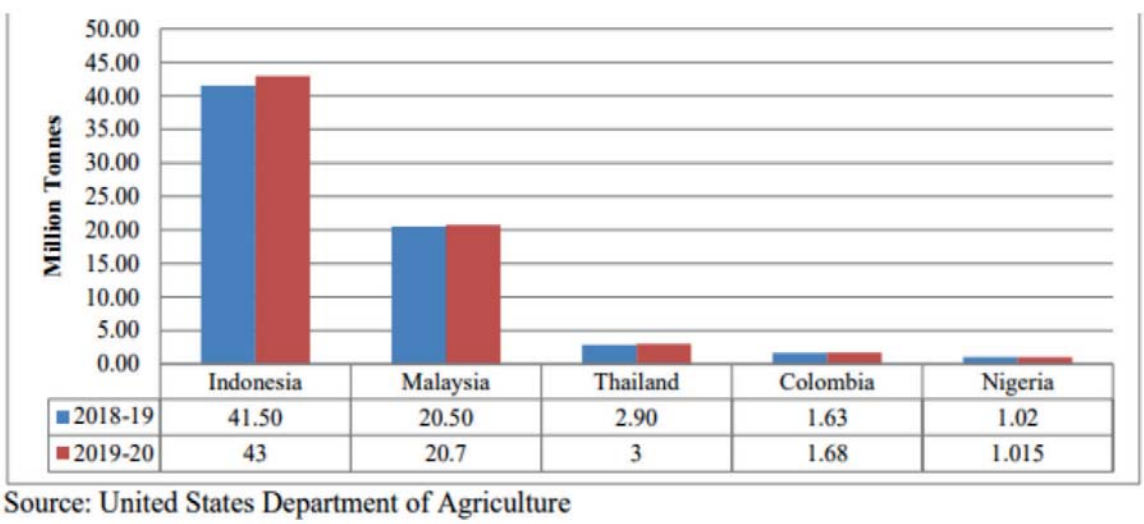


Fig.2. Percentage contribution



- Indonesia and Malaysia are major Palm oil producers in the world.

Fig.3.Production trend of palm oil during 2018-19 and 2019 -2020 in major Oil Palm growing countries Indonesia and Malaysia are the two leading countries producing bulk of palm oil.

Global Edible Oil Market

The global edible oil market is estimated to grow at a CAGR of 3.57% from a market value of USD 96.878 billion in 2019 to reach USD 119.571 billion by the end of 2025. The importance of Palm oil in global edible oil economy can be gauged from the fact that it accounts for one third of total global edible oil production from only 6 % of the total global oilseeds harvested area. It has about 60% share of the world's trade in edible oil pool. Palm oil had the largest increase, both absolute and relative, as its production went up to 44 million MT (or 197%) and it overtook soybean oil as the main vegetable oil produced in 2006. The use of palm oil for Biodiesel explains most of this spectacular growth. Spurred by income and population growth in developing countries as well as rapidly expanding food processing industries in Asia and other developing areas, the global growth in consumption of vegetable oils is outpacing that of most other agricultural products. Consumption of vegetable oils worldwide grew at an average annual rate of 4.2 % over the past decade.

According to the OECD-FAO Agricultural Outlook 2019-2028 statistics, the per capita vegetable oil consumption is predicted to grow by 0.9% per annum. This is comparatively lower than the 2.0% per annum growth observed during the time period of 2009-2018. Developing regions of the world are predicted to contribute to increasing the market growth for vegetable oil during the forecast period. The per capita consumption of vegetable oil in China and Brazil is predicted to be around 30 kg, and around 24 kg, respectively. For developing nations, the per capita consumption of vegetable oil is assumed to reach 27 kg with an annual growth rate of 0.4%. Next to China, India is the second-largest consumer and is ranked as the number one importer of vegetable oil at the international level. The country is projected to maintain the high per capita vegetable oil consumption with an annual growth rate of 3.1%, and further projected to achieve 15 kg by the end of 2028. The substantial growth is attributed to the expanding domestic production in India and growth of imports specifically palm oil from Indonesia and Malaysia.

For the Least Developed Countries (LDCs), the per capita availability of edible oil is projected to surge by 1.2 per annum and is further estimated to attain 10 kg in 2028. The utilization of vegetable oil for biodiesel production will, however, remain unchanged for the next decade, which was recorded as 8.5% per annum growth for the last decade, when biofuel support policies were starting to apply.

Global Development in Edible Oil Sector

The oil crops sector has been one of the most dynamic parts of world agriculture in the recent decades. In the three decades to 2007 it grew at 4.3% per annum compared with an average of 2.1% per annum for all agriculture, including livestock. A major driving force on the demand side for vegetable oils has been their use for non-food purposes. The strong growth of demand for protein products for animal feed was also a major supporting factor in the buoyancy of the oil crops sector. Trade deficit in Oilseed complex is likely to widen in India due to rise in consumption because of growths in human and livestock population as well as per capita income.

Consumption of Vegetable Oils Worldwide

Consumption of vegetable oils worldwide grew at an average annual rate of 4.2% over the past decade. Consumption of vegetable oils worldwide from 2013-14 to 2019-20, by oil type is given in Table 2 and Fig.4.Palm oil consumption continued to occupy a major position followed by soybean oil.

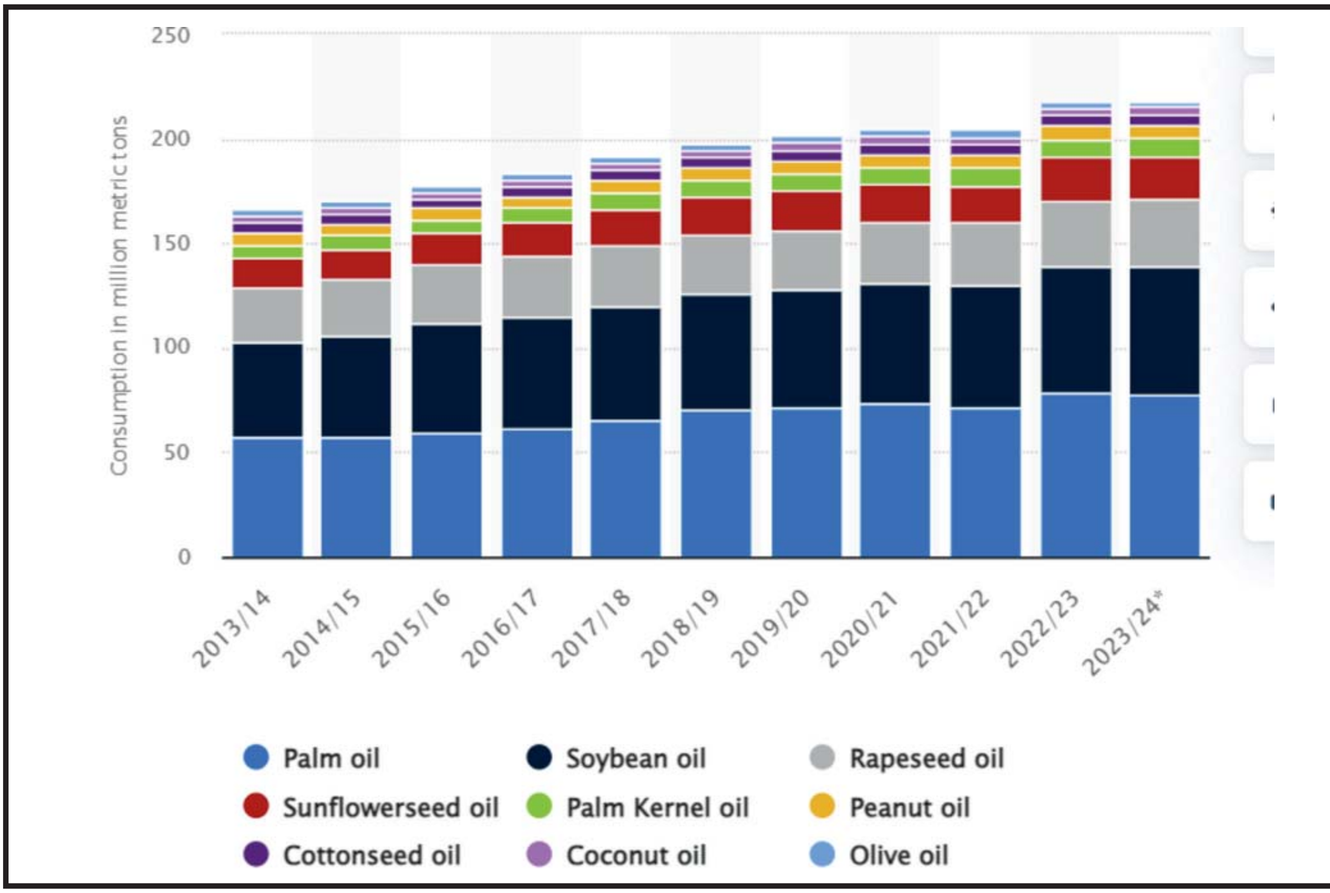
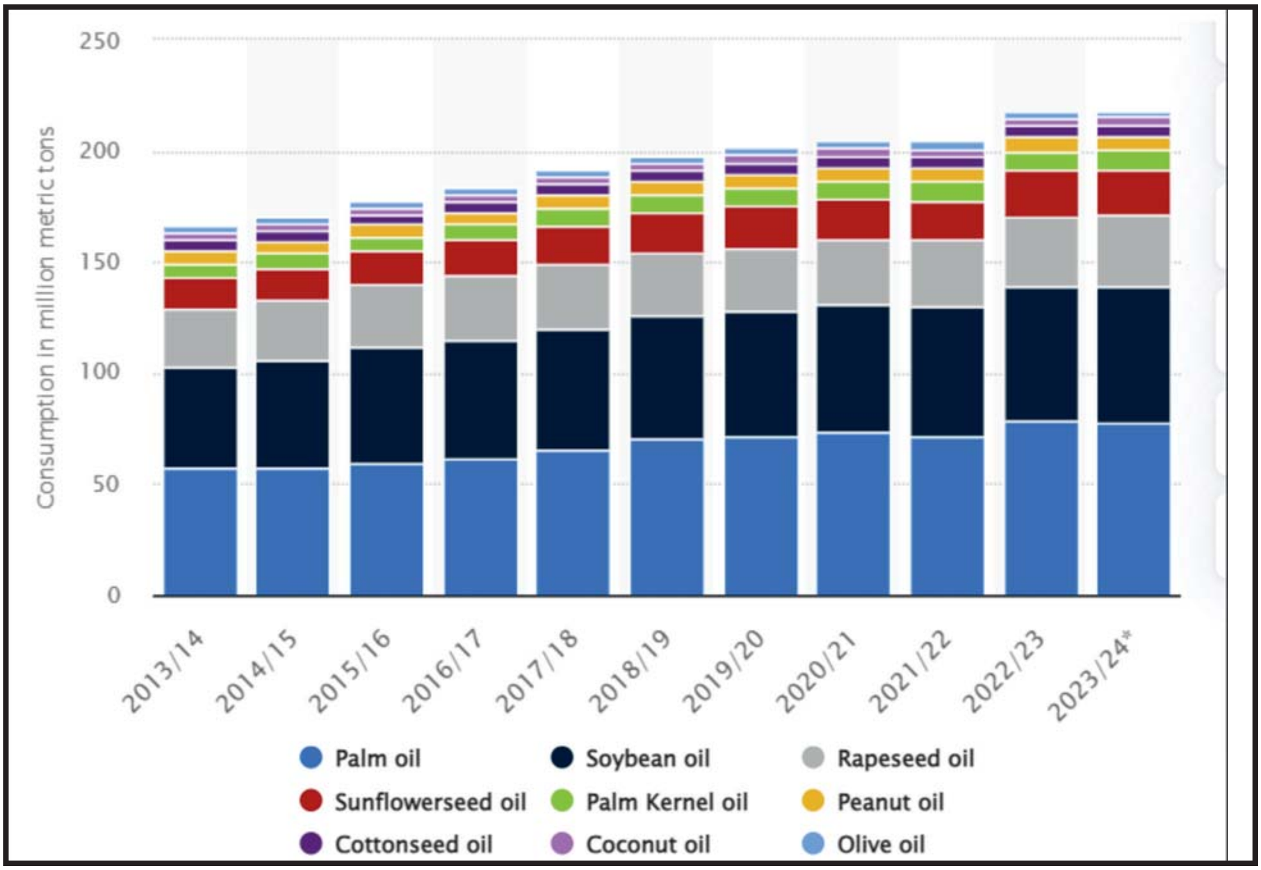


Fig.4. Consumption of vegetable oils worldwide from 2013/14 to 2023/2024, by oil type *(in million metric tons)*

Table 2. Consumption of Vegetable oils Worldwide from 2013-14 to 2019-20, by oil type (in million MT)

Year	Palm oil	Soybean oil	Sunflower seed oil	Palm kernel oil	Peanut oil	Cotton Seed oil	Coconut oil	Olive oil	Rapeseed oil
2019-20	71.48	55.46	19.33	8.56	6.12	5.08	3.65	2.97	27.62
2018-19	73.06	54.92	18.20	8.65	5.94	4.99	3.54	2.92	28.16
2017-18	66.99	54.56	17.42	8.09	5.73	5.05	3.40	2.81	28.86
2016-17	61.60	53.29	16.33	7.42	5.55	4.34	3.09	2.74	28.90
2015-16	59.38	52.09	15.02	7.00	5.41	4.36	3.24	2.81	28.27
2014-15	57.90	47.73	14.11	7.21	5.37	5.06	3.29	2.65	27.04
2014-15	57.52	45.27	14.14	6.58	5.68	5.09	3.34	2.97	26.17

Source :Statistica 2021



Statista 2024

Fig .4.Consumption of vegetable oils worldwide from 2013/14 to 2023/2024, by oil type
(in million metric tons)

The consumption of palm oil increased by 25.4% during 2019-20 in comparison with that during 2015-16 (i.e.59.378 million MT).

Global Vegetable Oil Situation till 2025 and 2028

The details of the Global vegetable oil situation till 2025 presented in Table 4 and world oilseed projection up to 2028 given in Table 5 are self-explanatory. All the oils produced are almost consumed (99.72%), while the consumption for food is 81.95 %.

Table 4. Global Vegetable Oil Situation till 2025

World Veg. Oil	Unit	Avg. 2013-15	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Production	Mt	174.1	180.5	184.2	188.5	192.7	197.1	201.2	205.6	210.1	214.3	218.9
of which palm oil	Mt	61.1	63.3	65.1	66.8	68.4	70.0	71.7	73.4	75.1	76.8	78.6
Consumption	Mt	173.4	181.0	184.1	187.8	192.1	196.7	200.7	204.9	209.4	213.8	218.3
Food	Mt	141.6	147.0	149.4	152.8	156.1	159.4	162.6	166.3	170.2	173.9	178.0
Biofuel	Mt	22.4	23.3	23.5	23.6	24.2	25.1	25.4	25.7	25.8	26.2	26.2
Exports	Mt	74.1	76.7	78.0	79.5	81.3	83.0	84.6	86.4	88.3	90.3	92.1
Closing stocks	Mt	23.7	22.5	22.7	23.3	23.9	24.3	24.8	25.5	26.2	26.7	27.2
Price	USD/t	782.2	736.5	759.8	761.9	777.2	806.0	826.6	826.5	821.1	830.3	834.3

USD 782 per tons means about Rs. 53 per kg

Global RM Production is likely to increase and Global RM Prices are likely to remain under pressure

Table 5. World Oilseed Projection (Marketing year)

		Average 2016-18est	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
VEGETABLE OILS												
World												
Production	Mt	202.6	210.6	214.0	216.9	220.1	223.4	226.7	229.9	233.2	236.4	239.8
of which palm oil	Mt	71.3	74.7	75.6	76.5	77.6	78.7	79.8	80.8	81.8	82.9	83.9
Consumption	Mt	201.2	210.9	214.2	217.1	220.2	223.3	226.6	229.8	233.1	236.4	239.7
Food	Mt	136.3	140.8	143.2	145.7	148.2	150.8	153.6	156.3	159.2	162.0	164.8
Biofuel	Mt	25.4	29.8	30.5	30.5	30.4	30.5	30.4	30.4	30.3	30.3	30.2
Exports	Mt	81.9	84.6	85.8	87.0	88.2	89.2	90.4	91.6	92.8	94.1	95.4
Closing stocks	Mt	22.3	21.1	20.9	20.7	20.6	20.7	20.9	21.0	21.0	21.0	21.1
Price[5]	USD/t	731.6	685.2	715.4	744.8	776.0	794.6	810.3	827.8	846.9	868.9	886.5
Developed countries												
Production	Mt	50.0	51.6	52.3	52.8	53.4	54.0	54.6	55.1	55.7	56.2	56.8
Consumption	Mt	53.9	56.1	56.4	56.7	57.1	57.2	57.2	57.2	57.2	57.2	57.1
Closing stocks	Mt	3.7	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Developing countries												
Production	Mt	152.6	159.0	161.7	164.1	166.7	169.5	172.1	174.8	177.5	180.2	183.0
Consumption	Mt	147.3	154.8	157.8	160.4	163.1	166.2	169.4	172.6	175.9	179.2	182.6
Closing stocks	Mt	18.6	17.6	17.4	17.2	17.2	17.2	17.4	17.4	17.5	17.5	17.6
OECD[2]												
Production	Mt	39.6	40.2	40.7	41.0	41.4	41.8	42.2	42.5	42.8	43.1	43.5
Consumption	Mt	53.2	55.1	55.4	55.8	56.1	56.2	56.2	56.2	56.3	56.3	56.1
Closing stocks	Mt	3.3	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1

Note: Average 2016-18est: Data for 2018 are estimated. Prices are in nominal terms.

1. Soybean, U.S., CIF Rotterdam (October/September).
2. Excludes Iceland but includes all EU member countries
3. Rapeseed, Europe, CIF Hamburg (October/September).
4. Weighted average protein meal, European port (October/September).
5. Weighted average price of oilseed oils and palm oil, European port (October/September).

Source: OECD/FAO (2019), "OECD-FAO Agricultural Outlook", *OECD Agriculture statistics* (database). doi: dx.doi.org/10.1787/agr-outl-data-en

There is an increase in the projection of total oilseed production from 210.6 million MT in 2019 to 239.8 in 2028 of which contribution from Palm oil is the highest (83.9 million MT). There is an urgent need for the developing countries to produce more as their per capita consumption has to go up.

Future Vegetable Oil Demand-2050

Global demand for edible oil had continuously increased from 2005 and the projected demand for and the population growth is a continuous process as depicted in Fig.5. To meet the increasing demand, we only have

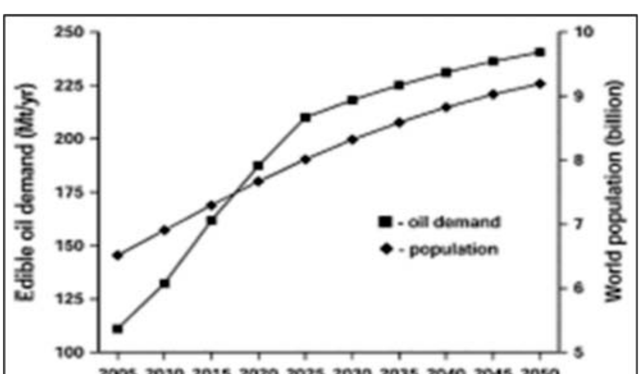


Fig 5. Global edible oil demand from 2005 to 2050

to gear up our production, which may be difficult with the conventional nine oil seed crops alone and hence there is need for promoting high oil producing perennial crop like Oil Palm. High yielding Oil Palm hybrids are available and appropriate technologies are to be integrated to achieve the target.

Indian Oilseeds Scenario

On the oilseeds map of the world, India occupies a prominent position, both in area and production. India is the 4th largest oil seed producing economy in the world after USA, China and Brazil, which contributes about 10% of the world oilseeds production, 6-7% of the global production of vegetable oil, and nearly 7% of protein meal and 9-10% of the total edible oil's consumption. Although India has 20.8% of the world's area under oilseed crops, it accounts for about 10% of global production. This is because of low productivity and year to year fluctuations in production. Over a period of time from 1950-51 to 2019-20, the area had increased from10.73 to 26.00 million ha and the production increased from 5.16 to 28.30 million MT. No doubt that the productivity had been doubled after 2000-01 as could be seen in Table 6.

Table.6.Indian Oilseeds-Area, Production, Productivity and Percentage coverage under irrigation from 1950-51 to 2019-20

Year	Area (million ha)	Production (million MT)	Productivity (kg/ha)	% Coverage under irrigation
1950-51	10.73	5.16	481	NA
1952-53	11.18	4.73	424	0.8
1960-61	13.77	6.98	507	3.3
1970-71	16.64	9.63	579	7.4
1980-81	17.60	9.37	532	14.5
1990-91	24.15	18.61	771	22.9
2000-01	22.77	18.44	810	23.0
2005-06	27.86	27.98	1004	28.0
2010-11	27.22	32.48	1193	24.5
2015-16	26.13	25.30	968	-
2019-20	26.00	28.30	1100	-
2020-21	30.30	43.10	1423	-
2021-22	31.20	45.65	1500	-

Source: Compiled from various sources of GOI Statistical data

Note: The productivity given above are worked out on the basis of production & area figures taken in '000 units.

The productivity of oilseed crops in India is comparatively lower than the world average except for castor (Table 7). There is ample scope for increasing the productivity of our annual oilseeds by using the latest varieties and hybrids coupled with improved technologies developed.

Table 7. Indian Productivity of Oil Seeds (kg/ha) compared with Global productivity and countries having the highest productivity

Crop	India	World	Country with highest productivity*	
Groundnut	1179	1676	4699	(USA)
Rapeseed-Mustard	1140	1873	3690	(Germany)
Soybean	1208	2374	2783	(Paraguay)
Sunflower	706	1482	2494	(China)
Sesame	426	518	1315	(Egypt)
Safflower	654	961	1489	(Mexico)
Castor	1455	1162	1455	(India)
Linseed	260	752	1358	(Canada)
Oil palm fruit	12380	14323	21901 FFB	(Malaysia)

(Source: FAOSTAT, 2012)* from among the countries with >80% global contribution

7.1. Indian Oilseeds Scenario briefly (2019-2020)

The status and anticipated area, production and yield of oilseed crops in India during 2019-2020 as given by Solvent Extractors Association (SEA) is presented in Table 8 shows that the current production is 7.0 million MT of edible oils and the import is 13.2. million MT.

The status and anticipated area, production and yield of oilseed crops in India are presented in Table 9.

Table 9. Status and anticipated area, production and yield of oilseed crops in India

Crop	Quinquennium ending 2016-17			Year 2022		
	Area (m. ha)	Production (m. tons)	Yield (tons/ha)	Area (m.ha)	Production (m. tons)	Yield (tons/ha)
Soybean	11.38	11.94	1.05	12.50	18.75	1.50
Groundnut	4.99	7.39	1.47	5.72	9.72	1.70
R & M	6.19	7.39	1.19	7.47	11.95	1.60
Sunflower	0.59	0.44	0.75	0.97	0.87	0.90
Safflower	0.16	0.08	0.53	0.27	0.22	0.80
Sesame	1.75	0.77	0.41	1.97	1.18	0.60
Niger	0.26	0.08	0.32	0.32	0.16	0.50
Castor	1.06	1.80	1.70	1.40	2.45	1.75
Linseed	0.28	0.14	0.49	0.57	0.34	0.60
Total	**26.67**	**30.06**	**1.13**	**31.20**	**45.64**	**1.46**

Source: DFI Committee Estimates based on data compiled from DACNET

Source: Adopted from NFSM Status Paper

It could be seen that over a period of five years (2016-to 2022), the Doubling the Farmers Income (DFI) Committee estimated the area increase to 31.20 million ha, production 45.64 million tons with a productivity of 1.46 t /ha.

7.2. Import of Vegetable Oils to India

YEAR*	VEGETABLE OILS	
	QUANTITY	VALUE
2009-10	67.34	22,316.68
2010-11	60.39	25,919.59
2011-12	70.82	38,909.02
2012-13	96.06	53,561.61
2013-14	79.43	44,038.04
2014-15	127.32	64,889.60
2015-16	156.44	68,676.62
2016-17	140.07	73,038.98
2017-18	153.61	74,995.91
2018-19	150.28	69,023.80

*Quantity in lakh tonnes; Value in Rs crore; *Apr-Mar.*
Source: Department of Commerce.

The import of vegetable oils had increased by 223.1% over a decade from 2009-10 to 2018-19 and the value by 309.29% (Table 10).The import of palm oil had increased 20 times in the past 25 years. (Fig. 6).

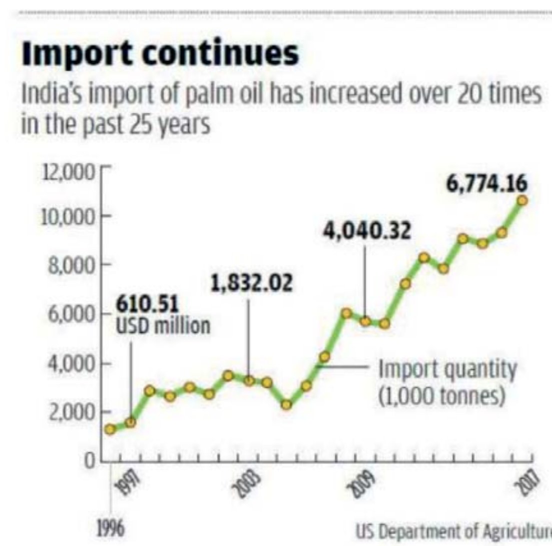


Fig.6.Import of Palm oil (1996 to 2017)

India consumed an estimated volume of nearly 23 million MT of vegetable oils (from coconuts, cottonseeds, olives, palm, peanuts, rapeseed, soybeans, and sunflowers) in fiscal year 2020. Edible oil consumption showed that Palm oil consumption had increased from 29.1% to 42.1 % over a period from 2101-02 to 2018-19 followed by soyabean oil. This shows the acceptability of Palm oil as an edible oil by the people.

The sector wise Indian edible oil market is presented in Fig.7.(**2014 -2024 in BN USD)**

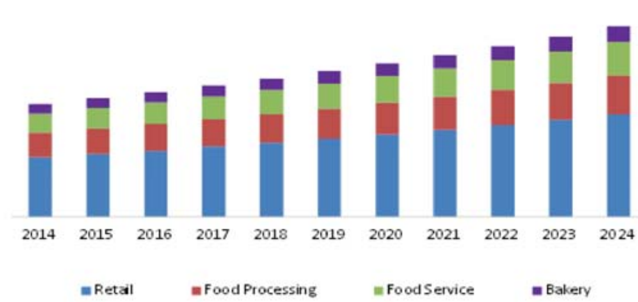
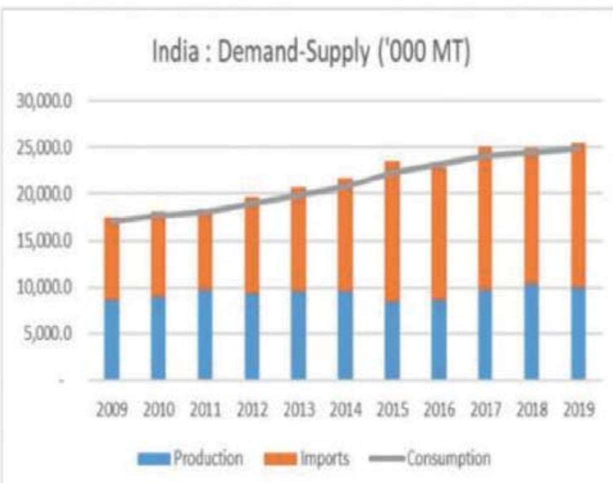


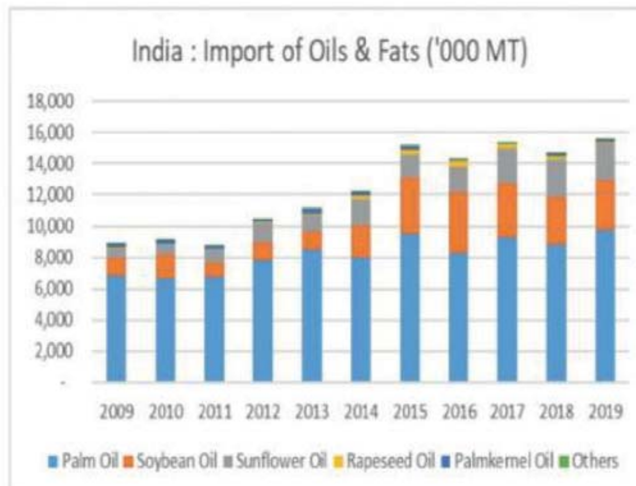
Fig.7. Indian Edible Oil Market, By End Use, 2014 -2024 in BN USD

Bulk of the palm oil goes for retail use i.e., household cooking, followed by food processing and food service, a small quantity is going for bakery production. It is likely that bakery consumption may increase in due course due to its cheaper price.

The edible oil market in India is projected to grow from around US$21.5 billion in 2019 to US$35.2 billion by 2025 due to increasing disposable income and rising consumer awareness about healthy lifestyle & wellness. Moreover, strong marketing activities by leading edible oil brands, changing tastes and preferences of consumers, expanding population, and shifting consumption pattern towards branded oils is leading to rising consumption of edible oils in the country.

Indian demand-supply and import of oils and fats for the period from 2009 2019 is given in Fig.8, which clearly indicates that import had considerably increased since the domestic production was not able to meet the demand. Among the imported oils and fats, Palm oil had the dominant position.





Source: Oil World

Fig.8. Indian demand- supply and the quantity of oils and fats imported

Demand for vegetable are always higher than production which has been reflected in the higher import. Palm is the largest vegetable oil followed by soyabean oil.

Future Demand for Vegetable Oil

Edible Oil Consumption –Long term Projection

The edible oil consumption projected with 2% and 3% and the population growth at 1.02 % presented by SEA and given in Table12 shows that the country needs 24.92 million tons with the per capita consumption of 17.86 kg.

Table 11. Edible oil consumption –Long term Projection

Year (Nov-Oct)	Population at 1.02% Growth	Consumption @ 2% Growth		Consumption @ 3% Growth	
	In Bin	Per Captia (Kg)	MnT	Per Capita (In Kg)	MnT
2018-19	1,300	17.46	22.70	17.46	22.70
2019-20	1,313	15.99	21.00	15.99	21.00
2020-21	1,327	16.21	21.50	16.21	21.50
2021-22	1,340	16.36	21.93	16.52	22.15
2022-23	1,354	16.52	22.37	16.85	22.81
2023-24	1,368	16.68	22.82	17.18	23.49
2024-25	1,382	16.84	23.27	17.51	24.20
2025-26	1,396	17.01	23.74	17.86	24.92

Source SEA,Dr.B.V.Mehta presentation

There is another demand projection is available for the period from 2020 to 2050. All projections (Table 13) indicate that the demand will be continuously increasing and we have to increase our domestic production to meet the demand or else import will continue to increase.

Table 12. Demand Projection of Vegetable oils in India

Demand Projections of Vegetable Oils in India

	2020	2030	2040	2050
Projected population (billion)	1.32	1.43	1.55	1.68
Per capita consumption considering 50, 60, 70 and 75 per cent above the prescribed consumption levels during 2020, 2030, 2040 and 2050, respectively				
Per capita consumption (kg/annum)	16.43	17.52	18.62	19.16
Vegetable oil requirement for direct consumption (million tonnes)	21.69	23.13	24.58	25.29
Vegetable oil requirement for non industrial use (million tonnes)	3.57	6.34	9.69	10.61
Total vegetable oil requirement (million tonnes)	25.26	29.47	34.27	35.90
Vegetable oil availability from secondary sources (million tonnes)	5.05	5.89	6.85	7.18
Total vegetable oil requirement from annual oilseed crops (million tonnes)	20.21	23.58	27.42	28.72
Total vegetable oilseeds requirement from nine annual oilseed crops (million tonnes)	67.37	71.45	80.65	82.06

Source: R.S.Paroda, 2012

Staus of Oil Palm Cultivation in India

Knowing the realistic value of palm oil, which is cheap and versatile(Fig.9), India too started Oil palm cultivtion right from 1965 as a forest crop, but not making much progress. Only during 1986, when its cultivation under irrigation as small holders' crop has begun,the momentam gained.

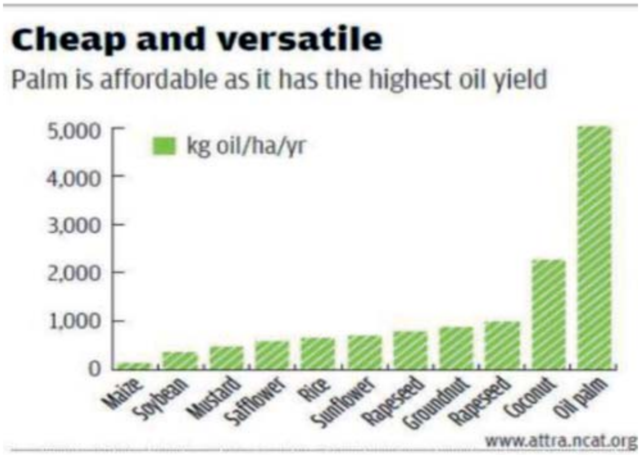


Fig. 9.Comparison of Oil yieids of different oil yielding crops

i) Earlier Initiatives by Government of India to promote Oil Palm Development

Initiatives by Government of India in view of the importance and significance of Oil palm cultivation, DAC&FW had taken up Technology Mission on Oilseeds & Pulses (TMOP) in 1991-92 in the potential states. A comprehensive centrally sponsored scheme, Oil Palm Development Programme (OPDP) was taken up during VIII and IX Plans. During X and XI Plans, Government of India provided support for Oil palm cultivation under Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM). Further to boost its cultivation, a Special Programme on Oil Palm Area Expansion (OPAE) under RKVY was formulated during 2011-12 with an objective to bring 60,000 ha area under cultivation, which continued till March, 2014. During the XII Plan, National Mission on Oilseeds and Oil Palm (NMOOP) was launched in which Mini Mission-II (MM-II) was dedicated to Oil palm area expansion and productivity increase. MM-II of NMOOP is being implemented in 13 States viz; Andhra Pradesh, Assam, Arunachal Pradesh, Chhattisgarh, Gujarat, Karnataka, Kerala, Mizoram, Nagaland, Odisha, Tamil Nadu, Telangana and Goa. The funding pattern was 50:50 between Central and State Governments during 2014-15, which was revised to 60:40 in case of general category States and 90:10 in case of North-Eastern and hill States from 2015-16.. Under MM-II, financial assistance is being provided to the farmers @ 85% cost of the planting material and @ 50% cost of other components like maintenance cost of new plantations for four years, installation of drip-irrigation systems, diesel/electric pump-sets, bore-well/water harvesting structures/ponds, inputs for inter-cropping during gestation period, construction of vermi-compost units and purchase of machinery & tools etc. sImplementation of Centrally Sponsored Oil Palm Development Schemes have resulted in area expansion under Oil palm from 8585 ha in 1991-92 to 3,16,600 ha by the end of 2016-17. Similarly, production of fresh fruit bunches (FFBs) and crude palm oil (CPO) have increased from 21,233 MT and 1,134 MT respectively in 1992-93 to 12,89,274 and 2,20,554 MT respectively in 2016-17. At present, Andhra Pradesh, Karnataka and Tamil Nadu are the major Oil palm growing States. Telangana is another upcoming state taking up Oil palm development with determined political will. Odisha also can come up in area expansion if some concerted efforts are with technical back up. Tamil Nadu is coming up well after some set back. It

ii) Progress made

The State-wise details of area achieved under Oil palm cultivation and production of FFBs and CPO up to the year 2017-18 are given in Table 14.

Despite several iniatives taken by the Government, the target of area expansion could not be achieved (Fig. 9) due to various reasons of which FFB price flactuation was the top most. Harvesting, non availabilty of credit facilities from banks, not settling the subsidy in time in some states, etc., are some of the other problems . Fig 10 shows the relatioship of FFB price and area expansion in Karnataka state. Same was the situation in Andhra Pradesh and Tamil Nadu. If these hurdles are removed, faster development is assured.

Table 13. Progress of Oil palm -area covered, production of FFB and CPO up to 2017-18

The State-wise details of area achieved under oil palm cultivation and production of FFBs and CPO up-to the year 2017-18 are given below:

Sl. No.	State	Area achieved during 2017-18 (in Ha)	Total Area Coverage upto March 2018	Production (in MT) in 2016-17		Production (in MT) in 2017-18	
				FFBs	CPO	FFBs	CPO
1.	Andhra Pradesh	6157	162689	1136579	190854	1427827	234695
2.	Telangana	1413	18312	88549	19979	147516	27274
3.	Karnataka	1120	43517	11912	2051	12917	2224
4.	Tamil Nadu	589	30900	7422	1115	6983	938
5.	Gujarat	76	5797	853	NA	-	-
6.	Goa	-	953	NA	NA	-	-
7.	Odisha	1005	21777	4965	NA	-	-
8.	Tripura	-	530	NA	NA	-	-
9.	Assam	814	1849	0	0	-	-
10.	Kerala	7	5785	34198	5929	30220	5191
11.	Maharashtra	-	1474	NA	NA	-	-
12.	Mizoram	885	28295	4796	626	-	-
13.	Chhattisgarh	773	4222	0	0	-	-
14.	Andaman& Nicobar	-	1593	NA	NA	-	-
15.	Arunachal Pradesh	843	1416	0	0	-	-
16.	Nagaland	800	1973	0	0	-	-
	Total	14482	331082	1289274	220554	1625463	270322

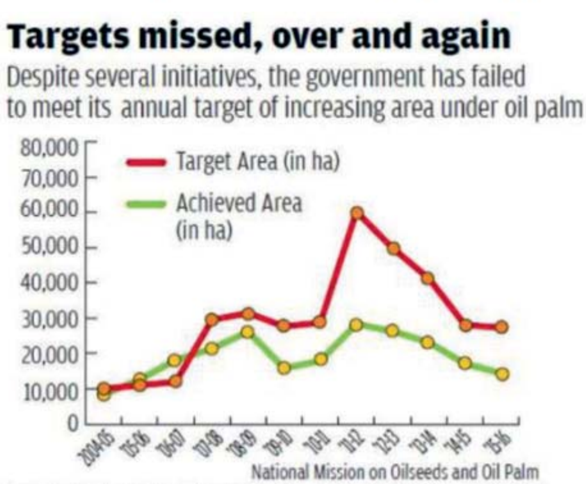


Fig .10 . Target and achievement over years

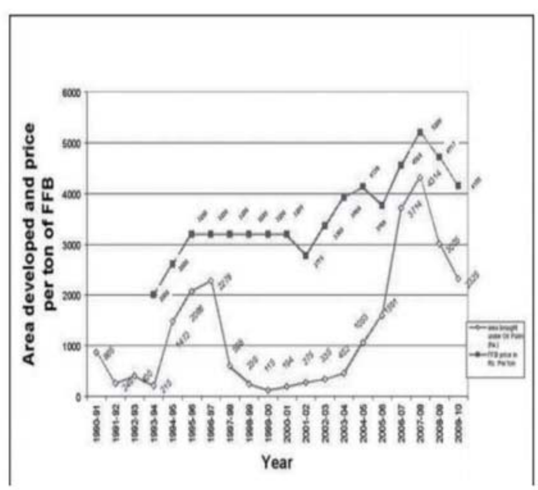


Fig.11.Relatioship of FFB price a area expansion in Karnataka State

iii) FFB Price in India - Month wise from 2013 -14 to 2019-20

The month wise FFB Price from 2013-14 to 2019-2020 is given in Table 15.Later half of the year the FFB price is good. If the price for FFB is good we can definitely expect area increase and production increase**.**

Table .14. FFB Price in India-Month wise from 2013-14 to 2019-2020

Year	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March
2013-14	5932	5808	6210	6464	6624	6971	6907	7900	7951	7824	7926	8441
2014-15	8267	7938	7510	7472	7071	6424	6589	6598	6370	6803	6557	6595
2015-16	6421	6473	6601	6240	5722	5352	5731	5733	5647	5837	6129	7207
2016-17	7586	7839	7494	7250	7792	8434	8142	8177	8455	8679	8891	8155
2017-18	7307	7321	6897	6897	6897	7702	8222	8222	8222	8251	8369	8909
2018-19	9121	9002	8720	8628	8370	8306	8276	8268	8078	7827	7911	7511
2019-20	7558	7157	7164	7207	7715	7977	7620	8500	9440	11367	9995	9043
2020-21	9540	8447	9544	9340	10074	10812	10848	13127	14190	—	—	—

iv) Highlights of Indian Oil Palm

In matured plantations, yield level of 20 to 25 t FFB/ha/year was obtained by many farmers and maximum yield of 50 t FFB /ha/year by some farmers gave the confidence that we can successfully cultivate Oil palm in our country. Maximum calculated yield potential of 12 t CPO /ha/year was also obtained in the plantations near Jangareddygudem, Andhra Pradesh as against 18 t CPO/ ha /year as maximum potential yield of Oil palm reported by Malaysia. Farmers taking up systematic cultivation of Oil palm are reaping the benefit, which could be seen in the East & West Godavari as well as Krishna Districts who had taken oil palm cultivation right from 1988-89 even before OPDP was initiated.

Fig.12.Oil palm development in Andhra Pradesh (GOOGLE photo)

Fig.13.Oil Palm plantation in Farmers Field, A.P.

Fig.14. Inter/mixed crops in Oil Palm

In the process of cultivation of Oil palm, many production technologies including raising of suitable inter/ mixed/ multi storied cropping / farming systems to get a sustainable income by the farmers were developed. Over a period of time, we could develop six hybrid seed gardens to produce tenera hybrid seeds in the country and could reduce the import of planting materials. However, nearly 60 % to 75 % of planting materials were imported from the identified sources and the performance was always good.

Oilseed crops can be raised during the Juvenile period of Oil Palm.

Reasonably adequate research facilities have been developed to help the farmers with technologies and training. Starting from Zero we have developed 27 processing units in the country which has the processing capacity of 589.3 t /hr. Andhra Pradesh alone has 13 units with processing capacity of 454 t/hr and occupies the top rank in the country both in area and production and average productivity. Most of the machineries for the processing units are manufactured locally except a few critical equipment. Thus, indigenous skill has been developed in the processing technology. We now have indigenous technologies right from one ton/ hr to 20 t/ hr.

More than 21 entrepreneurs are involved in Oil Palm Development Programme in the country of which four of them are operating in more than one state. They are very confident that Oil palm can be grown successfully and profitably if some shortfalls identified are removed. As far as cultivation technologies are concerned, we are more competent since we have grown Oil palm successfully in soils with pH 5.5.to 8.5., maximum temperature going beyond 40 to 45^{o} C, minimum temperature going below 10 ^{o}C as in North East, rain fall much less but supplemented with drip irrigation and humidity many times less than required.

In terms of importing newer hybrids, compacts, poly clonal, drought and cold tolerant materials, we should not hesitate and so also upgrading processing technologies from Malaysia.

Self Sufficiency of Edible Oil is Everybody's Concern

Everybody is concerned with self-sufficiency in edible oil and some of their statements /concerns appeared in Media and Webinars during the last year are presented here.

- Hon'ble Prime Minister Shri.Narendra Modi appealed on 23 July 2020 to the farmers in the North-East States to take up Oil palm cultivation in a big way. It is a step to support the Atmanirbhar Bharat initiative and will reduce the imports of Palm oil and make India self-sufficient in edible oils too. Shri Atul

- Noted agricultural economist Dr.Ashok Gulati, Infosys Chair Professor at the Indian Council for Research on International Economic Relations (ICRIER) in New Delhi opined that if India wants to produce as much edible oil as it is consuming through its traditionally-grown oilseeds, the country may need at least 30 million ha of area for cultivating them and this is next to impossible. India currently meets 65% of its edible oil needs through imports. Of India's total edible oil imports, 75 % is palm oil. According to him, Oil palm is the only tree that can give 4 tonnes oil per hectare. In comparison, other edible oil complexes do not give even 400 kg of oil per hectare.

- Union Finance Minister, Smt. Nirmala Sitharaman has reiterated government's plan to focus on growing more oilseeds to cut down the swelling import bills of edible oil. The finance minister, while hailing pulses farmers for sustainable growth in pulses production, has called upon farmers to produce more oilseeds.

- "India imports about 15 million MT of edible oil spending around Rs 77,000 crore to meet the annual requirement. "The annual requirement of edible oil is 23 million MT. We produce only 7-8 million MT and for remaining, we have to depend on imports. There is only announcement for becoming self-reliant in edible oil, action is missing," said B V Mehta, Executive Director, Solvent Extractors' Association (SEA).

- According to Mr. Sudhanshu, Secretary, Food, GOI indicated three suggestions to meet the requirement are: increase the area under cultivation by 23%, increase productivity by 25% and overall production by 55%.

- India spends over Rs 70,000 crores to import about 15 MT edible oil to meet its annual requirement of 25 MT, making it one of the biggest buyers of the cooking medium. The need for a "zero edible oil import" plan was discussed by Union Commerce Minister, Sri. Piyush Goyal at an inter-ministerial meeting.

  A road map for India to attain self-sufficiency in edible oil production is to be prepared. The aim is to help farmers and local industry, apart from reducing the current account deficit.

- Under the Government's plan to double farmers' income, achieving self-sufficiency in oilseeds production by 2030 is a major target (Bloomberg file)

- "The strategy for self-sufficiency should encompass all three sources of oils — seven edible (soybean, rapeseed-mustard, groundnut, sesame, sunflower, safflower and niger) and two non-edible (castor and linseed) oilseed crops, all of nine (9) constituting the primary sources; secondary sources (rice bran, cotton seed, solvent extracted oils); and tree borne oils (TBOs), namely, palm oil, coconut, other tree and forest origins," according to the report of the committee on doubling farmers' income.

- The Department of Agriculture has set a target of first increasing oilseed production from primary sources from the current 31 million MT to 45 million

MT by 2022-23. This is expected to help to increase the edible oil production in the country from the current 7.1 million MT to a range of 11-14 million MT. Contribution from secondary sources and TBOs are likely to add another 3 million MT, restricting the import dependency to about 16 million MT, which otherwise will be much higher by 2022-23.

- To boost up palm tree cultivation, the Committee has suggested a price incentive mechanism for farmers through creation of an Edible Oil Development Fund (EODF), with contributions coming from a specially levied cess of 0.5% on the imports of crude and refined palm oil.
- The committee observed that despite huge domestic supply deficit, farmers have not been enjoying high market prices. The capacity utilisation of the domestic oil industry is 35-50% because of low availability of raw material.
- *Dr. Basanta K. Sahu, Faculty (Economics), IIFT, New Delhi puts forth three options* to regain self-sufficiency in the oilseeds sector.

  a. improving domestic production and supply of oil seeds,

  b. to promote alternative sources like rice bran oil (RBO)

  c. reduce import of edible oils by raising import tariffs and other trade measures.

Despite several public programs for the oilseeds sector in India such as National Mission on Oilseeds and Palm Oil (*NMOOP*), Technology Mission on Oilseeds (*TMO*), Yellow Revolution etc, India's oilseeds sector has been unable to reap its comparative advantages, mainly due to both domestic and external issues, which need more policy focus. From the domestic front, improving productivity and reducing productivity gaps across regions and sectors should be prioritized with better inputs, irrigation, technology and effective price support. Improving India's average productivity in the oilseeds sector, at least up to the world average, can make it self-sufficient.

Transformation of Edible oil consumption over the years

According to GGN Research, an Indore-based Agri-commodity analytics firm, 58% of ndia's estimated edible oil consumption of 2.29 mt in 1973-74 was accounted for by groundnut. This was followed by mustard (28%), cottonseed (10%) and other indigenous oils such as coconut and sesame. But in 2001-02, 29.1% of the total consumption of 10.13 mt was constituted by palm oil, which, along with soybean (22.3%), had relegated mustard and groundnut to third and fourth places. By 2017-18, the combined share of palm and soybean oil had increased to more than 60%. Adding sunflower oil took it further up to nearly 72%.

Can Self-sufficiency come from concerted Oil Palm cultivation in India?

Yes, it is possible and it is the only way where we can definitely make success with concerted political, bureaucratic and farmers will to promote Oil palm cultivation in the identified states under irrigated condition.

- "Palm is the only tree that can give 4 tonnes oil per hectare. In comparison, other edible oil complexes do not give even 400 kg of oil per hectare," said Gulati, Infosys Chair Professor at the Indian Council for Research on International Economic Relations (ICRIER) in New Delhi. If that to happen, Indian corporates should get into growing Oil palm as it is partly done in Indonesia. There both corporates and farmers are into palm cultivation. However, there is another problem. In India, Oil palm is treated as horticulture crop, not as a plantation crop. If it is treated as plantation crop, it may attract corporate investment, said Prof. Gulati adding that he had submitted a plan involving ¹ 10,000 crore to the government some years ago on promoting palm cultivation.

- The real impetus to self-sufficiency, however, can come from oil palm — the only crop capable of yielding 4 tonnes of oil per hectare. “At present, local palm oil production is just 0.25 mt. India can potentially cultivate Oil palm in 1.9-2 million ha, giving 7.5-8 mt oil. But since the trees take four years to yield fresh fruit bunches, one has to plan now. Oil palm should be declared as a plantation crop and exempted from land ceiling laws to attract investments from corporates. Simultaneously, we must restrict imports, especially of refined palm oil,” adds Dr.S.V.Mehta. ,Executive Director, SEA.

- Mr.Chaturvedi, President, Solvent Extractors’ Association of India (SEA) said that Solvent Extraction Association since many years has been raising this issue to focus on oil palm plantation to reduce our dependence on imported palm oil.

- Solvent Extractors Association of India (SEA) jointly with Globe Oil organized a WEBINAR on Future of Palms in India on 26 June, 2020. Dr. B.V. Mehta made very good presentation on oil seed scenario, edible oil import and stressed the need to develop oil palm in the country. He touched on very vital points, 1. Oil palm to be treated as a plantation crops and land ceiling should not affect area expansion 2. Oil palm gives the highest oil yield of 4 to 6 tons of oil /ha/yr 3 In the next five years 5.0 lakh ha to be brought under oil palm cultivation.

- Dr. Shatadru Chattopadhyay, MD, SOLIDARIDAD Network Asia Ltd. - suggested oil palm as inter crop in Tea plantations. However ,Dr.Chadha Committee 1988 identified that oil palm can be cultivated in the available vacant lands in Tea Plantations.

- *Dr. Basanta K. Sahu, Faculty (Economics), IIFT, New Delhi.said that* India is now cultivating palm oil and it can be expanded further to meet the existing consumption and to reduce dependence on imports.

- Mr. Sudhanshu, Secretary, Food, GOI expressed that oil palm is a potential source to increase the vegetable oil pool in the country since it could give 4.0 tons of oil /ha /year but the performance of oil palm in the country is not comparable to Malaysia and Indonesia. He also stressed the need of concerted efforts to be made for increasing the productivity.

- Mr. Siva kumar from ITC also said that the oil palm is a good source for increasing vegetable oil production and the expert teams had identified potential areas of about 2.0 million ha which need to be exploited.

- Mr. Nasim Ali, Godrej AGROVET- Oil Palm has said that, primarily the support price, crop insurance, increasing drip irrigation subsidy to 100% etc. need to be addressed.

- Dr. P.Rethinam , Founder Director of N.R.C. for Oil Palm and Chairman GOI Team constituted in 2011 and person who proved the success of oil Palm under irrigated condition in India , had brought out a policy paper on Perspective role of Oil Palm in the Vegetable oil economy and Farmers’ prosperity in India . He had indicated how to go about bring 2.0 million ha under oil palm in next 20 years.

Efforts made by Government to increase edible oil production

Edible oil being an essential part of human diet and cakes of oilseeds as cattle feed, development of “Maximized production of groundnut” was launched during 1966-67 in Andhra Pradesh, Karnataka and Uttar Pradesh. This scheme was extended in other groundnut growing states like Gujarat, Maharashtra, Madhya Pradesh, Odisha, Punjab, Rajasthan and Tamil Nadu during 1967-68 and 1968-69. The scheme continued during 4th Plan (1969-74). Demonstration of Rapeseed-Mustard (R&M), Soybean, Sunflower, Niger and Castor were also initiated during 4th Plan. An Intensive Oilseeds Development Programme (IODP) covering Groundnut, R&M, Sesame, Safflower, Linseed and Castor was launched during 5th Plan (1974-79) in major oilseed growing states. The programme continued during 6th Plan (1984-

89) with special project on Groundnut and Soybean. National Oilseeds Development Project (NODP) was also launched during 6th Plan period (1984-85) and continued during 7th Plan (1985-86). Technology Mission on Oilseeds (TMO) was launched in 1986 with continuation of NODP on 50:50 sharing basis between Central and State Government and a special project entitled Oilseeds Production Thrust Project (OPTP) with 100% assistance from Central Government. These programmes continued under the aegis of TMOP till 2003-04 with 100% assistance under OPTP up to 1990-91 and, thereafter, as a single oilseed production programme on 75:25 sharing basis. The programme of oilseeds development including oil palm were re-structured and a new CSS entitled, "Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM)" was launched from 2004-05 and continued up to 2013-14 on 75:25 sharing basis. Pulses (2010-11) and Maize (2013-14) were subsequently transferred to National Food Security Mission (NFSM) and ISOPOM was re-structured into National Mission on Oilseeds and Oil Palm (NMOOP) including Tree Borne Oilseeds (TBOs) which was launched during 2014-15.

Under NFSM-Micro Mission 2 Oil Palm financial assistance are given for Supply of Planting Material, Maintenance Cost during gestation period, Inputs for Intercropping in oil palm, Drip Irrigation, Supply of Diesel/Electric Pump sets, Bore well/water harvesting structure/ponds at oil palm farm, Establishment of Seed Gardens, Construction of vermi-compost units at oil palm fields, Machinery & tools, Special component for NE/ Hilly States/LW Areas/regions, Training of Farmers, Training of Extension Officials/Workers/Input dealers, Demonstrations on Oil Palm cultivation at Farmers field, Research & Development (R&D) Schemes, Project Management Expenses (PME) - 3% of AAP and Flexi Fund (10% of AAP).

The efforts made by Department of Agriculture and Farmers Welfare , Ministry of Agriculture and Farmers Welfare from 1966 till now made so much efforts to increase the edible production in the country and no doubt that there is area increase ,, production increase and also productivity increase in the annual oilseeds .The inclusion of Cotton Seed Oil and Rice Bran Oil as well as Tree Beariing Oil Crops(TBO) also contributed to the vegetable pool. But increase in population as well as increase in purchasing power had considerably increased the demand and thereby our import also has increased. Now our attempt is to develop self-reliance and to reduce the import cost by reaching near self-sufficiency and finally reaching self-sufficiency.

Recent initiative a made through National Mission on Edible Oil- Oil Palm (NMEO OP)

Target of National Mission on Edible Oils (NMEO-OP)

This is an ambitious Project formulated taking the initial lead and encouragement gained through Oil Palm Development Project (OPDP) implemented since 1990 to2019-20.

The target fixed for Oil palm area expansion by 2025-26 under NMEO-Oil palm is given below:

To increase area of oil palm to 10 lakh hectares from 3.5 lakh ha during 2019-20 by 2025-26 (additional 6.50 lakh ha) of which it is targeted 3.22 lakh hectares for general state and 3.28 lakh ha in North Eastern states with targeted FFBs production of 66.00 lakh tonnes.

To increase in Crude Palm Oil production from 0.27 lakh tonnes during 2019-20 to 11.20 lakh tonnes by 2025-26.

Increase consumer awareness to maintain consumption level of 19.00 kg/person/annum till 2025-26.

The progress made during the last three years is given below :

The State-wise oil palm area expansion targets and achievement (Ach) under NMEO-OI

(Area in hec

Sl. No.	State	2021-22		2022-23		2023-24	
		Target	Ach	Target	Ach	Target	Ach*
1	Andhra Pradesh	15000	11257	20000	13752	24000	15859
2	Chhattisgarh	500	424	1500	176	800	224
3	Goa	20	0	20	0	5	0
4	Gujarat	500	58	500	0	100	0
5	Karnataka	2000	1172	1735	848	2454	839
6	Kerala	152	105	1000	46	800	86
7	Odisha	0	474	1500	483	1100	559
8	Tamil Nadu	800	511	900	382	400	0
9	Telangana	8100	7286	71200	32949	80000	18240
10	Arunachal Pradesh	600	320	800	457	7000	1700
11	Assam	1500	0	4000	6	12000	0
12	Manipur	150	0	500	0	1200	0
13	Mizoram	100	51	50	35	500	128
14	Nagaland	0	800	1500	703	5556	1389
15	Tripura	0	0	530	0	2000	0
	Total	**29422**	**22458**	**105735**	**49837**	**137915**	**39024**

*Achievement up to 30th January 2023.

Though the initial progress is slow, timely mid term correction suggested can definitely yield fruitful results.

Strategies for Enhancing Oilseed Production

Strategy for Enhancing the Production of Edible Oil

- Increase the productivity of annual oilseeds by making available of quality seeds of high yielding varieties and hybrids in adequate quantities at the right time of sowing, increasing the irrigated area, fixing remunerative price for the crop, and effective implementation of the envisaged programmes in various Micro Missions.
- If necessary, import and make available some of the high yielding varieties.
- Promote Oil yielding tree crops in the vast wastelands in different states as corporate crop
- In paddy lands growing oilseeds and pulses is very common to utilise residual moisture and nutrients. This can be intensified

Strategies for Enhancing the Oil Palm Cultivation to produce more Palm Oil.

Two pronged approaches have to be made as short- and long-term programmes.

I) Short Term Programme

At present, 3.5 lakhs ha may be under Oil palm cultivation producing about 3 lakhs tons of Crude Palm Oil. Continuous removal Oil palm plantation is also happening due to various reasons. To improve the yield potential of the existing plantations, they are to be assessed jointly by the implementing agencies of the state government and the Companies who are operating in that particular region and ensure timely supply of various inputs (manures, fertilizers and water etc.) for the coming years. With effective field level monitoring in a time targeted Mission Mode programme, the average yield can be doubled or even more. Three stage benefits can be assured: i) farmer gets increased yield and income, ii) the processors get more FFB to processing thereby increasing the capacity utilisation with more CPO production and iii) increase in the contribution to vegetable oil pool.

II). Medium- and Long-Term Programmes

i) Replanting of old plantations of 25 to 30 years depending on the growth and yield level of palm has to be continuously taken up.

ii) new planting in the balance area of 1.7 million ha in a war footing starting with 40,000 to 50,000 ha for first two or three years and then about 1,00,000 ha for next 4 year and later on increase by 1.25 lakh to 1.5 lakh ha per year and complete the planting by 2035. Planting materials must be imported to supplement the domestic availability. (The policy paper by the author provides complete details and copy may be made available ,if needed).

iii) **Oil Palm in waste lands with under ground water sources** : India has got vast stretch of Waste lands as shown in Fig., including Northeastern Region., particularly in the identified potential states . These lands can be identified and allotted to the processors operating in the respective regions on long term lease or allotted to landless farmers and the processors may be asked to provide facilities making use government subsidies . M/S Vaidegi Oil palm Private Ltd I is doing it in Nyagarh and Boudh Districts which can be seen.

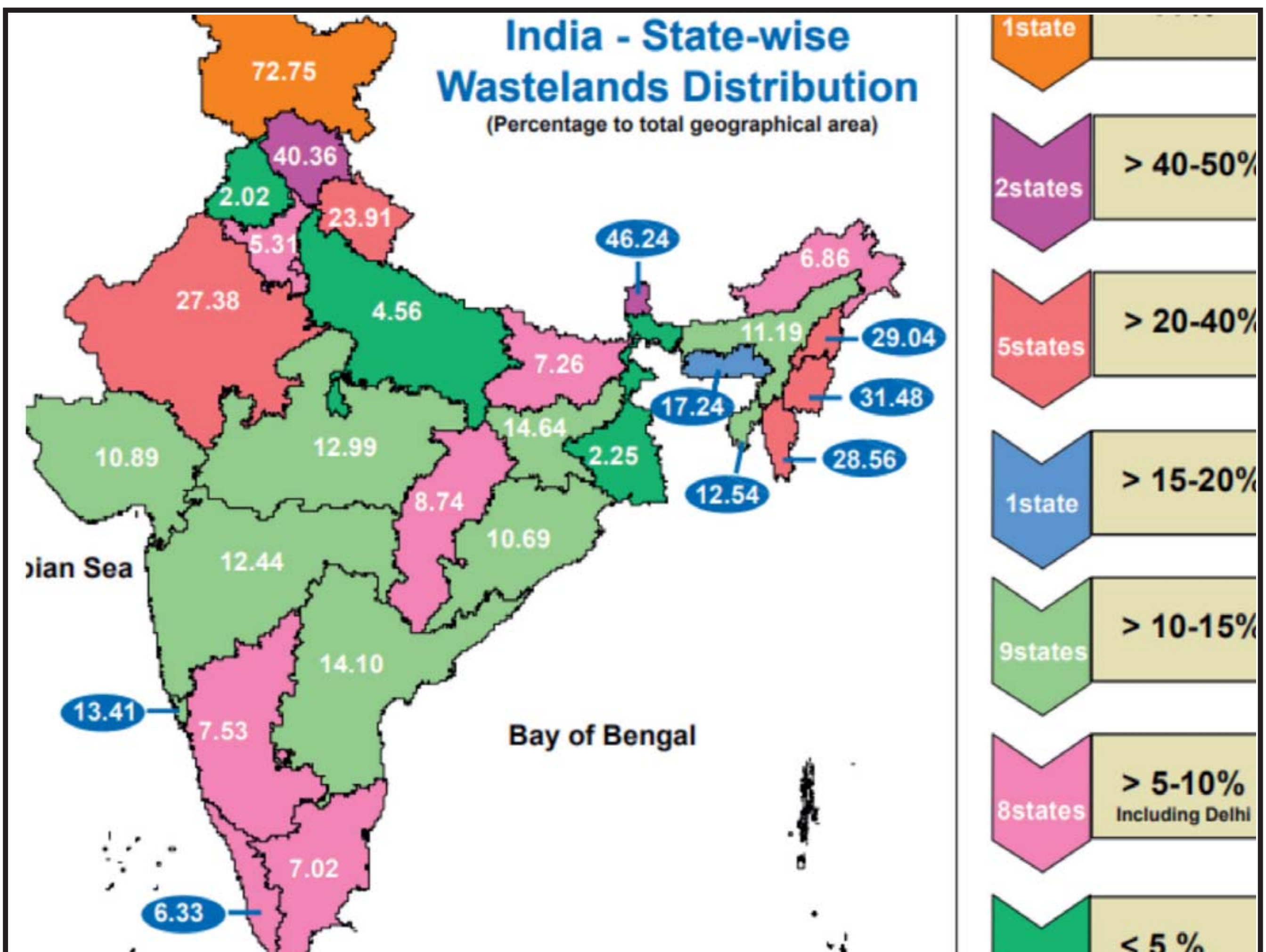


Fig.15. State wise waste lands distribution in India

If about three to four million ha could be identified and oil palm development can be taken , it should be possible to produce additional 9 to 12 million tons of Crude Palm Oil(CPO) and also lot of biomass energy..

The possibilities of creating irrigation facilities are indicated below as has been done in Odhisa.

Fig 16. Irrigation sources /water harvesting ponds in wastelands/ check dams

The possibilities of creating irrigation facilities are indicated below as has been done in Odhisa.

Fig.17. Performance of Oil Palm in waste lands

Policy issues needing attention from Government for Smart Oil Palm Development in the country.

1. To Farmers

- 100% assistance for Micro-irrigation / Water harvesting ponds and making drip irrigation as mandatory for all the Oil Palm planted area in all states. Subsidy for drip irrigation is to be given to entire planting area proposed for that year and also to the existing plantation where drip irrigation facility was not provided earlier.
- Establishment of Harvest Banks and encouraging Rural Service Providers for such activities.
- Fixing support Price of Rs.11,500 /ton of FFB.
- Encourage group / cluster farming approach as well as large scale Oil palm cultivation to any extent.
- Extending the credit facilities crop loan from banks, crop insurance etc.

2. To Industry

- Government land may be allocated on long term lease for establishment of state of art nursery, processing mill, waste management, ETP, by-product utilisation, Demo oil palm plantation and Farmers' training centre etc., may also be supported to start a small R&D unit to cater to the need of the farmer. Financial Assistance may be granted for establishment of processing mills to cater to the requirement on PAN India basis.
- To achieve more area, financial assistance may be extended for development of oil palm in institutional/ private lands increasing the present level of 25 ha
- Allotting cultivable waste lands with adequate underground water potential and financial assistance may be extended to Processing companies in the respective regions for establishment of oil palm plantation.
- Use of AI, IOT, Drones ,sensors may used to exploit the productivity potential of crops.

3. By Government

- Treating oil Palm as plantation crop and exempting from Land Ceiling Act.
- Area expansion should be decided two years in advance to make arrangements for importing seeds sprouts and raising seedlings and distribution of one year old seedlings to farmers.
- Drip irrigation/ fertigation subsidy should be extended to the targeted area and not peacemeal.
- Oil Palm development is a Government programme. So, import duty on importing germinated seeds for raising nursery should not be collsected the concerned Ministry.
- Ensuring fund allocation to reach the beneficiaries well in time and without any reduction.
- Creating oil palm cess fund from the collection of Import duty on vegetable oil.
- Creating Price stabilization fund to support the farmers whenever the FFB price goes below support price.
- Effective implementation / monitoring mechanism at State level with special staff for OPDP as was done at the initial period when OPDP was started.
- Effective utilisation of experienced retired officers in the relevant field with an aptitude for field level monitoring as Advisors.
- An effective well monitored mission mode approach for getting desired goal without diverting funds to any other activities.
- Research and development should be part of Development as in the case of Malaysia and Indonesia. The processing companies be associated taking up R&D..NMEO-OP may consider to fund seed money for starting R& D.
- An Apex body for implementing the programme is a long felt need for the success of the progrmme.

Achieving self sufficiency is definitely possible by 2040 if concerted efforts are made implement the programme;

Lipid modification technologies and their applications in food industry

Aishwarya Dhiman[1], **Dr Rajni Chopra[1*]**
[1]Department of Food Science and Technology, National Institute of Food Technology Entrepreneurship and Management, Kundli, Haryana, India
*Corresponding Author: rajnichopra.niftem@gmail.com, aishwaryadhiman11@gmail.com

Abstract

The escalating incidence of non-communicable chronic illnesses such as diabetes, obesity and cardiovascular disorders has resulted in a growing interest of consumers towards healthier alternatives for traditionally available lipids which are rich in saturated and trans fats. The ongoing governmental initiatives have already led to the extinction of trans-fatty acids from the food products. Nevertheless, the reduction of saturated fats from the diet is now being targeted along with an intended increase in consumption of unsaturated fatty acids. Solid fats however, play a major role in providing the acceptable texture and techno-functional properties to the food products, but are also associated with chronic health effects. Thus, in such a scenario, lipid modification technologies emerge as an excellent solution for development of fat analogs for substitution of saturated and trans fats. This review provides a concise overview of key lipid modification techniques, including hydrogenation, interesterification, fractionation, enzymatic modification, and transesterification. By examining current advancements, it also discusses the challenges and future prospects of lipid modification, highlighting the potential for developing healthier, more functional lipid-based products.

Keywords: Lipid modification, Designer fats, Structured Lipids, Trans-Fats, Saturated Fats.

1. Introduction

Lipids not only play a crucial role in human diet, but are also one of the most essential ingredients of food formulations. They impart palatability to the food and enhance its aroma and texture. They also act as a heating medium and provide satiety to the consumers. Nutritionally, they act as carriers for several bioactive compounds and essential fatty acids, namely, eicosapaentaenoic acid, docosahexaenoic acid and alpha-linolenic acid. The most primary component of all lipids is triglyceride, which is further made up by a glycerol backbone, with three fatty acids attached to it (Devi & Khatkar, 2016). The difference between these fatty acids on the triglyceride molecule forms the basis for the difference in the properties of oils and fats. Fatty acids can be categorized as saturated and unsaturated depending on the absence or presence of double bonds in their structure (Rosqvist & Niinistö, 2024). Saturated fats do not contain any double bond in their structure and are associated with negative implications on the health of consumers. These fatty acids along with trans fats from partially hydrogenated vegetable oils (PHVO) are one the major contributors to prevalence of cardiovascular diseases, obesity, inflammation and type-2 diabetes (DiNicolantonio et al., 2016). Contrary to this, unsaturated fatty acids, especially polyunsaturated fatty acids (containing two or more than two double bonds in their structure) have been reported to have positive effect on the health of the consumers. These have been known to lower LDL cholesterol, and blood pressure, while maintaining or improving cardiovascular health. Studies have also reported them to exhibit potential against mental disorders like, anxiety, depression, and alzheimer’s disease (Bork et al., 2022; Homroy et al., 2023).

The food industry majorly relies on fats high in saturated fats or trans-fats for formulating products requiring solid or semi-solid fats for their texture and functionality. These comprise of palm oil, butter, margarine (made form PHVO). These products do not solve the problem of trans fats or high saturated fat content and low unsaturated fat composition. Thus, modification techniques play a crucial role to obtain products with desirable techno-functional properties in terms of solid fat content (SFC), melting and crystallization profile, texture, plasticity and even oxidative stability (Dhiman et al., 2024). These methods include hydrogenation, fractionation, interesterification, and oleogelation. These techniques have enabled the creation of tailored lipids with specific functional attributes, including improved shelf life, healthier fatty acid compositions, and customized melting profiles. These modifications have profound implications, not only for product performance but also for addressing consumer demands for healthier and more sustainable food products.

This review aims to provide a concise yet comprehensive overview of the major structural modification technologies used in lipid processing. By examining these methods—ranging from traditional chemical approaches to modern enzymatic processes—this paper highlights their principles, applications, and potential to shape future innovations in lipid-based products. Additionally, it addresses the challenges and opportunities that lie ahead for developing novel, sustainable, and functional lipids to meet the growing needs of various industries.

2. Need for modification of lipids

The traditionally available oils and fats have very varied fatty acid profile, i.e., a few of them are composed of high amount of saturated fatty acids, while others are rich in unsaturated fatty acids. The WHO recommends a 1:1.5:1 ratio of saturated: monounsaturated: polyunsaturated fatty acids, and 5-10:1 ratio of omega-6 to omega-3 ratio for any oil to be referred to as healthy (Dhyani et al., 2022). There is no such natural oil available to fulfill this ideal requirement despite of the wide variety available. Therefore, lipid modification technologies are becoming more popular to fulfill this demand as consumers are becoming more aware of their food choices and transitioning towards healthier and nutritious foods.

Furthermore, the majority of fats employed in bakery and confectionary industry are composed of saturated fats, which have adverse implications on the health of consumers. They even comprise of trans fats, when developed from partially hydrogenated vegetable oil, which even in small quantities pose harmful effect on health, including an elevated rick of CVD and stroke. In such a scenario, it is important to replace such fats with healthy fats and oils. However, oils rich in PUFA and MUFA, such as perilla seed oil, chia seed oil and olive oil have relatively lower thermal and oxidative stability (Du et al., 2022). Thus, structural modifications are necessary to develop nutritious lipids with desirable techno-functional and organoleptic properties.

3. Lipid Modification Technologies

3.1. Blending

Blending is a very simple and cost-effective method for ameliorating the properties of oil by altering their fatty acid profiles. It involves the blending of two or more oils with different properties. This enhances the nutritional profile of the final oil by altering its' overall fatty acid composition, along with incorporation of antioxidants and other bioactive compounds(Lakhlifi El Idrissi et al., 2024). It is also the most acceptable method as it doesn't involve any chemical treatments and is non-destructive in nature (Sharma et al., 2023). The oils can be blended to achieve a balanced fatty acid composition and this can play a major role in improving the health of the consumers. For instance, blending peanut oil with omega-3 fatty acids from walnut oil resulted in a balanced ù6/ù3 ratio along with an increased oxidative stability (Lakhlifi El Idrissi et al., 2024). Another study observed an enhanced nutritional profile, sensory properties and oxidative stability on blending of perilla sed oil with olive oil (Torri et al., 2019). Similar study with black cumin oil, rice bran oil and rapeseed oil resulted in an improved PUFA/SFA along with ù6/ù3 ratio (Rudziñska et al., 2016). This also led to an increase in antioxidant potential of the oil. Nevertheless, blending also poses a major drawback of phase separation, when used for preparing blends using oils with different densities and thermal properties. This can be improved by processes like hydrogenation and interesterification.

3.2. Hydrogenation

Hydrogenation is the process of conversion of unsaturated fatty acids to less unsaturated or saturated fatty acids. This leads to an increase in the solid fat content of the resulting vegetable oils, which is also accompanied by a rise in its melting point (Kemeny et al., 2019). The process involves the addition of hydrogen to the oil in presence of a catalyst. Hydrogenation has major application in the bakery and confectionary industry, where solid fat is desirable. This not only enhances the textural profile of the fat, but also leads to an improved oxidative stability. This method can be classified as partial and full hydrogenation. The former results in the formation of a fat with desirable functional and textural properties, but with formation of trans-fats, which have adverse effects on health of consumers (Pokorný & Schmidt, 2010). This is majorly used in development of solid fats like margarine and shortenings. Fully hydrogenated fats have zero-trans fats, but are so hard, that they have very low applicability in the food industry and need to be blended with other oils, to soften them.

3.3. Fractionation

Fractionation is a promising technology of oil modification involving the separation of fractions of oil based on the variations in their constituent TAG melting points. The final products include a solid and a liquid fraction of the lipid, referred to as stearin and olein respectively (Yýlmaz & Aðagündüz, 2022). As compared to other methods, fractionation is generally cheaper, simpler and a safer technology.

Fractionation is an advanced oil modification technology that involves separating oil into different fractions based on the melting points of their triacylglycerols (TAGs). The process yields two primary lipid fractions: a solid fraction known as stearin and a liquid fraction called olein. Compared to alternative methods, fractionation is generally more cost-effective, simpler, and safer.

In industrial applications, there are three principal techniques for fat crystallization: detergent fractionation, solvent fractionation, and dry fractionation (Kayahan, 2002; Kellens et al., 2007). Among these, dry fractionation is the most economical and straightforward. Additionally, because it does not involve chemicals, it avoids waste generation, making it one of the most widely adopted methods in edible oil processing (Timms, 2005). Palm oil is the most frequently fractionated oil, predominantly using dry fractionation techniques (Omar et al., 2015). However, dry fractionation cannot completely separate the liquid from the solid phase. In comparison, solvent fractionation is more efficient in reducing liquid oil entrapment, resulting in higher oil yields and a firmer solid fraction. Despite this, its higher cost and associated health risks, similar to those of detergent fractionation, have diminished its industrial usage (Huey, Let, & Beng, 2015). Furthermore, detergent fractionation poses the risk of detergent contamination in the final products (Kellens et al., 2007). Due to these limitations, dry fractionation remains the preferred method in the edible oil industry.

3.4. Interesterification

Interesterification is a process of rearrangement of fatty acids in a mixture of triacylglycerides. This involves the breakdown and reformation of ester bonds connecting the fatty acids ti the glycerol backbone that forms the basis of TAG structure. It is a major technology used in the food industry for modification of physicochemical and functional attributes of the oil. It is used as an alternate to processes like hydrogenation to develop a trans-fat free fat for use application in margarine and shortenings (Gibon & Kellens, 2014). The brief process of interesterification has been depicted in Figure 1. Interesterification can be differentiated as chemical or enzymatic interesterification depending on the type of catalyst used in the study. Chemical interesterification is the most common method of interesterification implemented at industrial scale. It takes place randomly and lacks specificity. Additionally, the separation is difficult and it also leads to the production of more undesirable by-products as compared to enzymatic interesterification, which is carried out in presence of enzyme and is a more specific process. A comparison between the two has been depicted in Table-1. Amongst the technoliges discusses above, enzymatic intersterification, desoite of its high cost is a potential method to produce solid fats with zero trans fats, without any major effect on the its organoleptic properties. The different type of interesterification, based on the type of type of substances involved in the reaction has been classified as follows.

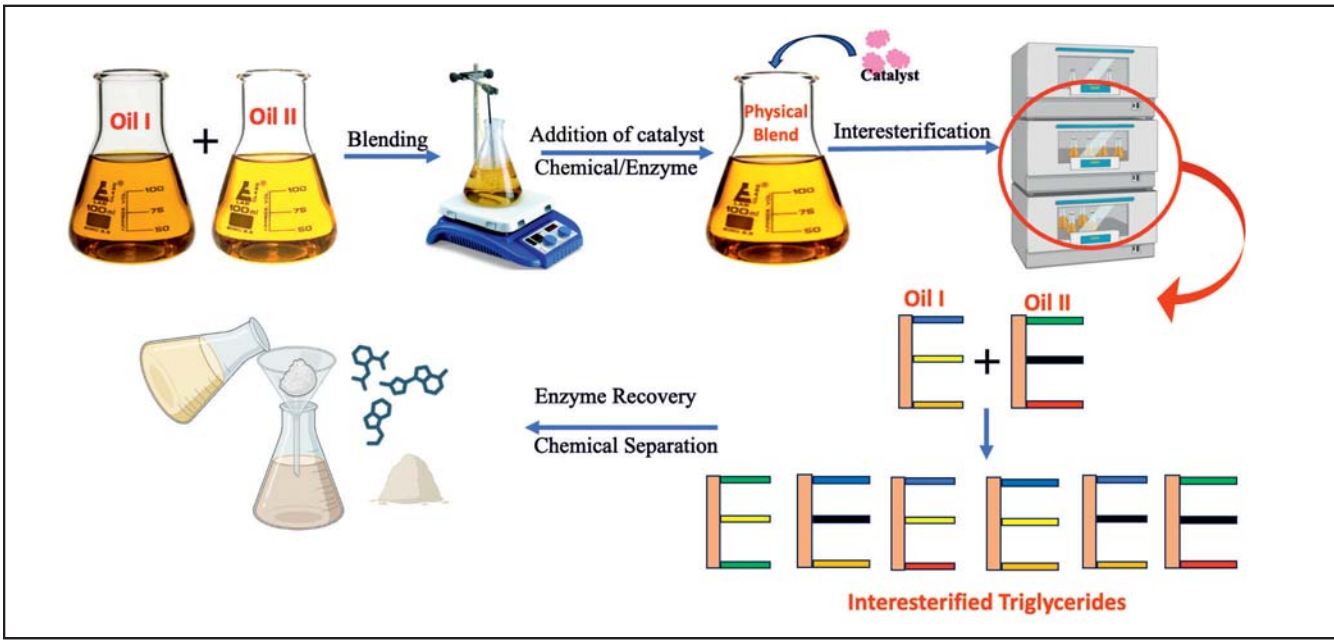


Figure 1: Diagrammatic representation of Interesterification reaction

3.4.1. Acidolysis: It is a process involving the transfer of acyl groups amongst the TAG molecules and the FFA groups. The reaction is generally catalyzed by an acid-base catalyst resulting in partial hydrolysis of the TAG molecule leading to formation of MAGs and DAGs. These MAGs and DAGs react with FFAs to develop new molecules of TAGs. This method is considered quite effective for ameliorating the nutritional properties of fats by incorporating novel FAs to the TAGs. However, the process is not economically friendly due to its high cost as well as inefficiencies in separation of the high concentration of FFAs formed.

3.4.2. Glycerolysis: In case of glycerolysis, the reaction can either be catalyzed by an alkali or an acid (in case of chemical interesterification) or by lipase enzyme (in case of chemical interesterification). The process is initiated by the reaction of one mole of TAG with three moles of alcohol, thus forming a mixture of alkyl esters and glycerol (Kadhum & Shamma, 2017). This glycerol then reacts with TAGs, which leads to a transfer of acyl groups to finally develop MAGs and DAGs.

3.4.3. Trans-esterification: It is the process of rearrangement of fatty acids amongst the same of different TAG species. It is initiated by the cleavage of ester bonds linking the fatty acid to the glycerol backbone (Jadhav & Annapure, 2021). This is then followed by the reattachment of the fatty acid to a different position, either on the same or different TAG molecule.

Table 1: Difference between enzymatic and chemical interesterification

Characteristic	Chemical	Enzymatic
Catalyst	Chemical	Enzyme
Specificity	✗	✓
Temperature	↑⚠	↓⚠
Cost	Low cost	Expensive
By-product	High	Low
Environment concern	Hazardous	Environment Friendly

3.5. Oleogelation

Oleogelation is a relatively recent method of lipid modification used for converting liquid plant-based oil to solid fat by application of oleogelators. This has been used to develop novel food ingredients with functional properties similar to fats, but nutritional properties that of oil. They have been used in a variety of food products, namely dairy, meat, bakery, and confectionery products. They offer a dual advantage as substitutes for saturated and trans fatty acids as well as carriers for water soluble bioactive compounds (Pehlivanoglu et al., 2018). Additionally, they act as stabilizers in products that don't comprise emulsifiers, aid in oil binding and enhance the thermal stability of heat labile products.

4. Food Applications of modified lipids

A vast majority of the resesrcherss had focused on studying the sturctural and rheological characteristics of the modified fats and lipids, however, only a few of them had actually reported on their functionality for potential application in food formulations. This section would cover some of the notable instances of these applications for several food categories.

4.1. Bakery Fats

Bakery fats, primarily categorized as shortening and butter (or margarine), are essential ingredients in various bakery products like bread, biscuits, pastries, and cakes. These fats play multiple roles in dough and contribute to the desired qualities of the final baked goods. They act as a lubricant, promoting a tender texture, and contribute to aeration, resulting in a larger volume and a uniform cell structure (Dhiman et al., 2022). Moreover, bakery fats help retain moisture, ensuring the product remains soft and moist over time, thus extending its shelf life. The quest to find suitable replacements for bakery fats has led to the exploration of fat mimetics like wax-based oil gels, polymer gels, and structured emulsions (Gutiérrez-Luna et al., 2021). While these mimetics may not perfectly replicate the rheological properties of dough made with traditional fats, studies have shown that the final baked products often exhibit comparable characteristics. For example, a study demonstrated that cookies made with oil gels from various natural waxes and vegetable oils had similar hardness, spread, and fracturability to those made with commercial margarine, despite variations in oleogel properties (Hwang et al., 2016). Similarly, it was found that wax oleogels could replace shortening to create softer cookies with a greater spread (Jang et al., 2015).

Further research supports the viability of fat replacement in various baked goods. Another research successfully substituted up to 50% of shortening in muffins with fat mimetics without compromising quality, and similar results were observed in gluten-free aerated products with up to 45% replacement (I. K. Oh & Lee, 2018).

One area where fat replacement remains particularly challenging is in laminated pastries like puff pastries and croissants. These products require specialized roll-in shortenings or laminate fats with specific plasticity, melting range, and hardness (Patel et al., 2020). However, promising advancements have been made by utilizing modified structured emulsions as substitutes for these specialized fats.

4.2. Margarines and shortenings

Table spreads and margarines, which are fat-continuous emulsions, have different fat content depending on their intended use. Low-fat spreads (35–42% weight) and very low-fat spreads (<30% weight) are typically used for spreading on bread, while high-fat spreads (70–82% weight) are mainly used for cooking or frying (Syan et al., 2024). Solid fat contributes to these products in three main ways: it creates a crystalline network in the oil phase, influencing texture and spreadability; it stabilizes water droplets; and it enhances mouthfeel and flavor release. Wax-based oil gels can mimic these functions of fat and are commonly researched as fat replacements in spreads and margarine. However, challenges remain, including a waxy aftertaste, low firmness, and potential instability over time. Plastic fats, widely used in food processing, are traditionally made through partial hydrogenation of vegetable oils. This process creates unhealthy trans fats linked to cardiovascular disease (Lakum & Sonwai, 2018). A healthier alternative, designer lipid, are created by modifying triglycerides through interesterification or acidolysis. These methods don't alter the fatty acid structure, avoiding trans-fat formation .

Designer lipids can be created from various vegetable oil sources. Unsaturated fatty acid sources like sunflower, canola, cottonseed, and groundnut oils can be combined with saturated fatty acid sources like coconut and palm kernel oils to create plastic fats with specific physical properties (Jadhav & Annapure, 2021). The distinctive attributes of plastic fats include solid fat index, crystal structure, and melting behavior, all of which can be controlled through interesterification or acidolysis. SFI influences mouthfeel and spreadability, with lower SFI at body temperature providing a better mouthfeel. The â2 crystal structure is desirable for its smooth appearance and moderate melting point. Several studies demonstrate the use of designer lipids as plastic fats (Devi & Khatkar, 2016). One study blended milk fat and palm olein, resulting in improved spreadability and a lower melting point. Another study created a trans-fat-free margarine stock from soybean oil and corn oil, achieving a desirable SFI and â2 crystal structure (Lakum & Sonwai, 2018). A more recent study used mustard oil, and palm stearin to create a modified lipid with suitable SFI and â2 crystals (Manzoor et al., 2024). These studies highlight modified lipids' potential as a healthy replacement for traditional plastic fats, offering a better option for consumers concerned about cardiovascular health.

4.2. Meat Products

Modified fats are used in meat products to reduce animal fat and cholesterol, improve nutritional content by increasing unsaturated fatty acids, and lower overall calories. These replacements have been used in various meat preparations, from sauces and batters to processed meats like sausages and patties. For example, an ethyl cellulose oleogel successfully replaced some beef fat in frankfurters, maintaining similar texture compared to the original product (Kouzounis et al., 2017). In another study, oil gels from hydrophilic polymers were used in patties, with a 50% replacement achieving the best results and significantly improving the saturated to unsaturated fat ratio (I. Oh et al., 2019).

4.3. Confectionary

A major challenge in maintaining the quality of chocolate and confectionery products is preventing oil migration and leakage during storage. Since solid fat typically acts as an oil binder, replacing it with fat mimetics requires careful consideration to avoid compromising product stability. Traditionally, hydrogenated oils, added at 2%wt or less, have served as the primary oil binders. However, recent studies have demonstrated the successful use of alternative structuring agents, such as shellac wax and hydrophilic cellulose derivatives, to replicate oil binding functionality in peanut butter and chocolate paste formulations. These structuring agents, added at levels of 1–2%wt, achieved comparable stability and rheological properties to traditional formulations. Cocoa butter, a key ingredient in chocolate and confectionery, is expensive and sometimes scarce. Therefore, food scientists are developing cost-effective alternatives using abundant vegetable oils like palm oil, olive oil, mango fat, and canola oil. Palm oil is often favored due to its low cost and suitable fatty acid composition. These alternatives aim to replicate cocoa butter's unique fatty acid composition, which allows it to melt at body temperature. This involves creating modified lipids through interesterification, a process that rearranges the fatty acids in triglycerides. For example, one study used palm mid-fraction and stearic acid with an enzyme to create a designer lipid with similar properties to cocoa butter, achieving a comparable fatty acid distribution and crystal structure (Huang et al., 2021). Another study used *Cinnamomum camphora* seed oil and hydrogenated palm oil to create a medium-chain fatty acid-rich structured lipid with a similar melting point to cocoa butter (Xu et al., 2018). It's important to distinguish between "cocoa butter equivalents" and "cocoa butter substitutes." Equivalents, derived from plant fats without lauric acid, closely mimic cocoa butter's properties. Substitutes, which contain lauric acid, do not. Some studies have also explored developing substitutes using palm kernel oil and fully hydrogenated palm oil, resulting in a product with a different crystal structure that allows chocolate production without tempering.

5.0. Conclusion and future aspects

The recent government initiatives imposing a removal of trans fats along with limiting saturated fat consumption have led to an increased interest of industries and researchers towards innovations involving fat reformulation and lipid modification. Furthermore, the transformation of consumer perception towards healthier food is another reason for researchers to look for healthier alternate sources of traditional fats, which are rich in saturated fat and comprise of trans fats. Modified lipids, not only exhibit an improved nutritional profile, but also do not alter the sensory attributes of the food products.

6. References

1. Bork, C. S., Lundbye-Christensen, S., Venø, S. K., Lasota, A. N., Schmidt, E. B., & Overvad, K. (2022). Plant n-3 PUFA intake may lower the risk of atherosclerotic cardiovascular disease only among subjects with a low intake of marine n-3 PUFAs. *European Journal of Nutrition*, *61*(1), 557–559. https://doi.org/10.1007/s00394-021-02581-5

2. Devi, A., & Khatkar, B. S. (2016). Physicochemical, rheological and functional properties of fats and oils in relation to cookie quality: A review. *Journal of Food Science and Technology*, *53*(10), 3633–3641. https://doi.org/10.1007/s13197-016-2355-0

3. Dhiman, A., Chopra, R., & Garg, M. (2022). Edible Film and Coating for Food Packaging. In *Biodegradable Composites for Packaging Applications*. CRC Press.

4. Dhiman, A., Chopra, R., Singh, P. K., Homroy, S., Chand, M., & Talwar, B. (2024). Amelioration of nutritional properties of bakery fat using omega-3 fatty acid-rich edible oils: A review. *Journal of the Science of Food and Agriculture*, *104*(6), 3175–3184. https://doi.org/10.1002/jsfa.13225

5. Dhyani, A., Singh, P. K., Chopra, R., & Garg, M. (2022). Enhancement of Oxidative Stability of Perilla Seed Oil by Blending It with Other Vegetable Oils. *Journal of Oleo Science*, *71*(8), 1135–1144. https://doi.org/10.5650/jos.ess22013

6. DiNicolantonio, J. J., Lucan, S. C., & O'Keefe, J. H. (2016). The Evidence for Saturated Fat and for Sugar Related to Coronary Heart Disease. *Progress in Cardiovascular Diseases*, *58*(5), 464–472. https://doi.org/10.1016/j.pcad.2015.11.006

7. Du, Q., Zhou, L., Li, M., Lyu, F., Liu, J., & Ding, Y. (2022). Omega-3 polyunsaturated fatty acid encapsulation system: Physical and oxidative stability, and medical applications. *Food Frontiers*, *3*(2), 239–255. https://doi.org/10.1002/fft2.134

8. Gibon, V., & Kellens, M. (2014). 8—Latest Developments in Chemical and Enzymatic Interesterification for Commodity Oils and Specialty Fats. In D. R. Kodali (Ed.), *Trans Fats Replacement Solutions* (pp. 153–185). AOCS Press. https://doi.org/10.1016/B978-0-9830791-5-6.50013-7

9. Gutiérrez-Luna, K., Astiasarán, I., & Ansorena, D. (2021). Gels as fat replacers in bakery products: A review. *Critical Reviews in Food Science and Nutrition*, *62*, 1–14. https://doi.org/10.1080/10408398.2020.1869693

10. Homroy, S., Chopra, R., Singh, P., Dhiman, A., chand, monika, & Talwar, B. (2023). Role of encapsulation on the bioavailability of omega-3 fatty acids. *Comprehensive Reviews in Food Science and Food Safety*, *23*, 1–35. https://doi.org/10.1111/1541-4337.13272

11. Huang, Z., Guo, Z., Xie, D., Cao, Z., Chen, L., Wang, H., Jiang, L., & Shen, Q. (2021). *Rhizomucor miehei* lipase-catalysed synthesis of cocoa butter equivalent from palm mid-fraction and stearic acid: Characteristics and feasibility as cocoa butter alternative. *Food Chemistry*, *343*, 128407. https://doi.org/10.1016/j.foodchem.2020.128407

12. Hwang, H.-S., Singh, M., & Lee, S. (2016). Properties of Cookies Made with Natural Wax-Vegetable Oil Organogels. *Journal of Food Science*, *81*(5), C1045-1054. https://doi.org/10.1111/1750-3841.13279

13. Jadhav, H. B., & Annapure, U. (2021). Designer lipids -synthesis and application – A review. *Trends in Food Science & Technology*, *116*, 884–902. https://doi.org/10.1016/j.tifs.2021.08.020

14. Jang, A., Bae, W., Hwang, H.-S., Lee, H. G., & Lee, S. (2015). Evaluation of canola oil oleogels with candelilla wax as an alternative to shortening in baked goods. *Food Chemistry*, *187*, 525–529. https://doi.org/10.1016/j.foodchem.2015.04.110

15. Kadhum, A. A. H., & Shamma, M. N. (2017). Edible lipids modification processes: A review. *Critical Reviews in Food Science and Nutrition*, *57*(1), 48–58. https://doi.org/10.1080/10408398.2013.848834

16. Kemeny, Z., Bhaggan, K., Brüse, F., Creanga, A., Diks, R., Gambelli, L., Le Bail-Collet, Y., & Ribera, D. (2019). MCPDE and GE: An Update on Mitigation Measures. In *Encyclopedia of Food Chemistry* (pp. 578–587). Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.21827-1

17. Kouzounis, D., Lazaridou, A., & Katsanidis, E. (2017). Partial replacement of animal fat by oleogels structured with monoglycerides and phytosterols in frankfurter sausages. *Meat Science*, *130*, 38–46. https://doi.org/10.1016/j.meatsci.2017.04.004

18. Lakhlifi El Idrissi, Z., El Guezzane, C., Boujemaa, I., El Bernoussi, S., Sifou, A., El Moudden, H., Ullah, R., Bari, A., Goh, K. W., Goh, B. H., Bouyahya, A., Harhar, H., & Tabyaoui, M. (2024). Blending cold-pressed peanut oil with omega-3 fatty acids from walnut oil: Analytical profiling and prediction of nutritive attributes and oxidative stability. *Food Chemistry: X*, *22*, 101453. https://doi.org/10.1016/j.fochx.2024.101453

19. Lakhlifi El Idrissi, Z., El Guezzane, C., Boujemaa, I., El Bernoussi, S., Sifou, A., El Moudden, H., Ullah, R., Bari, A., Goh, K. W., Goh, B. H., Bouyahya, A., Harhar, H., & Tabyaoui, M. (2024). Blending cold-pressed peanut oil with omega-3 fatty acids from walnut oil: Analytical profiling and prediction of nutritive attributes and oxidative stability. *Food Chemistry: X*, *22*, 101453. https://doi.org/10.1016/j.fochx.2024.101453

20. Lakum, R., & Sonwai, S. (2018). Production of trans-free margarine fat by enzymatic interesterification of soy bean oil, palm stearin and coconut stearin blend. *International Journal of Food Science & Technology*, *53*(12), 2761–2769. https://doi.org/10.1111/ijfs.13888

21. Manzoor, S., Masoodi, F. A., Akhtar, G., & Rashid, R. (2024). Production of trans-free shortening by lipase catalysed interesterification using mustard oil and palm stearin: Optimisation and characterisation. *Biomass Conversion and Biorefinery*, *14*(12), 13027–13043. https://doi.org/10.1007/s13399-022-03315-1

22. Oh, I. K., & Lee, S. (2018). Utilization of foam structured hydroxypropyl methylcellulose for oleogels and their application as a solid fat replacer in muffins. *Food Hydrocolloids*, *77*, 796–802. https://doi.org/10.1016/j.foodhyd.2017.11.022

23. Oh, I., Lee, J., Lee, H. G., & Lee, S. (2019). Feasibility of hydroxypropyl methylcellulose oleogel as an animal fat replacer for meat patties. *Food Research International*, *122*, 566–572. https://doi.org/10.1016/j.foodres.2019.01.012

24. Patel, A. R., Nicholson, R. A., & Marangoni, A. G. (2020). Applications of fat mimetics for the replacement of saturated and hydrogenated fat in food products. *Current Opinion in Food Science*, *33*, 61–68. https://doi.org/10.1016/j.cofs.2019.12.008

25. Pehlivanoglu, H., Ozulku, G., Yildirim, R. M., Demirci, M., Toker, O. S., & Sagdic, O. (2018). Investigating the usage of unsaturated fatty acid-rich and low-calorie oleogels as a shortening mimetics in cake. *Journal of Food Processing and Preservation*, *42*(6), e13621. https://doi.org/10.1111/jfpp.13621

26. Pokorný, J., & Schmidt, Š. (2010). 15—Effects of processing and storage on antioxidant efficacy in foods. In E. A. Decker (Ed.), *Oxidation in Foods and Beverages and Antioxidant Applications* (pp. 368–393). Woodhead Publishing. https://doi.org/10.1533/9780857090447.2.368

27. Rosqvist, F., & Niinistö, S. (2024). Fats and oils – a scoping review for Nordic Nutrition Recommendations 2023. *Food & Nutrition Research*, *68*, 10.29219/fnr.v68.10487. https://doi.org/10.29219/fnr.v68.10487

28. Rudziñska, M., Hassanein, M. M. M., Abdel–Razek, A. G., Ratusz, K., & Siger, A. (2016). Blends of rapeseed oil with black cumin and rice bran oils for increasing the oxidative stability. *Journal of Food Science and Technology*, *53*(2), 1055–1062. https://doi.org/10.1007/s13197-015-2140-5

29. Sharma, K., Kumar, M., Lorenzo, J. M., Guleria, S., & Saxena, S. (2023). Manoeuvring the

physicochemical and nutritional properties of vegetable oils through blending. *Journal of the American Oil Chemists' Society*, *100*(1), 5–24. https://doi.org/10.1002/aocs.12661

30. Syan, V., Kaur, J., Sharma, K., Patni, M., Rasane, P., Singh, J., & Bhadariya, V. (2024). An overview on the types, applications and health implications of fat replacers. *Journal of Food Science and Technology*, *61*(1), 27–38. https://doi.org/10.1007/s13197-022-05642-7

31. Torri, L., Bondioli, P., Folegatti, L., Rovellini, P., Piochi, M., & Morini, G. (2019). Development of Perilla seed oil and extra virgin olive oil blends for nutritional, oxidative stability and consumer acceptance improvements. *Food Chemistry*, *286*, 584–591. https://doi.org/10.1016/j.foodchem.2019.02.063

32. Xu, Y., Zhu, X., Ma, X., Xiong, H., Zeng, Z., Peng, H., & Hu, J. (2018). Enzymatic production of trans-free shortening from coix seed oil, fully hydrogenated palm oil and *Cinnamomum camphora* seed oil. *Food Bioscience*, *22*, 1–8. https://doi.org/10.1016/j.fbio.2017.12.010

33. Yýlmaz, B., & Aðagündüz, D. (2022). Fractionated palm oils: Emerging roles in the food industry and possible cardiovascular effects. *Critical Reviews in Food Science and Nutrition*, *62*(7), 1990–1998. https://doi.org/10.1080/10408398.2020.1869694

Nutritional properties of different fats: Implications for product development

Pulkit Mathur[1*] and Samriddhi Manral[2]
[1]Professor, Lady Irwin College, University of Delhi
[2]PhD Scholar, Lady Irwin College, University of Delhi
*Corresponding Author: pulkit.mathur@lic.du.ac.in

Abstract

Consumer health and product functionality are both critical factors in food formulation. Fats, as a primary energy source, significantly impact the shelf life, flavor and texture of food products. However, their health implications differ based on their chemical structure and source. Fat replacement is a key innovation to reduce fat content in food products, either through fat substitutes or fat mimetics. Fat replacers, such as dietary fibers, whey protein concentrate, and starch-based alternatives, can lower fat and calorie content without compromising food quality. These alternatives can improve health outcomes by reducing calorie intake, which may lower the risk of obesity and cardiovascular diseases. Saturated fats, linked to heart disease, can be reduced or balanced with unsaturated fats, appealing to health-conscious consumers. Omega-3 fortified products, rich in polyunsaturated fatty acids, offer added health benefits but stability and taste must be managed due to susceptibility to oxidation. Despite these advancements, developing low-fat products remains challenging due to the critical roles fat plays in sensory attributes. Key characteristics like smooth, creamy texture, rich flavor, and satiating effects are influenced by fat droplets, making it crucial to maintain these qualities for consumer satisfaction. Successful fat reduction strategies must preserve both the sensory and nutritional characteristics of foods. Ongoing innovations in fat replacement technologies provide promising opportunities to create healthier food products without sacrificing functionality or taste but they do not come without limitations. Balancing health benefits with consumer preferences remains a priority in this evolving field.

Keywords: Micronutrients, Triglycerides, Cholesterol, Trans fats, Speciality fats, Saturated fats, unsaturated fats.

Introduction

Fats are one of the three essential macronutrients and are essential to human nutrition. They not only provide energy and help in transporting fat-soluble vitamins but are also essential for hormone synthesis. Other than this, healthy growth and metabolism depends on the consumption of essential fatty acids. Additionally, fats lubricate the gastrointestinal tract and are a crucial part of cell membranes. In our diet, lipids and fats generally consist of triacylglycerols, free and esterified fatty acids, sterols (e.g., cholesterol), phospholipids, non-glyceride components of fat (fat soluble vitamins, oryzanol, sesame lignans, etc.) They are essential for flavour, texture, palatability in addition to structural and sensory aspect of food. Fat creates a sense of fullness by delaying hunger and lengthening the transit time through the gut.

However, the type of fat used in food processing has significant implications for human health. Certain types of fats are being linked to increased risks of chronic diseases, such as cardiovascular disease, obesity and type 2 diabetes (Siri-Tarino et al., 2015; Khosla &Khosla, 2017). WHO suggests that fats should contribute between 20-35% of total daily energy intake. Saturated fats (SF) should account for less than 10% and trans fats must be limited to fewer than 1% of total consumed energy (WHO, 2010). The use of trans fat developed in the process of partial hydrogenation of oils has been popular in food industry due to its stability and long shelf life (Amico et al., 2021). However, dietary trans fats is linked with increased levels of low-density lipoprotein and decreased levels of high-density lipoprotein, which contributes to negative cardiovascular effects (Anderson et al., 1961). This resulted in trans fats being largely phased out in many countries following regulatory measures. In 2015, U.S. Food and Drug Administration stated trans fats as not "Generally Recognized as Safe" (FDA, 2024).

In response to these regulatory and consumer-driven changes, the food industry has sought alternative fat sources and innovative fat replacement strategies with an emphasis on reducing or replacing harmful fats like trans fats and saturated fat (Amico et al., 2021). These include the use of unsaturated fats, such as plant-based oils (e.g., olive, sunflower, and canola oils), as well as emerging technologies involving fat mimetics and structured lipids designed to mimic the functional properties of traditional fats without the associated health risks. Such shifts in fat usage raise important questions about the nutritional implications of these substitutes, including their long-term effects on human health, food quality, and overall consumer acceptance (Nourmohammadi et al., 2024; Marcus 2013).

This review aims to explore the nutritional properties of different fats which can guide product development decisions. By mapping current research and identifying key developments in fat replacement technologies, this review will provide a comprehensive understanding of how the food industry is responding to the call for healthier, more sustainable fat choices.

Types of fat and implications for product development

1. Saturated Fats (SF)

Existence of single bonds between carbon atoms along with high melting point and solid state at normal temperature are features of SFs. They are not susceptible to further oxidation and rancidity when exposed to the atmosphere. It is found in animal products like ghee, butter, lard, dairy, meat and some tropical oil sources (coconut oil, palm oil). Nutritionally, they are known to raise levels of LDL cholesterol (often termed "bad" cholesterol) in blood, which is associated with increased risk of heart disease (Vieira et al 2015). However, the link between SFs and heart disease is more complex and may depend on the overall dietary context.

Implications for Product Development

Consider reducing or balancing the amount of SF, possibly by blending with unsaturated fats, to appeal to health-conscious consumers. For certain applications, like bakery products, the use of SFs can be crucial for the desired texture and flavour, necessitating a balance between product quality and nutritional profile (Vieira et al 2015). In products like baked cookies fluffy texture can be given by incorporating air through solid fats. It also helps in minimizing the migration of oil from the product as in case of crackers and cookies. Solid fats are important for providing a flaky texture to food like pastries. This texture is achieved by inhibiting the formation of a gluten network. Solid fats are used for the mouthfeel of creaminess in milk and yogurt as well as for providing lubrication to the products like ice cream and meats, SFAs are important to give melting mouthfeel as in case of chocolates. They form a network of solid crystals that are important for texture in food like frozen desserts. (Rios et al., 2014; Vieria et al, 2015; Rao, 2003; Colla et al., 2018).

2. Unsaturated Fats

Unsaturated fats primarily consist of double bonds in carbon chain. They are usually liquid at normal temperature and known for their low melting points. They are susceptible to further oxidation and rancidity when exposed to the atmosphere and hence an antioxidant is required to prevent rancidity (Decker et al., 2010). MUFA improves blood cholesterol levels, which in turn reduces the risk of heart disease. For examplerich source of oleic acid are olive oil, avocado, groundnut, rapeseed, mustard, canola, ricebran and seasame. Examples of PUFAs are linolenic acid, linoleic acid, docosahexanoic acid, arachidonic acid, eicosapentanoic acid. Long chain PUFAs, specifically docosahexaenoic acid and arachidonic acid is significant for growth and development during early life stages. Omega-3 is particularly found in sources such as flaxseeds, fish, walnuts, legumes whereas omega 6 rich oils include sunflower, safflower, corn oil. Omega-3 fatty acids are particularly noted for their role in heart health, reducing inflammation, and supporting brain function. Deficiency of linolenic and linoleic acid is associated with skin lesions and other adverse effects.

Implications for Product Development

Unsaturated fatty acids become rancid easily and produce off flavours and toxic-compounds decrease the shelf life and destroy vitamins. Therefore, incorporation of these into prepared food could be challenging (Vieira et al., 2015; Decker et al., 2010). But since unsaturated fatty acids are considered comparatively healthier than saturated fats, formulating products with unsaturated fats can enhance their health appeal with consumers. Omega-3 fortified products can be marketed for their added health benefits, though stability and taste must be carefully managed due to omega-3's sensitivity to oxidation.

3. Trans Fats

Trans fats are produced through hydrogenation, a process that transforms liquid oils into solid forms at room temperature. This method increases the shelf life and stability of fats but has been linked to negative health effects, particularly concerning heart health. Trans fats increase levels of LDL cholesterol while decreasing HDL levels. Due to associated health risks, trans fats have been banned or strictly limited in many countries.

Implications for Product Development

The use of trans fats should be minimized or avoided in product formulations to comply with regulations and meet consumer health expectations. Innovation with alternatives that provide similar functionality in terms of texture and shelf life without the health risks, such as interesterified fats or blends of saturated and unsaturated fats.

4. Functional and Specialty Fats

These include structured lipids and fats designed for specific health benefits or functional properties in food applications. Examples include medium-chain triglycerides (MCTs) for energy products or phytosterol-enriched fats for cholesterol-lowering properties.

Implications for Product Development

Specialty fats can offer a competitive edge for products aimed at niche markets or specific health concerns. The formulation must carefully consider the cost, regulatory approval, and consumer perception of these specialized ingredients.

Landscape of Fat Usage and Innovations in Fat Replacement

In 2023, the low-fat product market was valued at approximately $8.9 billion, with projections suggesting it could reach around $17.9 billion within the next decade. The market is anticipated to undergo significant growth with a compound annual growth rate of 7.2% (FMI, 2023). SF replacement requires finding a solution which provides similar physico-chemical properties, leading to increased use of tropical oils like coconut and palm (Amico et al.,2024).

Merely lowering the fat content of food will alter its chemical and physical makeup as well as its physiological and sensory aspects. Therefore, fat replacers serve a variety of purposes in food, including stabilizing, emulsifying, thickening, and supplying texture (Wylie-Rosett, 2002). Fat replacers are ingredients that could provide some or all functions of fat and at the same time giving lesser calories as compared to fat. Additionally, they may aid in averting the harmful consequences of consuming too much fat (Therdthai, 2022).

Essentially, there are two types of fat replacers: fat mimetics and fat substitutes. Ingredients that resemble fats in terms of physiochemical properties and chemical structure are known as fat substitutes. They are either indigestible or provide fewer calories per gram. Components with chemical structures that are distinctly different from fat are known as fat mimetics (O'Connor & O'Brien, 2011). Usually, they are protein or carbohydrates based. Their various functional properties, including viscosity, mouthfeel, appearance and replicate some of the physicochemical characteristics and desirable sensory attributes of fat (Logan et al., 2006; O'Sullivan et al., 2017).

Fats substitutes

Fat substitutes resemble the appearance, texture, taste of original fats. They are of three types namely protein, carbohydrate and fat-based. Carbohydrate-based fat substitutes retain water which gives a creamy texture. Additionally, it also provides form and structure which resembles as given by fat (Wylie-Rosett, 2002). But they are not generally preferred for cooking or frying (O'Sullivan, 2017). Carbohydrate-based fat substitutes are employed in products like cakes, cookies, dairy, salad dressing, frozen desserts. Carbohydrate based hydrocolloids are high weighted hydrophilic bipolymers having high water retention capacity. For replacement of cocoa butter an oat beta glucan based hydrocolloid can be used in chocolate production. Protein-based substitutes are blended to hold water which gives a creamy texture. They are used in products such as butter, cheese, ice creams, sour cream, mayonnaise, dairy, salad dressings. Examples include milk, microparticulated protein, egg white, whey protein concentrate. They contribute less calories and total fat (Bhattacharya, 2023). Due to the structural changes caused by heat, they are unsuitable for baking or frying (O'Connor & O'Brien, 2011). Fat-based fat substitutes often contain a higher concentration of fatty acids as compared to triglycerides, making them excessively huge for digestion, therefore, they do not contribute to fats or energy. However, consuming them in large quantities may lead to a deficiency in fat-soluble vitamins or gastrointestinal issues. They can be substituted in chocolate, savories, baked goods, snacks and confections. Examples include Caprenin mono- and diglycerides, Olestra, Salatrim and short and long chain fatty acids (O'Connor & O'Brien, 2022).

Fat mimetics

They replicate the structural and sensory characteristics of conventional fats present in food products. They are categorized into carbohydrate, protein and fat-based (Nourmohammadi et al., 2024). Protein-based mimetics are appropriate for products that experience milder cooking methods for example baking or retorting. However, frying is not advisable, as the protein can denature, resulting in a loss of its creamy sensory characteristics (Marcus, 2013). Nutritionally, protein-based fat mimetics of plant origin lack cystine and methionine and have anti nutritional factors like trypsin inhibitors, hence additional processing is required (Bohrer et al., 2017; Vélez-Erazo et al., 2022). Carbohydrate-based fat mimetics serve as fat replacements by retaining water inside the food product and forming a matrix that resembles gel. By this process thickness and structure is enhanced and thereby a creamy texture identical to conventional fat products is created. Their use is limited as they are not suitable for frying (Marcus, 2013). However, water activity in such food product increases which increases microbial growth and reduces shelf life (Aswathy, 2023). Fat based fat mimetics such as organogels consist of organogelators, liquid oil, crystalline additives as well as surfactants (Marcus, 2013). They consist of a bulk liquid oil that is encapsulated by a minimal concentration of solid lipid material (organogelators) of less than 10% by weight. This combination forms a network where the liquid oils are intertwined with the organogelators and creates a lipo-philic liquid inside a thermo reversible, three-dimensional gel structure (Siraj et al., 2015). Confectionery and bakery products like candies and chocolate have cream either inside or on top of the product which primarily constitutes of SFs and unsaturated fats (Stortz et al., 2012). But fat blooms and cracks appear on the surface of the product as a result of melting and movement of fat from cream. Therefore, organogelators with the help of their oil withholding characteristics can be employed for prevention or reduction of oil movement and hence, the

Table 1: Fat Substitutes: Examples and Use

Type of Fat Substitute	Examples	Use Cases
Carbohydrate-based	Carrageenan, cellulose gels, cornstarch, fruit purees, guar gum, Oatrim, Z-trim, maltodextrins, polydextrose, xanthan gum	cake and cookie mixes, dairy products, frostings, frozen desserts, salad dressings
Protein-based	Milk, Egg white protein, microparticulated protein (e.g., Simplesse), whey protein concentrate	butter, cheese, dairy products, ice cream, mayonnaise, salad dressings, sour cream
Fat-based	Short chain fatty acid, long chain fatty acids Caprenin, mono- and diglycerides, Olestra, Salatrim, acid	baked goods, chocolate, confections, snacks, savory products

Table 2: Fat mimetics: Examples and use cases

Type of Fat Mimetic	Examples	Use Cases
Protein-based	Simplesse (microparticulated whey protein), Dairy Lo (whey protein), K-Blazer (Kraft Foods)	Dairy products, salad dressings, frozen desserts, table spreads.
Carbohydrate-based	Gums (e.g., guar gum), dextrins, maltodextrins, polydextrose, cellulose derivatives, starch derivatives, oat flour derivatives	Biscuits, cakes, cookies, ice cream
Fat-based	Organogels, emulsion, structured lipids	Confectionery candies, chocolates, meat

quality of the product will remain intact. Apart from being used in confectionery, organogels can also be employed in the meat industry to improve lipid composition (Siraj et al.,2015).

Conclusion

Consumer demand is driven by health concerns with respect to fat replacement. SFs are essential in products like pastries, ice cream, chocolate, cakes and cookies. Saturated and trans fats pose a risk to heart health, therefore moderation in consumption is recommended. Novel and innovative fat replacement options are crucial without compromising quality, texture or taste. Although fat replacement offers fewer calories and less health risk, it is not free from limitations like reduced shelf life and inability to fry. Safety of the ingredients used is also vital to consider so that the products are healthier than the ones they are replacing. It is crucial for the industry to have confidence in the fat replacements methods they utilize, thus, research in this area should be a top priority.

References

1. Amico, A., Wootan, M. G., Jacobson, M. F., Leung, C., & Willett, A. W. (2021). The Demise of Artificial Trans Fat: A History of a Public Health Achievement. The Milbank Quarterly, 99(3), 746–770. https://doi.org/10.1111/1468-0009.12515

2. Anderson, J. T., Grande, F., & Keys, A. (1961). Hydrogenated Fats in the Diet and Lipids in the Serum of Man. The Journal of Nutrition, 75(4), 388–394. https://doi.org/10.1093/jn/75.4.388

3. Bhattacharya, S. (2023). Chapter 10—Fats and oils. In S. Bhattacharya (Ed.), Snack Foods (pp. 251–281). Academic Press. https://doi.org/10.1016/B978-0-12-819759-2.00014-8

4. Bohrer B.M. Review: Nutrient density and nutritional value of meat products and non-meat foods high in protein. Trends Food Sci. Technol. 2017;65:103–112. doi: 10.1016/j.tifs.2017.04.016.

5. Colla, K., Costanzo, A., & Gamlath, S. (2018). Fat Replacers in Baked Food Products. Foods, 7(12), Article 12. https://doi.org/10.3390/foods7120192

6. Decker, E. A., Elias, R. J., & McClements, D. J. (2010). Oxidation in Foods and Beverages and Antioxidant Applications: Understanding Mechanisms of Oxidation and Antioxidant Activity. Elsevier.

7. FDA. (2024, September 6). Trans Fat. FDA; FDA. https://www.fda.gov/food/food-additives-petitions/trans-fat

8. FMI. (2023, March). Low Fat Product Market Sales, Product, Outlook, 2031 | FMI. https://www.futuremarketinsights.com/reports/low-fat-product-market

9. Khosla, I., & Khosla1, G. C. (2017). Saturated Fats and Cardiovascular Disease Risk: A Review. Journal of Clinical and Preventive Cardiology, 6(2), 56. https://doi.org/10.4103/JCPC.JCPC_7_17

10. Lipid Choices, Roles and Applications in Nutrition, Food Science and the Culinary Arts—

ScienceDirect. https://www.sciencedirect.com/science/article/abs/pii/B9780123918826000066

11. Logan, C. M., Wallace, J. M. W., Robson, P. J., & Livingstone, M. B. E. (2006). 16—Testing novel fat replacers for weight control. In C. Williams & J. Buttriss (Eds.), Improving the Fat Content of Foods (pp. 391–407). Woodhead Publishing. https://doi.org/10.1533/9781845691073.2.391

12. Marcus, J. B. (2013). Lipids Basics: Fats and Oils in Foods and Health: Healthy

13. Nourmohammadi, Austin, & Chen. (2024). Recent trends in design of healthier fat replacers: Type, replacement mechanism, sensory evaluation method and consumer acceptance. Food Chemistry, 447, 138982. https://doi.org/10.1016/j.foodchem.2024.138982

14. O'Connor, T. P., & O'Brien, N. M. (2011). Butter and Other Milk Fat Products | Fat Replacers. In J. W. Fuquay (Ed.), Encyclopedia of Dairy Sciences (Second Edition) (pp. 528–532). Academic Press. https://doi.org/10.1016/B978-0-12-374407-4.00330-7

15. O'Connor, T. P., & O'Brien, N. M. (2022). Fat Replacers. In P. L. H. McSweeney & J. P. McNamara (Eds.), Encyclopedia of Dairy Sciences (Third Edition) (pp. 555–559). Academic Press. https://doi.org/10.1016/B978-0-12-818766-1.00302-0

16. O'Sullivan, M. G. (2017). Chapter 9—Nutritionally Optimised Low Fat Foods. In M. G. O'Sullivan (Ed.), A Handbook for Sensory and Consumer-Driven New Product Development (pp. 177–196). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100352-7.00009-9

17. Rao, M. A. (2003.). Phase transitions, food texture and structure. Retrieved October 4, 2024, from https://www.researchgate.net/publication/279433877_Phase_transitions_food_texture_and_structure

18. Rios, R. V., Pessanha, M. D. F., Almeida, P. F. de, Viana, C. L., & Lannes, S. C. da S. (2014). Application of fats in some food products. Food Science and Technology, 34, 3–15. https://doi.org/10.1590/S0101-20612014000100001

19. 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

20. Siri-Tarino, P. W., Chiu, S., Bergeron, N., & Krauss, R. M. (2015). Saturated Fats Versus Polyunsaturated Fats Versus Carbohydrates for Cardiovascular Disease Prevention and Treatment. Annual Review of Nutrition, 35(Volume 35, 2015), 517–543. https://doi.org/10.1146/annurev-nutr-071714-034449

21. Stortz, T. A., Zetzl, A. K., Barbut, S., Cattaruzza, A., & Marangoni, A. G. (2012). Edible oleogels in food products to help maximize health benefits and improve nutritional profiles. Lipid Technology, 24(7), 151–154. https://doi.org/10.1002/lite.201200205

22. Vélez-Erazo, E. M., Okuro, P. K., Gallegos-Soto, A., da Cunha, R. L., & Hubinger, M. D. (2022). Protein-based strategies for fat replacement: Approaching different protein colloidal types, structured systems and food applications. Food Research International, 156, 111346. https://doi.org/10.1016/j.foodres.2022.111346

23. Vieira, S. A., McClements, D. J., & Decker, E. A. (2015). Challenges of Utilizing Healthy Fats in Foods. Advances in Nutrition, 6(3), 309S-317S. https://doi.org/10.3945/an.114.006965

24. Vp, A. (2023). A comprehensive review: Carbohydrate-based fat replacers and their role in food formulation.

25. WHO. (2010). Fats and fatty acids in human nutrition. Report of an expert consultation (pp. 1–166).

26. Wylie-Rosett, J. (2002). Fat Substitutes and Health. Circulation, 105(23), 2800–2804. https://doi.org/10.1161/01.CIR.0000019402.35632.EB

Reducing trans fat in bakery products: Challenges and opportunities for sensory quality and health

Dr Kodandaram Reddy Desham[1] and **Dr Pulkit Mathur[2*]**
[1]Assistant Professor, Department of Food & Nutrition and Food Technology,
Lady Irwin College, University of Delhi
[2]Professor, Department of Food & Nutrition and Food Technology,
Lady Irwin College, University of Delhi
*Corresponding Author: pulkit.mathur@lic.du.ac.in; dekore@lic.du.ac.in

Abstract

The reduction of trans fats in bakery products is a crucial endeavor driven by public health concerns and regulatory mandates, particularly those from the Food Safety and Standards Authority of India (FSSAI). Trans fats are associated with a range of health issues, including cardiovascular disease, diabetes, and obesity. However, their removal or reduction presents significant challenges in terms of maintaining sensory qualities such as texture, flavor, and shelf life. This review explores the scientific background of trans fats, evaluates the sensory and health impacts of their reduction, and presents strategies and alternative ingredients that can be employed by the baking industry. The review also considers advances in emulsifiers, oleo gels, antioxidants, and other functional ingredients that could offer solutions to these challenges, while highlighting the role of consumer adaptation and education in the transition to healthier formulations.

Keywords: Trans-fat, Bakery products, Sensory quality, FSSAI guidelines, Alternative fats, Emulsifiers, Oleo gels

1. Introduction

Trans fats, a type of unsaturated fat containing trans-isomeric fatty acids, have been a topic of concern for decades due to their role in increasing low-density lipoprotein (LDL) cholesterol and decreasing high-density lipoprotein (HDL) cholesterol. These effects contribute to a heightened risk of cardiovascular diseases (CVD), as well as other metabolic disorders such as diabetes and obesity (Mozaffarian et al., 2006; Brouwer et al., 2010).

Bakery products, including pastries, cookies, and cakes, are among the largest contributors to dietary trans fats. These products rely on partially hydrogenated oils (PHOs), which impart desirable textural and sensory qualities (De Deckere et al., 1998). However, with growing evidence of the adverse health effects of trans fats, regulatory bodies like the FSSAI have imposed stringent guidelines limiting their content in food products. This review delves into the technological challenges of reducing trans fats in bakery products and explores viable alternatives to maintain product quality.

2. Regulatory Background and Health Impacts

The FSSAI, aligned with the World Health Organization (WHO), has set guidelines to reduce the trans-fat content in edible oils and fats to 2% by weight by 2022. This is in line with global efforts to eliminate industrially produced trans fats from the food supply. A significant body of research links trans fat consumption to an increased risk of coronary heart disease (CHD), with estimates suggesting that replacing trans fats with healthier fats could prevent up to 500,000 premature deaths annually worldwide (WHO, 2019). Studies such as Mozaffarian & Micha (2017) have established the strong association between trans fat consumption and adverse health outcomes, reinforcing the urgency for reformulation in the food industry.

3. Challenges in Sensory Quality and Technological Functionality

The functional role of trans fats in bakery products is well-documented. Trans fats contribute to product aeration, lamination, and moisture retention, key factors in the sensory attributes of flakiness, tenderness, and shelf life (Reddy et al., 2020). Reducing or eliminating trans fats while maintaining these qualities poses several challenges:

3.1. Texture and Mouthfeel

Trans fats contribute to the smooth and creamy mouthfeel characteristic of many baked goods. When hydrogenated fats are removed, products can become dense or dry (Grundy et al., 2012). Research indicates that liquid oils, such as sunflower or canola oils, lack the solid crystalline structure necessary to mimic these textural qualities (Ghotra et al., 2002). Alternative fat systems, including interesterified fats, palm-based fats, and structured emulsions, are being explored to replicate the role of trans fats.

Oleo gels—structured systems of liquid oils gelled with oleogelators—offer a promising solution. Studies on 12-hydroxystearic acid and ethyl cellulose-based oleo gels have shown potential in replicating the solid fat content required for texture in bakery products (Patel & Dewettinck, 2016; Martini & Clegg, 2012).

3.2. Flavour and Aroma

Trans fats also carry flavors and contribute to the browning reaction during baking, enhancing aroma and taste (Prentice, 1997). Replacing these fats can lead to a loss of flavor intensity, requiring the use of flavor enhancers or fat mimetics. Research by O'Brien (2004) and Poorthuis et al. (2019) indicates that natural antioxidants, such as tocopherols, and fat-replacing emulsifiers can stabilize flavor compounds and prevent off-flavors, while sensory panels are used to adjust flavor profiles in reformulated products.

3.3. Shelf Life

Trans fats have long been favored for their oxidative stability, which prolongs the shelf life of baked goods. When replacing trans fats with unsaturated oils, the risk of lipid oxidation increases, potentially leading to rancidity (Warner, 2009). Natural antioxidants like rosemary extract and tocopherols have been widely studied for their ability to prevent oxidation (López-Varela et al., 1995). Packaging innovations, such as oxygen-barrier films, can also help extend shelf life by minimizing exposure to oxygen.

4. Alternative Fats and Emulsifiers

To maintain the sensory and functional properties of bakery products, various fat substitutes have been explored. These alternatives include:

4.1. Interesterified Fats

Interesterification is a process where the fatty acids in oils are rearranged to alter their melting properties. Studies by Boukouvalas & Rousseau, (2021) show that interesterified fats can provide the solid fat content needed for texture, without introducing trans fats.

4.2. Palm-Based Fats

Palm oil and its derivatives, including palm stearin, are frequently used as trans-fat replacements due to their solid nature at room temperature. However, the environmental and sustainability concerns associated with palm oil have led to efforts to source responsibly produced palm fats (Che Man et al., 1999).

4.3. Structured Emulsions and Oleo Gels

Structured emulsions that incorporate high-oleic oils or oleo gels offer a promising approach for fat reduction in bakery products. Research by Martins, A.J., Vicente, A.A., & Cunha, R.L. (2020) has demonstrated that oleo gels can mimic the plasticity and aeration properties of traditional fats, while also improving the nutritional profile of the product.

5. Successful Strategies and Industry Practices in Trans-Fat Reduction

The global food industry has been proactive in addressing the challenges of trans-fat reduction, employing various strategies to maintain product quality while complying with regulatory standards. This section explores what has worked, the studies available, and the initiatives undertaken by the industry in India and abroad.

5.1. Case Studies of Successful Trans-Fat Reduction

5.1.1. India's Initiative: In India, major food companies have responded to FSSAI's regulations by reformulating their products. For instance, Britannia Industries reduced trans-fat content across its biscuit range by switching to healthier fats and optimizing baking processes (FSSAI, 2020). Similarly, Parle Products adopted alternative fat systems and improved emulsification techniques to maintain texture and taste while eliminating trans fats (Economic Times, 2019).

A study by Bansal et al. (2015) analyzed the fatty acid composition of Indian snack foods and found significant reductions in trans-fat content following regulatory interventions. The industry leveraged locally available oils, such as rice bran and groundnut oil, which are naturally low in trans fats and rich in beneficial fatty acids.

5.1.2. International Efforts: Globally, companies like Nestlé and Unilever have led the way in trans-fat reduction. Nestlé reformulated its products by incorporating interesterified fats and using enzyme technology to modify fat properties without generating trans fats (Nestlé, 2018). Unilever invested in research to develop fat blends that provide the desired functionality in spreads and baked goods, utilizing a mix of tropical oils and high-oleic sunflower oil (Unilever, 2017).

In Denmark, the government implemented strict trans-fat regulations in 2003, leading to the near elimination of industrial trans fats from the food supply. Stender et al. (2006) documented how Danish bakeries successfully replaced partially hydrogenated fats with blends of butter and vegetable oils, achieving compliance without compromising product quality.

5.2. Technological Innovations in Fat Replacement

5.2.1. Enzymatic Interesterification: Enzymatic interesterification (EI) has emerged as a viable method to produce tailor-made fats with desired melting profiles. EI involves rearranging fatty acids on the glycerol backbone using lipase enzymes, resulting in fats that mimic the functionality of trans fats without their health risks (Zhou et al., 2012). Studies have demonstrated that EI fats can improve the textural properties of cookies and cakes, offering a practical solution for bakers (Ribeiro et al., 2009).

5.2.2. Use of Oleogels: Research into oleogels has expanded, with studies showing that ethyl cellulose and wax-based oleogels can successfully replace solid fats in baked goods. Yilmaz & Öçütcü (2014) reported that olive oil oleogels structured with beeswax provided acceptable texture and sensory attributes in cakes. Further, Tara gum and sunflower wax oleogels have been used to replace margarine in puff pastry, yielding products with comparable flakiness and taste (Li et al., 2019).

5.2.3. High-Oleic Oils: High-oleic variants of sunflower and canola oils offer improved oxidative stability and a healthier fatty acid profile. These oils have been used to create shortenings and margarines suitable for baking applications. A study by Przybylski & Aladedunye (2012) highlighted the effectiveness of high-oleic oils in reducing trans-fat content while maintaining product quality.

5.3. Emulsifiers and Stabilizers

Advanced emulsifiers, such as mono- and diglycerides, lecithin, and polyglycerol esters, have been employed to enhance dough properties and extend shelf life. These emulsifiers improve the gas-holding capacity of dough, resulting in better volume and crumb structure in baked goods (Krog, 2003). Additionally, the use of hydrocolloids like guar gum and xanthan gum can mimic the mouthfeel provided by fats, contributing to sensory quality (Rosell et al., 2001).

6. Industry Practices in India and Abroad

6.1 Indian Industry Adaptations

The Indian baking industry, comprising both large-scale manufacturers and small-scale artisanal bakers, has demonstrated resilience in adapting to trans-fat reduction regulations. Several key technical strategies have been employed:

Use of Healthier Fat Alternatives: Indian manufacturers have increasingly adopted indigenous oils with favorable health profiles, such as rice bran oil, mustard oil, and sesame oil. These oils are rich in monounsaturated fats, which offer not only health benefits but also enhance the flavor profiles of baked products. Research into lipid modification technologies, such as interesterification, has helped reformulate fat blends that maintain the desired textural properties without introducing trans fats.

Process Optimization: Manufacturers have optimized baking processes to compensate for changes in fat composition. Adjustments to baking temperatures, mixing times, and cooling protocols have been key to maintaining product quality in terms of texture and shelf life. For example, controlled lamination techniques for puff pastries allow for the use of semi-solid oils without sacrificing the flaky texture typically achieved by hydrogenated fats.

Emulsification and Structuring Technologies: Indian producers are incorporating advanced emulsifiers and fat-structuring agents, such as lecithin, monoglycerides, and hydrocolloids like xanthan gum. These additives help stabilize the dough and replicate the creamy mouthfeel previously imparted by trans fats. Additionally, structured emulsions have been applied in large-scale bakeries to reduce fat while maintaining aeration and moisture retention during baking.

Collaborative Research: Indian industry players, in partnership with academic institutions like the Central Food Technological Research Institute (CFTRI), have spearheaded research into trans-fat alternatives, resulting in pilot studies and scaled-up applications. CFTRI has developed fat-replacer formulations that incorporate a mix of healthier oils and functional ingredients to meet the regulatory limits while preserving the sensory appeal of baked goods.

Consumer Education and Marketing: Major brands like Britannia and Parle have been proactive in educating consumers about the health benefits of their newly formulated products. These companies leverage packaging claims and digital marketing to build trust around healthier alternatives, ensuring that reformulations align with both regulatory mandates and consumer preferences for taste and quality.

6.2 Global Industry Trends

Internationally, the food industry has adopted several cutting-edge practices to eliminate trans fats while maintaining high standards for sensory quality, shelf life, and consumer satisfaction. Key innovations include:

Enzymatic Interesterification (EI): The use of enzyme-catalyzed interesterification is one of the most widely adopted strategies for creating zero-trans-fat bakery products. This method allows for the reconfiguration of fatty acids to mimic the functionality of traditional hydrogenated fats. Leading companies, such as Nestlé and Unilever, have implemented this technology to produce healthier fats with customized melting profiles that suit various baking applications(*Nestlé Global*, 2018).

Oleogels and Structured Fats: Oleogels—solidified structures of liquid oils—have emerged as a promising alternative to trans fats. Research into sunflower wax, beeswax, and ethyl cellulose-based oleogels has demonstrated their ability to replicate the plasticity and mouthfeel of solid fats in baked goods. Leading bakeries have begun to integrate oleogels into formulations for cakes, cookies, and pastries, achieving desirable sensory qualities without the health risks of trans fats.

High-Oleic Oils and Palm Derivatives: High-oleic sunflower and canola oils have gained popularity due to their enhanced oxidative stability, which prolongs shelf life without the need for hydrogenation. Palm-based fats, particularly responsibly sourced palm stearin, are used for applications requiring semi-solid fats at room temperature. However, due to sustainability concerns, the Roundtable on Sustainable Palm Oil (RSPO) certification is becoming a standard industry requirement.

Advanced Emulsification Systems: Multinational companies have invested in next-generation emulsification technologies to maintain dough stability and achieve the desired crumb structure in baked goods. For example, emulsifiers like polyglycerol polyricinoleate (PGPR) and hydrocolloid stabilizers are increasingly used to enhance gas retention in doughs and improve the final product's texture. These technologies also contribute to extending the shelf life of baked products by preventing oxidation and moisture loss.

Packaging Innovations: Modified atmosphere packaging (MAP) and vacuum-sealed films are becoming more prevalent as they prevent oxidation and maintain the quality of trans-fat-free products without the need for artificial preservatives (Yam, Takhistov, & Miltz,). These packaging technologies create a controlled environment inside the packaging, reducing exposure to oxygen and thereby slowing down lipid oxidation in products made with unsaturated fats.

6.3 Regulatory Compliance and Global Standards

Compliance with global trans-fat regulations has become a critical driver for reformulation across industries:

Continuous Monitoring and Testing: Companies are required to regularly analyze fat content through advanced chromatographic methods (e.g., gas chromatography), ensuring compliance with trans-fat reduction mandates. Additionally, continuous monitoring of product stability and sensory attributes helps companies quickly adapt formulations when necessary.

Alignment with Codex Alimentarius: Globally recognized standards, such as those set by the Codex Alimentarius, guide trans-fat regulation across borders. Countries that have implemented trans-fat limits, such as Denmark, the U.S., and Canada, have seen major food producers reformulate their products using fat blends that comply with these stringent standards.

Research and Development (R&D) Investment: Companies have significantly increased R&D budgets to stay competitive in the trans-fat-free market. Leading firms are exploring biotechnological innovations such as gene-edited oils and advanced enzyme technologies to develop fat alternatives that not only meet regulatory standards but also address growing consumer demand for sustainable and health-conscious products.

7. Impact on Sensory Quality and Consumer Acceptance

7.1. Sensory Evaluation Studies

Sensory studies have been crucial in assessing consumer acceptance of trans-fat-reduced products. A study by Ghoshal & Kaushik (2018) found that consumers could not distinguish between standard and trans-fat-free biscuits in blind taste tests, indicating successful reformulation. Similarly, sensory panels conducted by Sakinah et al. (2018) on cakes made with oleogel-based shortenings reported high acceptance scores.

7.2. Consumer Education

Educating consumers about the health benefits of reduced trans-fat consumption has been essential. Public health campaigns and labeling initiatives have increased awareness, influencing purchasing decisions (Downs et al., 2013). The FSSAI's "Eat Right Movement" in India exemplifies efforts to promote healthier food choices (FSSAI, 2018).

8. Future Prospects and Research Directions

8.1. Novel Fat Replacers

Emerging research focuses on the use of plant-based proteins and polysaccharides as fat replacers. For example, chia seed mucilage and flaxseed gum have shown potential in reducing fat content while enhancing nutritional value (Cordeiro et al., 2018).

8.2. Biotechnology Applications

Advancements in biotechnology, such as genetically modified oils with customized fatty acid profiles, could offer long-term solutions. High-stearic soybean oil, developed through genetic modification, provides a stable fat with low trans-fat content suitable for baking (Liu et al., 2016).

8.3. Personalized Nutrition

The trend towards personalized nutrition may lead to the development of bakery products tailored to individual health needs, leveraging data analytics and nutrigenomics (Ordovás et al., 2018).

9. Conclusion

Trans-fat reduction in bakery products has witnessed significant progress, driven by regulatory mandates, technological innovations, and consumer demand for healthier foods. The industry has demonstrated that it is possible to reduce or eliminate trans fats without sacrificing sensory quality, through the use of alternative fats, emulsifiers, and process optimizations.

Studies and industry practices both in India and globally highlight successful strategies that can serve as models for ongoing efforts. Continued research, coupled with consumer education and regulatory support, will be critical in sustaining this momentum and achieving public health objectives.

References:

1. Ascherio, A., Katan, M.B., Zock, P.L., Stampfer, M.J., & Willett, W.C. (1999). Trans fatty acids and coronary heart disease. *New England Journal of Medicine*, 340(25), 1994-1998.

2. Brouwer, I.A., Wanders, A.J., & Katan, M.B. (2010). Trans fatty acids and cardiovascular health: Research completed? *European Journal of Clinical Nutrition*, 64(5), 563-568.

3. Che Man, Y.B., Haryati, T., Ghazali, H.M., & Asbi, B.A. (1999). Composition and thermal profile of crude palm oil and its products. *Journal of the American Oil Chemists' Society*, 76(2), 237-242.

4. Ghotra, B.S., Dyal, S.D., & Narine, S.S. (2002). Lipid shortenings: A review. *Food Research International*, 35(10), 1015-1048.

5. López-Varela, S., Riestra, P., Vila, R., & Lema, M. (1995). Natural antioxidants: The prevention of lipid oxidation in bakery products. *Journal of Food Protection*, 58(3), 303-309.

6. Marangoni, A.G., & Rousseau, D. (1998). Plastic fats: Rheological and structural properties. *Food Research International*, 31(4), 263-276.

7. Mozaffarian, D., Katan, M.B., Ascherio, A., Stampfer, M.J., & Willett, W.C. (2006). Trans fatty acids and cardiovascular disease. *New England Journal of Medicine*, 354(15), 1601-1613.

8. Patel, A.R., & Dewettinck, K. (2016). Oleo gels: An overview of the state of the art, potential applications and future challenges. *Food & Function*, 7(1), 20-29.

9. Warner, K. (2009). Chemistry of frying oils. In *Deep Fat Frying: Chemistry, Nutrition, and Practical Applications* (pp. 35-42). Springer.

10. World Health Organization (WHO). (2019). REPLACE action package: Eliminating trans-fatty acids.

11. Bansal, S., Chase, H. A., & Pascal, C. (2015). Fatty acid and sterol composition of edible oils extracted from plants widely available in India. *Journal of Food Science and Technology*, 52(8), 5048–5055.

12. Cordeiro, A. M. T. M., Medeiros, R. A. B., & Rocha, M. V. P. (2018). Fat replacers in bakery products. In *Sugar Reduction and Sweeteners* (pp. 199-223). Woodhead Publishing.

13. Downs, S. M., Thow, A. M., & Leeder, S. R. (2013). The effectiveness of policies for reducing dietary trans fat: a systematic review of the evidence. *Bulletin of the World Health Organization*, 91, 262-269H.

14. Economic Times. (2019). Parle Products reduces trans fat content in products. Retrieved from https://economictimes.indiatimes.com/

15. Euromonitor International. (2020). Global bakery industry trends.

16. FSSAI. (2018). Eat Right Movement. Retrieved from https://eatrightindia.gov.in/

17. FSSAI. (2020). Trans Fat Regulations. Retrieved from https://fssai.gov.in/

18. Ghosh, M., & Bhattacharjee, P. (2012). Use of indigenous oils in the Indian food industry. *Journal of Food Science and Technology*, 49(2), 125-134.

19. Ghoshal, G., & Kaushik, R. (2018). Sensory evaluation of low trans-fat bakery products. *International Journal of Food Science and Nutrition*, 3(2), 85-89.

20. Innova Market Insights. (2019). Top Ten Trends for 2019.

21. Krog, N. (2003). The functionality of emulsifiers in breadmaking. *Journal of the American Oil Chemists' Society*, 80(8), 745-750.

22. Li, X., Kong, X., Zhang, Z., & Huang, M. (2019). Evaluation of wax-based oleogels as a shortening replacer in baked products. *Food Chemistry*, 276, 537-542.

23. Liu, H., White, P. J., & Wang, H. (2016). Emulsifiers in high-stearic soybean oil for trans-free margarine.

Journal of the American Oil Chemists' Society, 93(1), 37-45.

24. Nestlé. (2018). Nestlé's efforts to remove trans fats. Retrieved from https://www.nestle.com/

25. Ordovás, J. M., Ferguson, L. R., & Tai, E. S. (2018). Personalised nutrition and health. *BMJ*, 361, bmj.k2173.

26. Przybylski, R., & Aladedunye, F. (2012). Stability of high-oleic vegetable oils. *European Journal of Lipid Science and Technology*, 114(8), 933-945.

27. Ribeiro, A. P. B., Grimaldi, R., Gioielli, L. A., & Gonçalves, L. A. G. (2009). Zero trans fats from soybean oil and fully hydrogenated soybean oil: Physico-chemical properties and food applications. *Food Research International*, 42(3), 401-410.

28. Rosell, C. M., Rojas, J. A., & de Barber, C. B. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids*, 15(1), 75-81.

29. RSPO. (2020). Roundtable on Sustainable Palm Oil: Impact Report.

30. Sakinah, A. M. M., Miskandar, M. S., Man, Y. C., Rahman, R. A., & Long, K. (2018). Application of palm-based oil blends for the production of trans-free margarines. *Journal of the Science of Food and Agriculture*, 98(7), 2539-2545.

31. Singh, S., & Singh, D. (2016). Process optimization in bakery products to reduce trans fats. *Indian Journal of Experimental Biology*, 54(5), 325-332.

32. Stender, S., Dyerberg, J., & Astrup, A. (2006). High levels of industrially produced trans fat in popular fast foods. *New England Journal of Medicine*, 354(15), 1650-1652.

33. Unilever. (2017). Unilever's approach to trans fats. Retrieved from https://www.unilever.com/

34. Yam, K. L., Takhistov, P. T., & Miltz, J. (2005). Intelligent packaging: Concepts and applications. *Journal of Food Science*, 70(1), R1-R10.

35. Yilmaz, E., & Öçütcü, M. (2014). Oleogels as fat replacers in bakery products. *Food & Function*, 5(1), 1-4.

36. Zhou, D., Liu, H., & Liu, H. (2012). Enzymatic interesterification for the production of zero trans margarine fats. *Food and Bioprocess Technology*, 5(5), 1732-1741.

Mustard oil and quality parameters

Anubhuti Sharma*[1], Purnima Sogarwal[2], P K Rai[1]
[1*]ICAR-DRMR Sewar, Bharatpur
[2]Department of Biotechnology GLA University , Mathura
*Corresponding Author: sharmaanubhuti98@gmail.com

Abstract

Present review focuses on essential fatty acids of edible oilseed crops and their implications to improve human health and industrial utility. This includes benefits of palmitic acid, stearic acid, oleic acid, omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs), arachidonic acid, eicosapentaenoic acid, ricinoleic acid, unusual monoenoic fatty acids, reduction in erucic acid and very long chain saturated fatty acids (VLSFA). The focus was also laid on as how new technological interventions (such as synthetic biology, next-generation sequencing, LC-MS/MS targeted lipid analysis, clustered regularly interspaced short palindromic repeats (CRISPR)/Cas9 technique and lipidomics) are mediating in the development of desired traits in transgenic oilseeds. Novel fatty acids produced by advanced techniques e.g. transgenics, hybridization etc would be good source of renewable raw materials.

Key words: Transgenic plants, Seed oils, Palmitic acid, Omega-3 Long-chain Polyunsaturated fatty acids (LC-PUFAs), Ricinoleic acid, Erucic acid

Introduction

India is one of the world's top producers of oilseeds, which supports Indian agriculture and provides a means of livelihood for rural communities (Rai et al., 2016). Mustard plant belongs to the genera Brassica and Sinapis (the mustard family). Mustard seeds are utilized as spice and condiments. Mustard leaves can be consumed as mustard greens and seeds can be crushed to make mustard oil. Mustard oil has been a integral part of human civilization and archeological evidences suggests that mustard plant was used during indus valley civilization also as spice, oil and mustard greens.

Brassica oil is a fantastic source of nutrients and energy for humans, even though degreased cakes are used as animal feed (Baltrukoniene et al., 2015). Brassica is one of India's most important edible oilseed crops, accounting for around one-third of the country's oil production. The amount of fat in oils that are derived from Brassica seeds used in industry and food determines their worth from the main oilseed crops in a substantial amount. Mustard and rapeseed, which are grown in India, are ranked in terms of sustainability and adaptability to a range of agro- ecological conditions after soybeans (Choudhary et al. 2022).

Rapeseed mustard, which is generated from Indian mustard (*B. juncea* L.; *B. campestris* L). ecotypes toria, brown, and yellow sarson; gobhi sarson (*B. napus* L.); Ethiopian mustard (*B. carinata*); and taramira (*Eruca sativa*), is used to make animal feed, vegetable oil, and biodiesel. *B. juncea* is one of the most common species of Brassica mentioned above, growing alongside *B. rapa* (syn. *B. campestris* L.) and *B. napus* L., which are important sources of edible oil for India.

Indian mustard, *Brassica juncea* has 36 chromosomes, it is an amphidiploid that is descended from *B. rapa* (2n = 20; genome AA) and *B. nigra* (2n = 16; genome BB) (genome AABB) (Rai et al. 2017). About 10%–18% of the entire seed set is outcrossed in Indian mustard (*B. juncea* L.); the rest of the seed is self-pollinated (Rai et al., 2012). Triglycerides and phospholipids are the building blocks of fatty acids, which are organic acids. Unsaturated fatty acids have a long carbon chain connected by double bonds and one carboxyl (-COOH) group, whereas saturated fatty acids have single bonds.

Fatty acids are the most prevalent type of dietary fat. Mustard seeds typically contain 37 to 42 percent oil in addition to the primary fatty acid types derived from Brassica species, such as palmitic acid (16:0), linoleic acid (18:2), stearic acid (18:0), oleic acid (18:1), eicosanoic acid (22:0), linolenic acid (18:3), and erucic acid (22:1). But there are also sizable concentrations of unfavorable fatty acids that are bad for people, including erucic acid.

Worldwide, a large number of brassica species are grown for their seeds, which are used to make industrial and culinary oils (Snowdon et al., 2007). Brassica oil's fatty acid makeup is more genetically varied than that of other vegetable oils. Brassica oil has different properties from other commercially manufactured plant oils, like erucic acid. The oil is suitable for industrial use but not for human consumption due to its high erucic acid level. Consequently, it is imperative to generate variants free of erucic acid, and lowering elevated erucic acid levels is a targeted breeding goal for Brassica oilseed crops. More focus has recently been placed on crop species that are higher in C18:1 and C18:2 fatty acids for human nutrition. High oleic and linoleic acid content deep-fried oils produce fewer unwanted byproducts and have greater oxidation resistance. Therefore, increasing the fatty acid profile and oil content of the seed oil is one of the main breeding objectives for *Brassica juncea*.

The rapeseed oil and seed meal quality enhancement programme aims to achieve the following:

The production and quality features of *B. juncea* and *B. napus* lines with low glucosinolate and low erucic acid were evaluated. — It is being researched to produce rapeseed and mustard varieties with lower erucic acid and/or glucosinolate contents. — Basic study to understand more about the genetics and breeding behavior of erucic acid and glucosinolate content, as well as the "0" and "00" reaction types to endemic illnesses and pests. The examination of both native and imported germplasm demonstrated the wide range of fatty acid variation found in *Brassica juncea*. The FAO/ WHO recommends a greater MUFA/SUFA ratio and a substantial amount of PUFAs, such as C18:2 and C18:3, in human nutrition. Table 1 shows the needed ratios, which are between 5:1 (x-6) and 10:1 (x-3). How much oil is in Indian mustard oil lacks the proper fatty acid composition, which is essential for human life and nutrition, as the preceding guidelines make evident. High eruate levels in mustard oil are detrimental to the health of various mammals, and particularly high erucic acid is not good for human health (Somerville et al., 2000).

Fatty acids are found in percentage of cultivated cultivars, as per Sinha et al. (2007). b) A report on "Fats and Oils in Human Nutrition," produced in cooperation with the UN Food and Agriculture Organization and the World Health Organization, was presented in Rome during October 19–26, 1993. In Brassica Species, Fatty acid: The unsaturated fatty acids in Brassica species include linoleic (20%), oleic (65%), linolenic (9%), and erucic acid (2%), while the saturated fatty acids are palmitic (6%) and stearic (2%) (Figure 1). These amounts correspond to the optimal fatty acid composition for human health. Brassica seed oil's nutritional value is determined by its fatty acid composition, with particular attention paid to the amounts of oleic, linoleic, linolenic, and erucic acids—all of which are essential for human nutrition and health.

Oleic acid in Indian mustard had a negative link with erucic acid and a favorable association with linoleic acid. All of the crops, including Indian mustard, showed a negative and substantial correlation between linoleic acid and erucic acid. Linolenic acid was likewise negatively and strongly correlated with erucic acid in Indian mustard and glucosinolate concentration in toria. Analysis and Biosynthesis of Fatty Acids: In two sets of oilseed rape (*B. napus*) cultivars, Dimov and Mollers (2010) examined the genetic diversity of saturated fatty acid concentration. The results indicated that there are highly significant genetic variations among the cultivars with a mean of 7.4 percent and a range of 6.8 to 8.1 percent in terms of total saturated fatty acids. The elongation of C18:1 (oleic acid) to C22:1 (erucic acid) is attributed to the Fatty Acid Elongase 1 (FAE1) gene, as demonstrated by the characterisation of mutants deficient in long-chain fatty acids in Arabidopsis thaliana (Lassner et al., 1996). The gene produces the enzyme â-ketoacyl- CoA synthase (KCS), which is particular to seeds and functions as a rate limiting enzyme in the production of erucic acid. Additionally, it is linked to the The half-seed technique (Harvey and Downey, 1964) for determining the fatty acid composition of individual seeds was developed as a result of the embryonic regulation of erucic acid. Globally, this method was applied to the genetic analysis of erucic acid and the creation of Brassica cultivars with zero erucic acid. With this technique, the plant breeder can analyze one cotyledon's fatty acid composition while keeping the other cotyledon with the embryo for planting. Kirk and Hurlstone (1983) developed low erucic acid *B. juncea* strains using this method

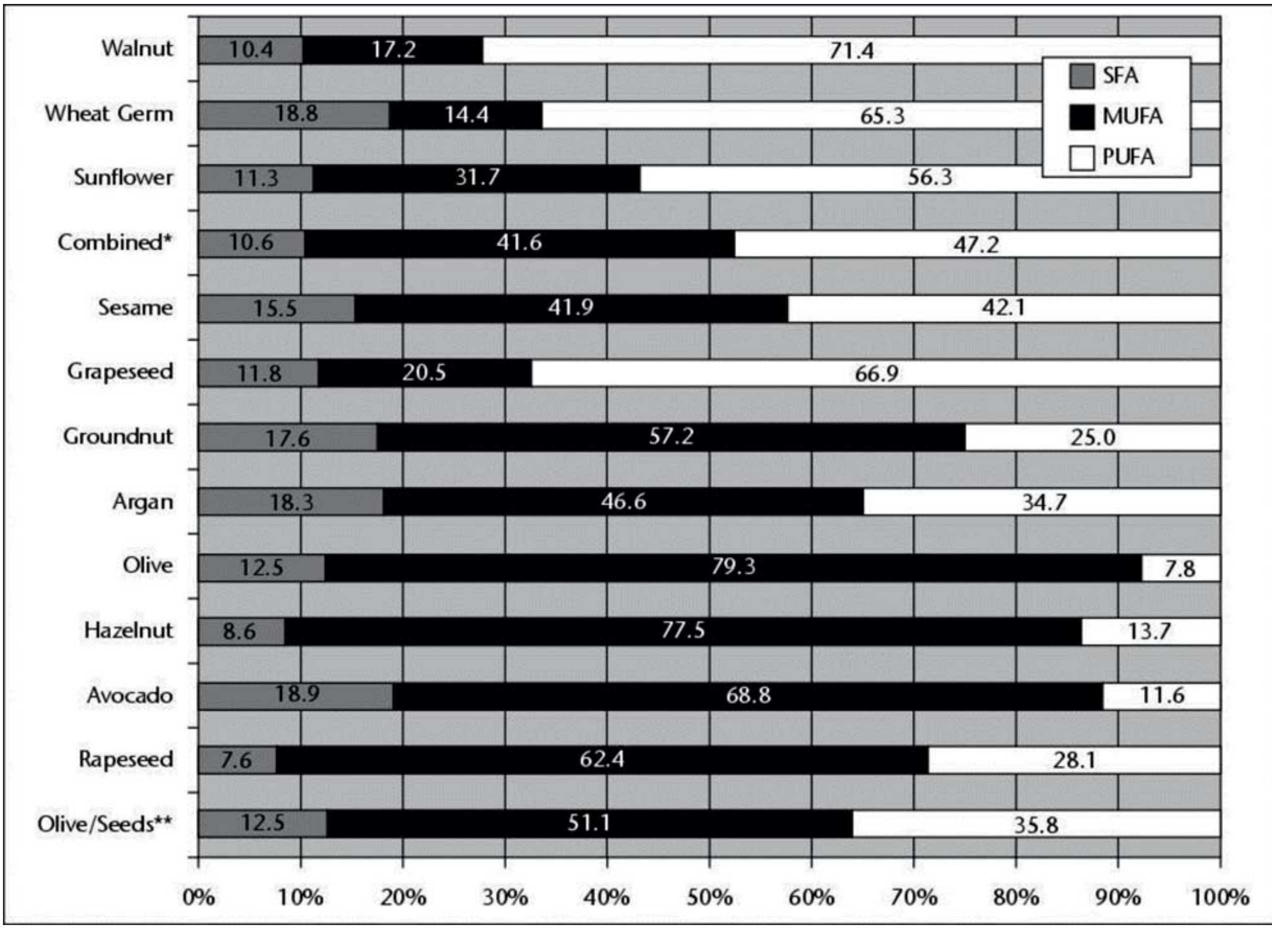


Figure 1: Fatty Acid in vegetable oil
(Source: www.google.com; (Vingering, Nathalie et al. 2010)

Table 1: Fatty Acid Composition of Indian Mustard Oil

Sr.	Name of Acid	Range
1	Palmitic	1-3%
2	Stearic	0.4-3.5%
3	Arachidic	0.5-2.4%
4	Behenic	0.6-2.1%
5	Lignoceric	0.5-1.1%
6	Oleic	12-24%
7	Eicosenoic	3.5-11.6%
8	Erucic	40-55%
9	Linoleic	12-16%
10	Linolenic	7-10%

(Source: www.google.com; (Yadav, Ram P. and Bibha Kumari, 2015)

Various fatty acid types found in Brassica juncea (Table 1)

palmitic acid (C16:0) and stearic acid (C18:0):- Rich in palmitic or stearic acids, fats can be found in many different types of food. Lower levels of low-density lipoprotein (LDL) cholesterol—which is widely acknowledged to be a contributing factor in coronary heart disease—are found in stearic acid as compared to palmitic acid. Stearic acid, in place of palmitic acid, reduces LDL-cholesterol levels and, thus, the disease's risk. In Western countries, palmitic acid (C16:0) and stearic acid (C18:0), two saturated fatty acids, are commonly ingested (Ervin et al., 2004). According to certain research, stearic acid raises cholesterol less than palmitic acid (Mensink 2016).

Oleic acid:

An important component of human nutrition, oleic acid is a type of unsaturated fatty acid. Rich in oleic acid fats and oils have exceptional heat and oxidation resistance, which makes them perfect for a variety of uses. Oleic acid-rich oils are perfect for replacing saturated fats in commercial food service applications because they offer long-term stability and a thermal stability that is either equivalent to or comparable to that of saturated fats. It reduces the amount of time that needs to cool and oil the food by enabling you to heat them to a higher temperature without smoking. Saturated fatty acids (palmitic and stearic) have the capacity to greatly raise blood cholesterol levels, but unsaturated fats and oils, like oleic acid oil, have the High C18:1 concentration vegetable oils are becoming more and more popular for usage in industry and nutrition.

Linoleic acid

Brassica oil's nutritional quality is significantly impacted by increased dietary requirements for linoleic acid (C18:2) and lowered dietary requirements for linolenic acid (C18:3). Since linoleic acid and its derivatives are obtained through diet and cannot be produced by the human body, they are regarded as essential fatty acids. In addition, the high linoleic acid content of the edible oil lowers blood cholesterol and protects atherosclerosis. Edible oils high in linoleic acid are therefore considered premium oils. Despite being a necessary fatty acid, linolenic acid can cause rancidity and an unpleasant flavor in oil.

Linolenic acid

Many dietary oils contain the fatty acid linolenic acid (C18:3). The three double bonds of linolenic acid cause it to oxidize quickly, shortening the oil's shelf life. Reducing the amount of linolenic acid derived from rapeseed is therefore one of the most crucial breeding objectives. Low-linolenic acid mutants are mostly seen in oilseed rape (*Brassica napus* ssp. oleifera), where genetic variability in linolenic acid content is limited. These mutants are produced by x-rays and chemical mutagens (Scarth et al., 1988). Either linoleic acid (C18:2) is desaturated to form linolenic acid, or C16:3 may be extended (Thompson, 1983).

Erucic acid

The genus Brassica exhibits significant variation in erucic acid concentration, which can be attributed to various factors such as genotype allelic makeup, ploidy level, genetic background, and environmental influence. When consumed insufficiently, it causes a number of health issues in people. Thus, low quantities of this fatty acid in genotypes and variations lead to a high nutritional grade. Studies have revealed that certain B. juncea, B. napus, B. rapa, and B. carinata all have zero-erucic acid genotypes. High erucic acid oil is essential for several products, including polyesters, detergents, surfactants, and plasticizers. Therefore, generating genotypes with elevated erucic content is a top focus in modern brassica breeding. Resynthesising the amphidiploid species B. napus, which has a high erucicacid content, from the genotypes of its diploid ancestors B. oleracea and B. rapa is one of the most beneficial breeding initiatives. Seed oil is more heat stable and therefore better for cooking due to its high oleic acid content. Oleic acid increases the suitability of seed oil for industrial use, hence increasing cooking oil efficiency. Additionally, since greater oleic acid levels raise blood levels of high-density lipoproteins (HDLs) while lowering levels of low-density lipoproteins (LDLs), it is thought that higher oleic acid levels are nutritious for human diet (Chang and Huang 1998).

Another significant MUFA that is recognized to be antinutritional and unfit for human ingestion is erucic acid, which is found in larger concentrations in edible oil. Cooking oil contains higher quantities of erucic acid due to the increased cardiac conductance in humans, which raises blood cholesterol levels (Sinha et al., 2007). Diverse industries will require multiple genotypes with elevated erucic acid levels. Rucic acid-rich oil is used as a raw material in the plastic, tannery, cosmetic, polyster, and detergent industries (Coonrod et al., 2008).

The low-erucic acid genotypes Pusa 30, PM-21, and PM-24 will be crucial in the future as Brassica breeding programs concentrate on creating zero-erucic lines for nutritional goals. It is known that polyunsaturated fatty acids (PUFAs) are the building blocks of long-chain fatty acids, which are necessary for the synthesis of physiologically significant substances like prostaglandins. Polyunsaturated fatty acids (PUFAs), such linoleic and linolenic acids, should be present in small amounts in cooking oil. The genotypes of *Brassica juncea*, *Brassica napus*, and *Brassica rapa* had linoleic and linolenic acid values of 11.0–45.30 percent, 11.10–26.72 percent, 18.57–26.93 percent, 9.99–17.23 percent, 14.08–18.18 percent, 9.82–26.66 percent, and 14.08–18.18 percent, respectively.

An essential fatty acid that the body cannot produce on its own and has to get from food is linoleic acid. Edible oil containing high levels of linoleic acid has been demonstrated to reduce blood cholesterol and prevent atherosclerosis. Although linolenic acid is recognized as an important fatty acid, its presence in oil can result in rancidity and an off taste (Sharafi et al., 2015). In different Brassica breeding programs, Brassica cultivars with high linoleic acid and low erucic acid levels can also be used to improve the quality and quantity of oil for industrial and nutritional uses.

Canola: Research to improve the quality of canola oil is essential for using it in both industrial and edible applications. Some of the fatty acids found in canola oil include palmitic acid, linoleic acid, stearic acid, oleic acid, arachidic acid, linolenic acid, and erucic acid (Wang et al., 2017). Because of its excellent nutritional content and ability to lower plasma cholesterol levels when compared to foods high in saturated fatty acids, canola oil is employed in human diets. Consuming canola oil has been demonstrated to influence biological processes that influence certain disease risk factors (Lin et al., 2013). Genetic regulation controls the amount of fatty acids in the oil, and it has been successfully changed to create products that are specifically tailored for their intended use.

Approximately half of the total fatty acid is usually present in canola oil, which is Consuming canola oil has been demonstrated to influence biological processes that influence certain disease risk factors (Lin et al., 2013). Genetic regulation controls the amount of fatty acids in the oil, and it has been successfully changed to create products that are specifically tailored for their intended use. About half of the total fatty acid found in canola oil is detrimental to humans since it has been associated with cardiac lipidosis.

Erucic acid makes up approximately 40% of total fatty acids in wild varieties of mustard and rapeseed, although it is rarely present in rapeseed grown for human use. According to the ICAR- DRMR annual report for 2020, gas chromatography analysis of the fatty acid profiles of several genotypes indicated palmitic and stearic acid were the main saturated fatty acids, whereas the yearly report included oleic, linoleic, and linolenic acid as important unsaturated fatty acids that were also nutritionally desirable.

Conversely, it was discovered that certain genotypes have less than 2% erucic acid. The annual report of DRMR Bharatpur (ICAR-DRMR, 2020) states that there has been a significant change in the fatty acid content of PM 29, PM 30, PDZ 1, and Kranti (Table 1). It has been discovered that the PDZ 1 variety is most suited for the timely sowing and irrigated conditions of the National Capital Region of Delhi and its surrounding areas in the states of Haryana, Rajasthan, and Uttar Pradesh. It also has lower levels of erucic acid and eicosenoic acid than the other three varieties.

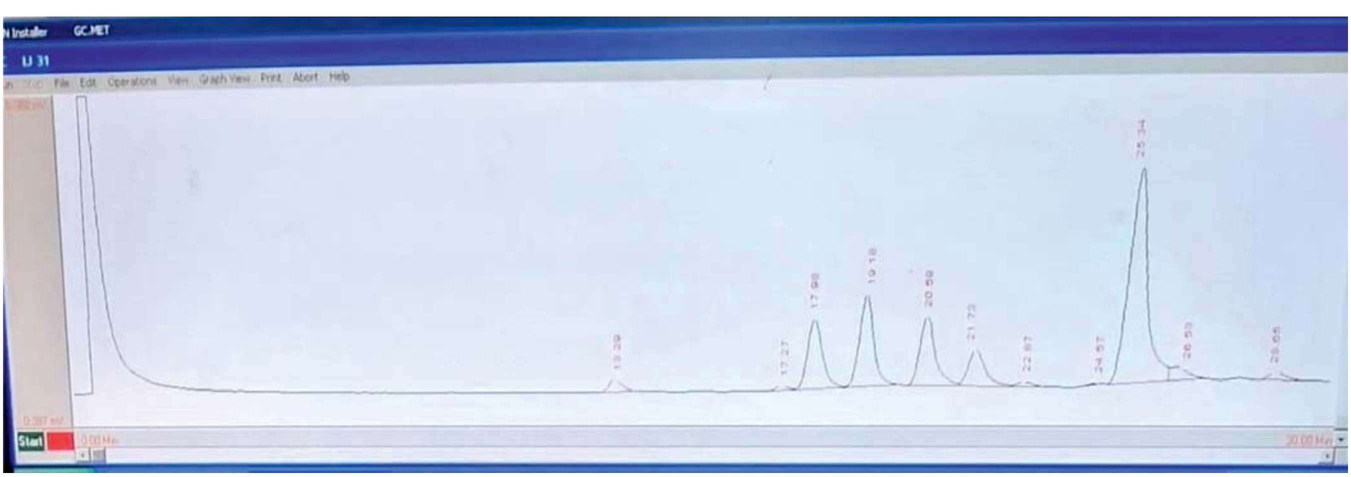


Figure 2:- Graphical presentation of fatty acid by gas chromatography (GC)

It produces yellow seeds with an oil content of 40.56 percent. The most recent annual report (ICAR-DRMR, 2020) states that PM 29 and PM 30 are low erucic acid (single zero) cultivars of Indian mustard, with 1.96 and 1.56 percent, respectively. Fatty acid analysis of varieties is advantageous because research indicates that consuming oleic acid may benefit people with cancer, inflammatory diseases, and autoimmune disorders. The PM29 concentration of linolenic acid, which is deemed hazardous to human health, dropped from 15.86 (2018) to 11.87 (ICAR-DRMR, 2020) (Figure 2).

Biotechnological interventions:

Plant lipid metabolism is rather more complicated than anticipated. New tools, techniques and strategies are the demands of coming aeon. We are actually at crossroads in terms of altering seed oil composition in an entirely predictable manner as an alternative to diminishing resources like fish oils. With the advents of technology and instrumentation, large number of crops have been sequenced, like flax, Arabidopsis, soybean and castor and aimed for genetic modifications. The combined efforts for proteomics, metabolomics, along with flux map analysis will give detailed insight into metabolic trafficking. Expressed sequenced tag (EST) were used for the marking the genes for TAG production. EST data along with pyrosequencing technology has also come up as a potential tool for the discovery of candid genes in TAG biosynthesis.

Present exponential growth in the number of genes involved in lipid metabolism has paved its way to the entirely new area of 'Lipidomics' which is described as the detailed analysis and global characterization of the lipids, both spatial and temporal, within a living system. The strategic categorization includes either separation of different lipid categories using extraction with chromatographic separation prior to class-specific mass analysis or directly using total lipid extraction by mass spectrometer followed by class-specific analysis. The later is particularly effective for the analysis of oilseeds engineered for altered lipid metabolism. Days have come where it is possible to know the substrate and product to unmatched levels of detail using MS/MS or LC-MS/MS targeted lipid analysis, thus making precise quantification for every engineering toil (Sayanova et al., 2011). Advances of synthetic biology and new techniques like clustered regularly interspaced short palindromic repeats (CRISPR)/Cas9 to lipidomics offers the probable rapid assembly of multiple genes for multigene insertion. This will aid scientists in introducing complex pathways, developing interchangeable segments and modulating assemblies of transgene cassettes. It is also envisaged that the future high-oil traits could be coupled with other traits with better health benefits or industrial values, such as omega-3 LC-PUFAs, petroselinic acid etc. Such transgenic crops may have the potential for direct use as a healthy food, animal feed or oleochemical feedstock. The rapid adoption of such technologies will continue to play pivotal role in giving a new shape to the oilseed markets and related stakeholders.

The seeds of old cultivars naturally accumulate TAGs carrying erucic acid (22:1), esterified at sn-1 and sn-3 locations within the glycerol backbone, making up 45–50 percent of the total fatty acid content. Two additive loci (EA & EC) on the A- and C-genomes regulate the amount of erucic acid in rapeseed genetically. Together, they account for 90% of the variance in erucic acid, but they are not equally distributed (Jourdren et al., 1996). The two loci were discovered in rapeseed using a QTL approach (Jourdren et al., 1996). According to Badawy et al. (1994), rats fed HEAR (high erucic acid rapeseed) oil experienced aberrant fat accumulation, cardiac lesions, and a drop in body weight. Recessive alleles (eA and eC) were inserted at both loci implicated in a 22:1 concentration, and Low Erucic Acid Rapeseed (LEAR) cultivars were chosen even though this detrimental nutritional impact has never been observed in humans.

Extraction processes:

Mustard oil is extracted from mustard seeds using different methods. Mustard oil owes its distinctive pungent flavor to allyl isothiocyanate, a compound that is also present in foods such as horseradish and wasabi. The mustard oil process begins with the thorough cleaning of the seeds to remove any impurities. Once cleaned, the seeds are ground into a coarse paste. The paste is then pressed to extract the oil. The extracted oil is collected and filtered to remove any solid particles.

Based on the extraction method, mustard oil can be found in two main varieties:

1. **Normal Mustard oil / Solvent extracted Mustard Oil:–** Most mustard oils found in the market are hot-pressed. This means they are made by using high heat and chemical solvents like Hexane to extract the oil from mustard seeds. While this results in more quantity of the oil being extracted, the quality of the oil including its taste and health benefits is significantly reduced. In fact, many of these solvents including Hexane or other hydrocarbons may be left in traces in the final product and are considered toxic with side effects ranging from headache, nausea, vomiting, dizziness, and lightheadedness. This extraction process also may oxidize the oil, turning it into trans fats. In fact, the smell of this chemically extracted oil is so rancid that a cleaning process has to take place using bleach to deodorize it. The oil is further subjected to the refining process to improve its shelf life and make it seem clearer in appearance to the consumer. In this process, more heat and chemicals are used, further declining the oil quality.

   Therefore, such refined oil looks clear, with devoid of pungency and is cheaper in price, it is poor in health benefits. Modern research has shown that refined oils are manufactured with chemical treatments which can boost the synthesis of omega-6 fatty acid to develop various health related issues including inflammation in the body. This can sometimes leads to development of diabetes, cancer and heart diseases. This process can also create rancid polyunsaturated fatty acids which on high temperature produces free radicals.

2. Cold-pressed or Kachi Ghani Mustard Oil:- This method uses mechanical pressure at room temperature to extract the oil. Although in this method the oil yield is lower, but all natural nutrients, essential fatty acids, vitamin E, and antioxidants are retained in extracted oil. Here this oil indicates purity and natural composition because of pungency and darker color. Hence cold pressed mustard oil is healthy and safe, offering a plethora of therapeutic benefits for your health. ORGANIC INDIA Kachi Ghani Mustard Oil or cold pressed mustard oil is made from the first press of high-grade, certified organic whole mustard seeds. Naturally rich in pungent flavour and aroma, this heart-friendly MUFA-rich (Monosaturated fatty acids) oil is ideal for enhancing the taste and nutrition of any dish. It's also great for hair and body massage.

Conclusion

Mustard oil, with its distinctive flavor, remarkable health benefits, and versatile uses, serves as a valuable addition to both culinary and wellness practices. Recent research suggest that mustard oil that is essential may aid in reducing the development of some fungus & microorganisms. Additionally, ALA, an omega-3 fatty acid found in mustard oil, may lessen pain and inflammation. Studies also suggest that mustard seed oil and its constituent parts may help slow the development and metastasis of some cancer cells. Despite conflicting evidence, mustard oil is rich in monounsaturated fats, which may lower a number of risk factors for cardiovascular disease. Fatty acids known as omega-3, which can be discovered in mustard oil, may help to reduce irritation and oxidative stress. The majority of the fat in natural mustard seed oil is monounsaturated and are more heat-resistant than polyunsaturated oils and have a smoke point

that is elevated. By choosing Organic India's Kachi Ghani Mustard Oil, you can further enhance the benefits of mustard oil with its superior quality and commitment to purity. Whether you use it in cooking, skincare, or body massage, mustard oil offers a natural and wholesome way to enhance your well-being.

Reference

1. Badawy, I., Atta, B. and Ahmed, W. (1994). Biochemical and toxicological studies on the effect of high and lowerucic acid rapeseed oil on rats, Nahrung, 38: 402– 411.

2. Baltrukoniene, G., Uchockis, V. and Svirmickas, G. J. (2015). The influence of compound feed enrichment with rapeseed and linseed cake on the meat characteristics and fatty acids composition of beef bulls. Zemdirbyste-Agriculture, 102: 319-324.

3. Bhoge, Y. N. (2015). Junk food & human health: A synoptic review. International Journal of Theoretical & Applied Sciences, 7(1): 51-55.

4. Burns, M. J., Barnes, S. R., Bowman, J. G., Clarke, M. H. E., Werner, C. P. and Kearsey, M. J. (2003). QTL analysis of an intervarietal set of substitution lines in Brassica napus: (i) seed oil content and fatty acid composition. Heredity, 90: 39–48.

5. Chang, N. W. and Huang, P. C. (1998). Effects of the ratio of polyunsaturated and monounsaturated fatty acids on rat plasma and liver lipid concentration. Lipids, 33: 481– 487.

6. Choudhary, R. R., Avtar, R., Singh, M., Chaurasia, H., Kumari, M., & Poonia, M. (2022). Trait Association Analysis for Yield & its Components in Indian mustard (Brassica juncea L.). Biological Forum – An International Journal, 14(1): 538-542.

7. Coonrod, D., Brick, M. A., Byrne, P. F., Debonte, L. and Chen, Z. (2008). Inheritance of long chain fatty acid content in rapeseed (Brassica napus L.). Euphytica, 164: 583–592.

8. Delourme, R., Falentin, C., Huteau, V., Clouet, V., Horvais, R., Gandon, B. and Renard, M. (2006). Genetic control of oil content in oilseed rape (Brassica napus L.). Theoretical and Applied Genetics, 113(7): 1331- 1345.

9. Dimov, Z., and Mollers, C. (2010). Genetic variation for saturated fatty acid content in a collection of European winter oilseed rape material (Brassica napus) Plant Breeding, 129(1): 82–86.

10. Ervin, R. B., Wright, J. D., Wang, C. Y., KennedyStephenson, J. (2004). Dietary intake of fats and fatty acids for the United States population: 1999– 2000. Adv Data. 348: 1–6.

11. Harvey, B. L. and Downey, R. K. (1964). The inheritance of erucic acid content in rapeseed (Brassica napus L.), Can. J. Plant Science, 44: 104–111.

12. Hong, C. P., Kwon, S. J., Kim, J. S., Yang, T. J., Park, B. S. and Lim, Y. P. (2008). Progress in understanding and sequencing the genome of Brassica rapa. International Journal of Plant Genomics,

13. ICAR-Directorate of Rapeseed-Mustard Research, 2020, Bharatpur 321 303, Rajasthan. Jourdren, C., Barret, P., Horvais, R., Foisset, N., Delourme, R. and Renard, M. (1996).

14. Identification of RAPD markers linked to the loci controlling erucic acid level in rapeseed. Molecular Breeding, 2: 61–71. Kirk, J. T. O. and Hurlstone, C. J. (1983). Variation and inheritance of erucic acid content in Brassica juncea. Z P flanzenzüchtung, 90: 331-33.

15. Lassner, M. W., Lardizabal, K. and Metz, J. G. (1996). A jojoba â-Ketoacyl-CoA synthase cDNA complements the canola fatty acid elongatin mutation in transgenic plants. The Plant Cell, 8: 281–292. Lin, L., Allemekinders, H. and Dansby, A. (2013). Evidence of health benefits of canola oil. Nutrition reviews, 71:

16. Mensink, R. P. (2016). Effects of Saturated Fatty Acids on Serum Lipids and Lipoproteins: A Systematic Review and Regression Analysis. World Health Organization; Geneva, Switzerland.

17. Priyamedha, S., Singh, B. K., Ram, B., Kumar, A., Singh, V. V., Meena, M. L. and Singh, D. (2014). Development and Evaluation of Double Low Quality Lines of Indian mustard (Brassica juncea L. Czern & Coss). SABRAO J. Breed Genet, 46: 274–283.

18. Qi, W., Zhang, F. and Sun, F. (2012). Over-expression of a conserved RNA- binding motif (RRM) domain (csRRM2) improves components of Brassica napus yield by regulating cell size. Plant Breeding, 131: 614- 619.

19. Rai, S. K., Charak, D. and Bharat, R. (2016). Scenario of oilseed crops across the globe. Plant Archives, 16(1), 125-132.

20. Rai, S. K., Gupta, S. K., Singh, A. K. and Rai, G. K. (2012). Development of hybrid in Mustard [Brassica juncea (L.) Czern and Coss]: Status, problems and prospects. Plant Archives, 12(1), 569-571.

21. Rai, S. K., Sandhu, R., Jat, L., Kumar, A., Kiran, U., Mukhtar, S. and Rai, G. K. (2017). Study of Heterosis and Combining Ability for Yield and its Component Traits in Brassica juncea L.

International Journal of Current Microbiology and Applied Sciences, 6(12), 2570-2579.

22. Ramos, M. J., Fernandez, C. M., Casas, A., Rodriuez, L. and Perez, A. (2009). Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour. Technol, 100: 261–268.

23. Scarth, R., McVetty, P. B. E., Rimmer, S. R. and Stefansson, B. R. (1988). 'Stellar' low linolenic-high linoleic acid summer rape. Can. J. Plant. Sci., 68: 509–511.

24. Sharafi, Y., Majidi, M. M., Goli, S. A. H. and Rashidi, F. (2015). Oil content and fatty acids composition in Brassica species. International Journal of Food Propertie, 18(10): 2145-2154.

25. Simopoulos, A. (2008). The importance of the omega6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Exp. Biol. Med., 233: 674– 688.

26. Sinha, S., Jha, J. K., Maiti, M. K., Basu, A., Mukhopadhyay, U. K. and Sen, S. K. (2007). Metabolic engineering of fatty acid biosynthesis in Indian mustard (Brassica juncea) improves nutritional quality of seed oil. Plant Biotechnol Rep, 1: 185–197.

27. Snowdon, R. J. (2007). Cytogenetics and genome analysis in Brassica crops. Chromosome Research, 15(1): 85-95.

28. Somerville, C., Browse, J., Jaworski, J. G. and Ohlrogge, J. B. (2000). Lipids. In:Buchanan B. B., Gruissem, W., Jones, R. L. (eds) Biochemistry & molecular biology of plants. American Society of Plant Biolo-gists, pp 456–527.

29. Thelen, J. J. and Ohlrogge, J. B. (2002). Metabolic engineering of fatty acid biosynthesis in plants. Metabolic engineering, 4(1): 12-21.

30. Thompson, K. F. (1983). Breeding winter oilseed rape, Brassica napus. Adv. Appl. Biol, 7: 1–104. Vigeolas, H. and Geigenberger, P. (2004). Increased levels of glycerol-3- phosphate lead to a stimulation of flux into triacylglycerol synthesis after supplying glycerol to developing seeds of Brassica napus L. in Planta. Planta, 219: 827–835.

31. Vigeolas, H., Waldeck, P., Zank, T. and Geigenberger, P. (2007). Increasing seed oil content in oil-seed rape (Brassica napus L.) by overexpression of a yeast glycerol-3- phosphate dehydrogenase under the control of a seed-specific promoter. Plant Biotechnology Journal, 5: 431–441.

32. Wang, Z., Qiao, Y. and Zhang, J. 2017. Genome wide identification of micro RNAs involved in fatty acid and lipid metabolism of Brassica napus by small RNA and degradome sequencing. Genetics, 619: 61-70.

33. Sayanova OV, Haslam RP, Calero´ n MV, Ruiz-Lo´ pez N, Worthy C, Rooks P, et al. Identification andfunctional characterization of genes encoding the omega-3 polyunsaturated fatty acid biosynthetic pathway from the coccolithophore Emiliania huxleyi. Phytochemistry. 2011;72(7):594–600. https://doi.org/10.1016/j.phytochem.2011.01.022

34. Vingering, Nathalie et al. "Fatty acid composition of commercial vegetable oils from the French market analysed using a long highly polar column." Oléagineux, Corps gras, Lipides 17 (2010): 185-192.

35. Yadav, Ram P. and Bibha Kumari. "Ultrasonic Studies on Mustard Oil: A Critical Review." (2015).

Antibacterial activity of essential oils against a group of food-borne pathogenic bacteria: A comparative study

Abhinav Pathak*, Raj Kumar, Alisha Paul, Pooja Rajput, Janhvi Gaur and Meenakshi Tripathi
FARE Labs Pvt. Ltd. Gurgaon-122002, Haryana, India
*Corresponding Author: abhinavpathak433@gmail.com

Abstract

Plant-derived essential oils (EOs) are recognized for their antimicrobial activity against specific pathogens, making them potential alternatives to synthetic antimicrobial agents. This study investigated the antibacterial effects of four essential oils—thyme, clove, lavender, and arborvitae against selected foodborne pathogens using the agar well diffusion assay. Among the oils tested, clove oil exhibited the highest antibacterial activity, while arborvitae oil showed the least. Overall, all four essential oils demonstrated antimicrobial properties. These findings suggest that essential edible oils can serve as promising alternatives to synthetic antimicrobials, enhancing food safety, health care, and personal care applications. Their natural origin and effectiveness may appeal to consumers seeking safer options. Further research and development are essential to optimize their applications and ensure their safety and efficacy across various settings. By exploring these oils more comprehensively, we can unlock their full potential and promote their use in diverse industries.

Keywords: Essential oils (EOs), Antibacterial activity, Gram-positive bacteria, Gram-negative bacteria.

Introduction

In recent years, food security has emerged as a critical public health issue worldwide. Foodborne pathogens refer to harmful microorganisms that can contaminate the food supply, leading to various illnesses. These microorganisms can produce toxic substances that cause direct or indirect health effects. Common pathogens associated with food poisoning include *Escherichia coli*, *Salmonella spp.*, *Listeria monocytogenes*, *Pseudomonas spp*., and *Staphylococcus aureus*. An increasing number of microorganisms have recently been identified as potential causes of illness or toxicity in humans. These pathogens not only pose significant risks to human health but also contribute to foodborne disease outbreaks (Ayaz *et al.*, 2015)

Antimicrobial agents, which are used to eliminate or inhibit the growth of pathogenic or foodborne microorganisms, can be derived from both synthetic and natural sources. However, the use of synthetic antimicrobial compounds as food preservatives has raised consumer concerns due to potential toxicological issues and safety concerns for human consumption (Singh et al., 2019). Natural resources offer a diverse array of complex compounds. Herbal extracts, edible oils, and essential oils exhibit antibacterial, antifungal, and antiviral properties and have been explored globally as potential sources for new antimicrobial compounds, food preservation agents, and treatments for infectious diseases (Astani *et al*., 2010; Safaei-Ghomi and Ahd, 2010).

Essential oils (EOs) are extracted from aromatic plants and consist of approximately 20 to 60 different components in varying concentrations. The primary constituents of these oils include terpenes and a range of aromatic and aliphatic compounds, such as alcohols, esters, ethers, aldehydes, ketones, lactones, phenols, and phenol ethers. Their complex composition contributes to the unique properties and applications of essential oils in various industries, including food, cosmetics, and health (Bakkali *et al*., 2008). Essential oils (EOs) from *Origanum vulgare* L., *Thymus vulgaris* L., *Salvia sclarea* L., and *Lavandula angustifolia* Mill., all belonging of the Lamiaceae family, have been valued for their medicinal properties for centuries, demonstrating antibacterial and antifungal activities (Fournomiti *et al*., 2015; Yuce *et al*., 2014).

Numerous studies have documented the antibacterial properties of essential oils (EOs). Most research focuses on the direct effects of EOs against various microorganisms. For instance, several Gram-negative and Gram-positive bacteria have demonstrated sensitivity to different EOs, as evidenced by clear inhibition zones in agar assays where the tested EO prevents microbial growth (Lambert *et al*., 2001). Additionally, some studies have measured the minimal inhibitory concentrations (MIC) and minimal bactericidal concentrations (MBC) of EOs in liquid media, providing insights into their effectiveness and potential applications as natural antimicrobial agents. These findings highlight the promising role of EOs in combating bacterial infections (Kalemba *et al*., 2003; Burt *et al*., 2004; Tsiri *et al*., 2009 & Poaty *et al*., 2015).

Findings from Oliveira et al. (2010) and Valeriano et al. (2010) suggest that essential oils with biocidal properties are promising alternatives for disinfection in indoor environments and the food industry. These natural agents effectively sanitize contaminated surfaces and equipment in food processing facilities, underscoring their potential to improve hygiene and safety. Incorporating essential oils into disinfection strategies allows for the adoption of eco- friendly methods that align with current health standards, while also decreasing reliance on synthetic chemicals. This innovative approach contributes to a safer environment for both consumers and workers in the food sector.

While essential oils have historically been used to treat various diseases and promote health, their applications have significantly expanded in recent years. They are now commonly utilized in pharmaceuticals, crop protection, food additives, aromatherapy, and more. This increased usage has led to heightened human exposure, necessitating a thorough re-evaluation of their toxicity and genotoxicity concerning mammalian cells. As highlighted by Slamenova et al. (2011), it is essential to assess the safety profiles of these natural compounds to ensure they can be used effectively without posing risks to human health.

This study aims to investigate the antimicrobial activity of essential oils against foodborne bacterial pathogens, specifically *Escherichia coli*, *Salmonella typhimurium*, *Staphylococcus aureus*, and *Listeria monocytogenes*. The agar well diffusion method will be employed to evaluate the zones of inhibition produced by these essential oils.

Methods and Materials:

Essential oils:

In this study, essential oils were sourced from various vendors in Delhi, India. The essential oils utilized included Thyme (*Thymus vulgaris*), Clove (*Syzygium aromaticum*), Lavender (*Lavandula angustifolia*), and Arborvitae (*Thuja occidentalis*).

Culture Maintenance:

Different pathogenic bacterial strains, including *Escherichia coli* (MTCC-739), *Salmonella typhimurium* (MTCC-733), *Staphylococcus aureus* (MTCC-737), and *Listeria monocytogenes* (MTCC-839), were taken to evaluate the antimicrobial activity of essential oils. Reference cultures of these strains were obtained from CSIR-IMTECH, Chandigarh. Prior to the assay, bacterial isolates were subculture at least twice from the stock onto Nutrient Agar (Himedia Laboratories Ltd., India) to prepare fresh cultures, ensuring the reliability and accuracy of the experimental results.

Preparation of inoculum:

Working stocks of the subculture bacteria were inoculated into Nutrient Broth and incubated at 37°C for 18 hours to achieve a turbidity equivalent to a 0.5 Mac-Farland standard. After incubation, the overnight broth cultures of the test pathogens were uniformly swabbed onto the surface of Muller-Hinton Agar (MHA) plates (Himedia Laboratories Ltd) using sterilized cotton swabs. One MHA plate was set aside as a media control, while a commercially available chloramphenicol disc (10 µg) served as a positive control. Four MHA plates were swabbed with the four different pathogens for pathogen control. For treatment control, four MHA plates were similarly swabbed with four different pathogens, with a single well cut into each plate. Approximately 20 ìl of 10 mg/ml of each essential oil sample was added to the wells. The plates were then incubated at 37°C for 24 hours. The zones of inhibition around the wells were observed, measured in millimeters, and results were recorded.

Statistical analysis:

Each experiment was conducted in triplicate to ensure the accuracy and reliability of the results. The mean and standard deviation (SD) were calculated for each bacterial strain to provide a clear statistical representation of the data. This methodology allows for a comprehensive understanding of variability in the measurements, facilitating the identification of significant differences in antimicrobial activity among the tested essential oils. Data analysis was performed using Microsoft Excel 2010 software. This systematic approach ensures that the findings are robust and can be confidently interpreted within the study's objectives.

Results and Discussion:

The antimicrobial activity of essential oils against various foodborne pathogens, including both Gram-positive and Gram-negative bacteria, is summarized in Table 1. While numerous studies have previously emphasized the antimicrobial properties of plant-derived essential oils, the current study specifically focuses on their effectiveness. All bacterial strains demonstrated susceptibility to each essential oil, as shown in Table 1.

The diameter of the zone of inhibition varied depending on the edible oil and bacterial species used as represented in (Fig 1). In present study, Clove oil reveals higher antibacterial activity as compared to other three edible oils showing zone of inhibition for *E.coli* (19.52±0.00 mm), *Salmonella typhimurium* (18.31±0.25 mm), *Staphylococcus aureus* (20.41±0.59 mm) and *Listeria monocytogenes* (17.23±0.34 mm) respectively. This finding is in agreement with the finding of Puskarova *et al*., (2017). Essential oil exhibits enhanced antibacterial activity, likely due to its lipophilic properties. These characteristics enable clove to interact effectively with the lipids in bacterial cell membranes, increasing their permeability. This mechanism of action may contribute to its potency against bacterial strains (Radunz et al., 2019). The antibacterial effect of clove essential oil is attributed to eugenol, a key compound that disrupts the bacterial cytoplasmic membrane. This disruption increases membrane permeability, facilitating the leakage of ions and the loss of intracellular proteins, ultimately resulting in cell death (Devi et al., 2010)

Several reports reveals that bioactive components present in essential oils penetrate the phospholipid bilayer of the cell membrane by which structural integrity of cell membrane is disrupted, which can detrimentally influence the cell metabolism casing cell death (Bajapai *et al.*, 2013). In present study *Staphylococus aureus*, shows higher sensitivity towards all essential oils as compared to other pathogenic strains. Similar studies carried out by Huang *et*

al., 2014, showed that Gram-positive bacteria are more susceptible to Essential oils as compared to Gram-negative bacteria. This can be attributed to the fact that Gram-negative bacteria have an outer membrane which is rigid, rich in lipopolysaccharide (LPS) and more complex, thereby limiting the diffusion of hydrophobic compounds through it, while this extra complex membrane is absent in Gram-positive bacteria which instead are surrounded by a thick peptidoglycan wall not dense enough to resist small antimicrobial molecules, facilitating the access to the cell membrane (Hyldgaard *et al.*, 2012).

Table 1: Antimicrobial Activity (zone of inhibition, mm) of Essential Oils against Pathogenic Microorganisms

	Escherichia coli	*Salmonella typhimurium*	*Staphylococcus aureus*	*Listeria monocytogenes*
Chloramphenicol	24.42±0.28	21.43±0.21	22.27±0.14	20.21±0.17
Thyme oil	15.43±0.42	14.53±0.42	17.35±1.11	13.73±0.00
Clove oil	19.52±00	18.31±0.25	20.41±0.59	17.23±0.34
Lavender oil	14.59±0.52	12.52±0.47	14.05±1.15	11.08±0.54
Arborvitae oil	7.27±0.16	9.82±0.56	8.42±0.74	6.72±0.53

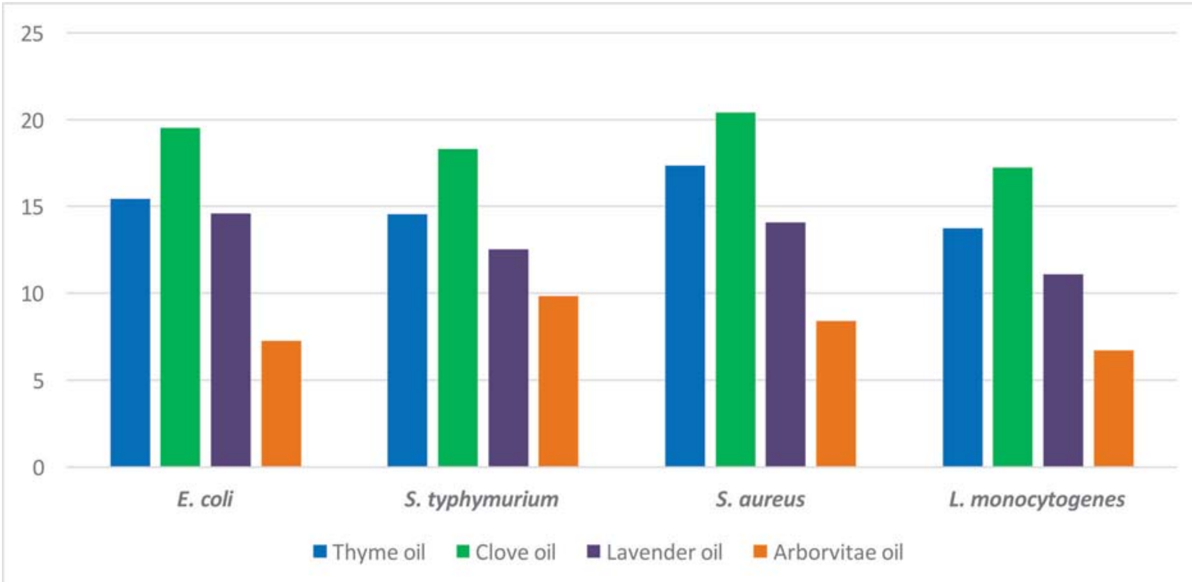


Fig 1: Sensitivity of food borne pathogens towards four different essential oils

Conclusions:

In conclusion, essential oils are rich in volatile compounds that exhibit diverse bioactivities, particularly antimicrobial properties. This study demonstrates that various essential oils and their individual components can serve as effective natural antimicrobials, helping to mitigate microbial activities in food products. Our findings highlight the potential of these oils as biocontrol agents, making them valuable resources for protecting food commodities against foodborne pathogens. While the efficacy of essential oils in controlling such bacteria is promising, further research is essential to fully explore their potential applications in the food industry. As the industry increasingly shifts toward green technology, investigating these natural alternatives can lead to innovative solutions that enhance food safety while minimizing reliance on synthetic preservatives. Overall, the exploration of essential oils as antimicrobial agents holds significant promise for improving food preservation and safety.

Acknowledgments:

The authors wish to express their gratitude to the Director, FARE Labs Pvt Ltd, Gurgaon 122001, India, for providing the facilities necessary for this research, conducted in the Department of Microbiology.

References

1. Astani A, Reichling J, Schnitzler P. Comparative study on the antiviral activity of selected monoterpenes derived from essential oils. Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives. 2010 May;24(5):673-9.

2. Ayaz M, Subhan F, Ahmed J, Khan AU, Ullah F, Ullah I, Ali G, Syed NI, Hussain S. Sertraline enhances the activity of antimicrobial agents against pathogens of clinical relevance. Journal of Biological Research-Thessaloniki. 2015 Dec;22(1):1-8.

3. Bajpai VK, Sharma A, Baek KH. Antibacterial mode of action of Cudrania tricuspidata fruit essential oil, affecting membrane permeability and surface characteristics of food-borne pathogens. Food control. 2013 Aug 1;32(2):582-90.

4. Bakkali, F., Averbeck, S., Averbeck, D. & Idaomar, M. Biological effects of essential oils - a review. Food Chem. Toxicol. 46, 446–475 (2008).

5. Burt, S. Essential oils: their antibacterial properties and potential applications in foods a review. Int. J.

Food Microbiol. 94, 223–53 (2004).

6. Burt, S. Essential oils: their antibacterial properties and potential applications in foods a review. Int. J. Food Microbiol. 94, 223–53 (2004).

7. De Oliveira, M. M. M., Brugnera, D. F., Cardoso, M. G., Alves, E. & Piccol, R. H. Disinfectant action of Cymbopogon sp. essential oils in different phases of biofilm formation by Listeria monocytogenes on stainless steel surface. Food Control 21, 549–553 (2010).

8. Devi, K.P., Nisha, S.A., Sakthivel, R., Pandian, S.K. (2010). Eugenol (an essential oil of clove) acts as an antibacterial agent against Salmonella typhi by disrupting the cellular membrane. Journal of Ethnopharmacology, 130 (2010), 107-115.

9. Fournomiti, M. et al. Antimicrobial activity of essential oils of cultivated oregano (*Origanum vulgare*), sage (*Salvia officinalis*),and thyme (*Thymus vulgaris*) against clinical isolates of *Escherichia coli*, *Klebsiella oxytoca*, and *Klebsiella pneumoniae*. Microb. Ecol. Health Dis. 26, 23289–23295 (2015).

10. Huang DF, Xu JG, Liu JX, Zhang H, Hu QP. Chemical constituents, antibacterial activity and mechanism of action of the essential oil from Cinnamomum cassia bark against four food-related bacteria. Microbiology. 2014 Jul;83(4):357-65.

11. Hyldgaard M, Mygind T, Meyer RL. Essential oils in food preservation: mode of action, synergies, and interactions with food matrix components. Frontiers in microbiology. 2012 Jan 25;3:12.

12. Kalemba, D. & Kunicka, A. Antibacterial and antifungal properties of essential oils. Curr. Med. Chem. 10, 813–829 (2003).

13. Kalemba, D. & Kunicka, A. Antibacterial and antifungal properties of essential oils. Curr. Med. Chem. 10, 813–829 (2003).

14. Lambert, R. J. W., Skandamis, P. N., Coote, P. & Nychas, G. J. E. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. J. Appl.Microbiol. 91, 453–462 (2001).

15. Poaty, B., Lahlah, J., Porqueres, F. & Bouafif, H. Composition, antimicrobial and antioxidant activities of seven essential oils from the North American boreal forest. World J. Microbiol. Biotechnol. 31, 907–919 (2015).

16. Radünz, Marjana, Maria Luiza Martins da Trindade, Taiane Mota Camargo, André Luiz Radünz, Caroline Dellinghausen Borges, Eliezer Avila Gandra, and Elizabete Helbig. "Antimicrobial and antioxidant activity of unencapsulated and encapsulated clove (Syzygium aromaticum, L.) essential oil." Food chemistry 276 (2019): 180-186.

17. Safaei-Ghomi J, Ahd AA. Antimicrobial and antifungal properties of the essential oil and methanol extracts of Eucalyptus largiflorens and Eucalyptus intertexta. Pharmacognosy magazine. 2010 Jul;6(23):172.

18. Singh B, Singh JP, Kaur A, Singh N. Antimicrobial potential of pomegranate peel: A review. International Journal of Food Science & Technology. 2019 Apr;54(4):959-65.

19. Slamenova, D., Horvathova, E., Kovacikova, Z., Kozics, K. & Hunakova, L. Essential rosemary oil protects testicular cells against DNA-damaging effects of H2O2 and DMNQ. Food Chem. 129, 64–70 (2011).

20. Tsiri, D. et al. Chemosystematic value of essential oil compostion of Thuja species cultivated in Poland-Antimicrobial activity.Molecules 14, 4707–4715 (2009).

21. Valeriano, C. et al. The sanitizing action of essential oil-based solutions against Salmonella enterica serotype Enteritidis S64 biofilm formation on AISI 304 stainless steel. Food Control 25, 673–677 (2012).

22. Yuce, E., Yildirim, N., Yildirim, N. C., Paksoy, M. Y. & Bagci, E. Essential oil composition, antioxidant and antifungal activities of *Salvia sclarea* L. from Munzur Valley in Tunceli, Turkey. Cell. Mol. Biol. 60(2), 1–5 (2014).

Prediction of oxidation stability of oils and fats by DSC measurement

D Mathur, CS Joshi, **Meenakshi Tripathi***, HB Singh, Praveen Kumar Yadav, Ayushi Shrivastav and Sapna Neolia
FARE Labs Pvt. Ltd., D-28, Infocity-II,
Sector-33, Gurugram-122002, Haryana, India
*Corresponding Author: meenakshi.tripathi@farelabs.com

Abstract

Due to vast application of oils and fats in food, cosmetic and pharmaceutical industries, it is important to predict shelf life of oil and fats with better repeatability and precision. Different methods have been used for shelf life assessment in oils and fats, here we have used differential scanning calorimetry (DSC) method and predicted shelf life in soybean, peanut, mustard, sunflower, palmolein, and rice bran oil by analysing the oxidation induction time (OIT). This method offered a stable baseline measurement during the OIT measurement and hence, improved the repeatability and precision of measurement. Additionally, the sample consumption and time required for OIT measurement was comparatively very small. The OIT values obtained from the measurement showed linear relationship with respect to the analysed temperature and good correlation coefficient ($R^2 = 0.999$) values increased the confidence for shelf life prediction and reliability of measurement.

Introduction

Oils and fats are among the most important ingredients in the basket of human diets. It provides nutritional and sensory pleasure to the human beings. Additionally, oils and fats are the most abundant lipids in nature and serve as major source of energy for the organisms. Lipids are the crucial ingredients in food industries for the manufacturing of various products such as ready to eat foods, butters, soups, chocolates etc. it is also very important in cosmetics and pharmaceuticals industries for the manufacturing of various products like lipsticks, cream, lotion, shampoo, oils, vitamins etc. Mostly, these products are manufactured by using the vegetable oils because this oil offers high amount of polyunsaturated fatty acids in comparison to the animal oils. These polyunsaturated fatty acids are very important which decides the stability of the products. In presence of oxygen, oxidation of unsaturated fatty acids takes place which led to the degradation of lipids and hence, change in flavour, taste, shelf life, quality of products may occur. Bad quality of product can compromise the safety, nutrition level and may generate the harmful compounds that might affect the health of human beings. Therefore, a comprehensive understanding of the oxidation stability of oils and fats is vital for both manufacturers and consumers [1].

Oxidation of lipid is very complex process which depends on processing condition and type of lipid. And the thermal oxidation of lipid releases heat which can be measured by using the differential scanning calorimetry (DSC) instrument. A range of analytical techniques and methods have been used for the assessment of oxidation stability of lipid such as oxygen bomb method, Schaal oven test, OXITEST method, oxidation stability index (Reanimate), active oxygen method along with DSC emerging as a particularly effective method [2]. DSC is a thermal analysis technique where sample is measured at fix/controlled air pressure, temperature and that measures heat flow associated with physical transitions in samples. This method delivers comprehensive understandings of the oxidation process, enabling the quantification of critical parameters such as oxidation induction time (OIT) and oxidative onset temperature. While other methods measures anisidine value, peroxide value, volatile compound by gas chromatography (GC) and UV spectrophotometer to assess the oxidative degradation of lipids. Moreover, using DSC for oxidation stability measurement of oils and fats has its own benefits, it offers rapid and repeatable measurement and sample quantity required for the measurement is very small or negligible in comparison to the others (e.g., Rancimat)[3,4].

In short, analysing oxidation stability in oils and fats by DSC is very important parameter in nutrition, food science, and product development. Present work discuses about the oxidation analysis of lipid using DSC. Additionally, it also discusses the calculation of oxidation stability from OIT and extrapolated graph. It provides insight into the thermal behaviour and oxidation kinetics of lipid which can improve quality and safety of products. As consumer demand for high-quality, stable lipid products continues to rise, the role of DSC in assessing oxidation stability will remain essential, guiding formulation strategies and ensuring product safety across various industries.

Materials and methodology

All the oil sample used in the experiment has been purchased from the local market. The standard (In and Zn) used for the calibration of DSC was provided by Perkin Elmer.

Sample preparation and pre-treatment

All the samples were prepared using the aluminium pan for oxidation induction time measurement by DSC. Approximately, 10 mg sample weighed in open aluminium pan using syringe and sample in open pan is placed in to the DSC sample holder, and start the measurement at required temperature. In order to get the best repeatability, representative sample is prepared and lipid sample is melted at required temperature to erase their previous thermal history.

Differential scanning calorimetry (DSC)

DSC technique is used for thermal analysis of sample which measures the difference between the heat flow rate of sample and reference as a function of time and temperature in controlled environmental condition. An empty pan is placed on the reference sensor on the other hand sample sensor hold pan with sample. Both the pan reacts similarly which led to the nil contribution of the pans. However, sample present in pan absorbs the energy and give the endothermic response and exothermic response is received upon release of energy from the sample.

Before the sample analysis, instrument is calibrated at one or two melting point using melting point certified reference materials. Calibration is performed by following ASTM (ASTM D3895-19) method or ISO (ISO 11357) method [5, 6]. After calibration, sample is weighed in open aluminium pan and loaded into the instrument with reference pan. Initially, nitrogen gas is allowed to purge for 5 minutes so that the inert atmosphere can be created. The flow of gas set at 50 ml per minute and heat flow rate set as 20 p C per minute. Isothermal heating procedure used for OIT measurement and heating is performed at 110, 120,130 and 140 p C. When the temperature reached at set temperature, sample was equilibrated for 5 minutes and purged gas changed from nitrogen to oxygen at same flow rate as nitrogen. This changeover time is considered as the zero point for OIT calculation. Isothermal operation is continues until the exotherm appeared. OIT is calculated by extending the base line beyond the exotherm and a steepest linear slope is extrapolated which intercept on the extrapolated baseline. The time is recorded between zero time and intercept is called the OIT **(Figure 1).**

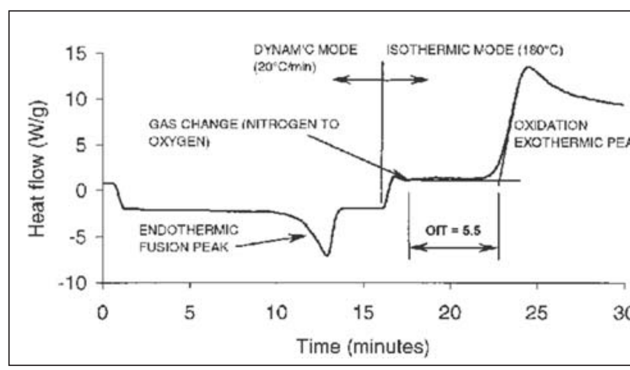


Figure 1: OIT determination by DSC [7].

Oxidation stability/shelf life

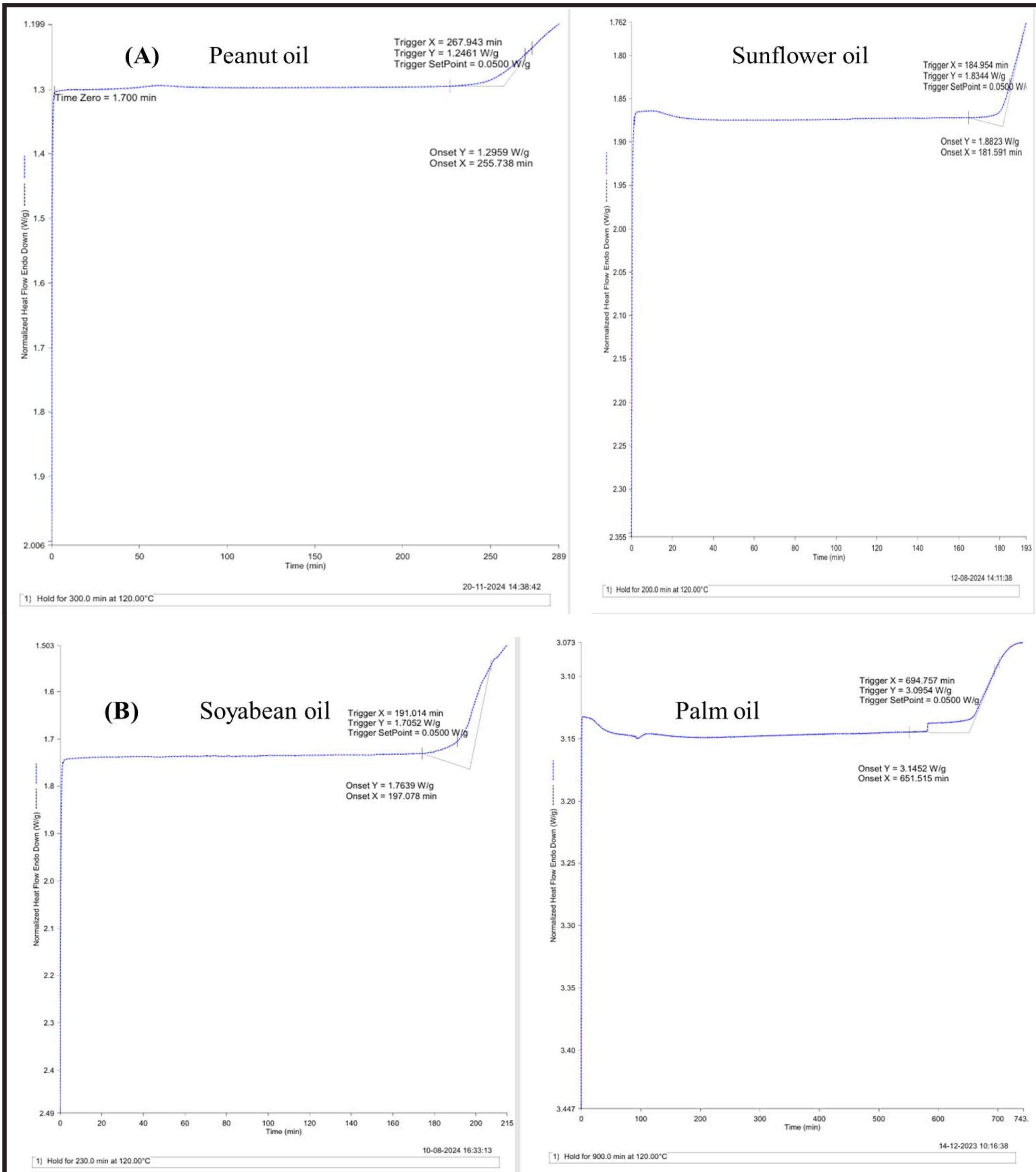
After measuring the OIT at 110, 120, 130 and 140 p C in different oil samples, oxidation stability (shelf life) of oils were predicted at 25 p C. The measurement of OIT at different temperature showed linear relationship and followed zero order kinetics (equation 1). Graph is plotted between Log OIT and temperature, and oxidation stability calculated by back extrapolation of graph at 25 p C.

$$\text{Log OIT} = \text{Log OIT}_0 - k_0\, t \qquad \ldots 1$$

Where OIT_0 represent OIT at time zero minute and, k_0 is constant and t stand for temperature.

Results and discussion

The period where no change in heat flow signal is appeared is considered as OIT. Unlike the OIT measurement in plastic materials, there is no standard guideline for OIT measurement in oil and fat samples using the DSC equipment. The present work followed the same procedure with some modification and measured OIT in different oil samples such as sunflower, peanut, mustard, palmolein, soybean and rice bran oil, given in **figure 1(A,B and C).**



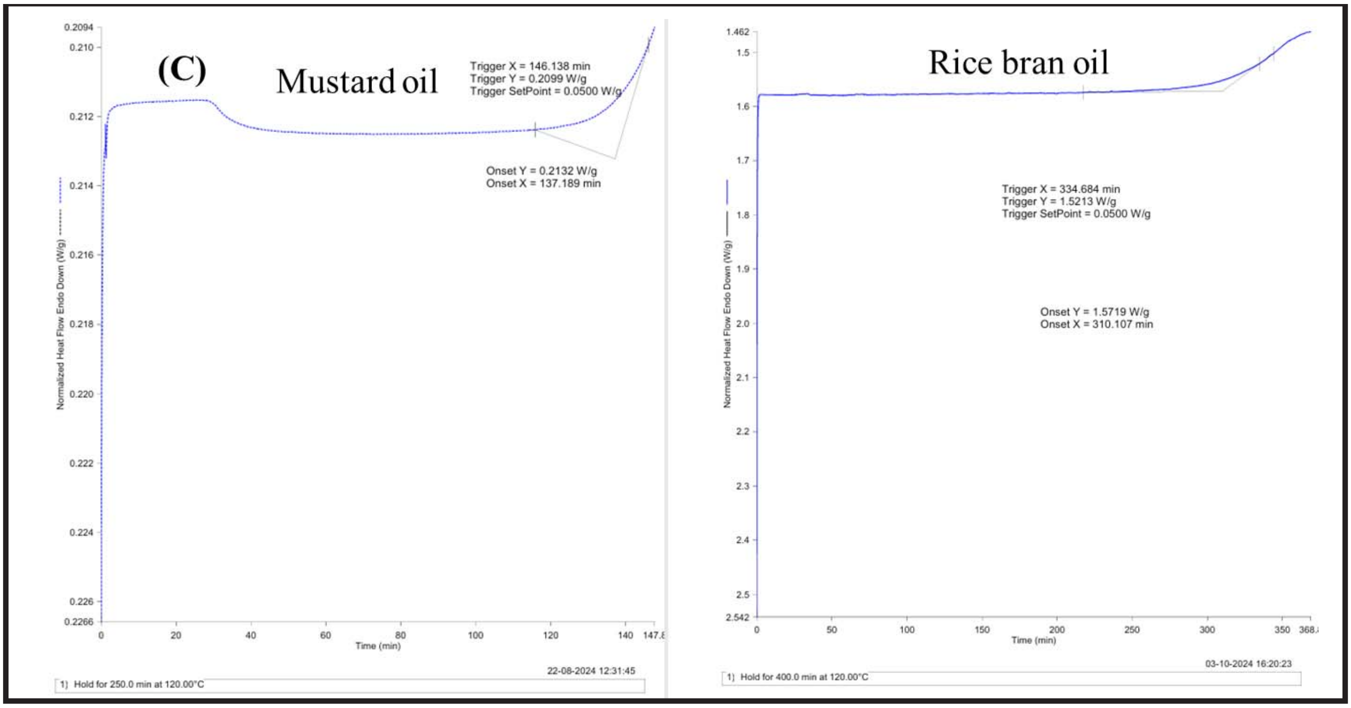


Figure 1: OIT measured at medium temperature (120 ^{O}C) in (A) peanut and sunflower oil, (B) soyabean and palmolein oil and (C) mustard and rice bran oil.

The time measured with DSC at different temperatures like 110, 120, 130 and 140p C is converted into log value and linearly plotted against the temperature for all sample, are discussed in **figure 2.**

The linearity obtained in all samples showed the regression coefficient (R^2) of greater than 0.999 except in soybean sample (R^2 = 0.983). Linearity is extrapolated backward and predicted the oxidation

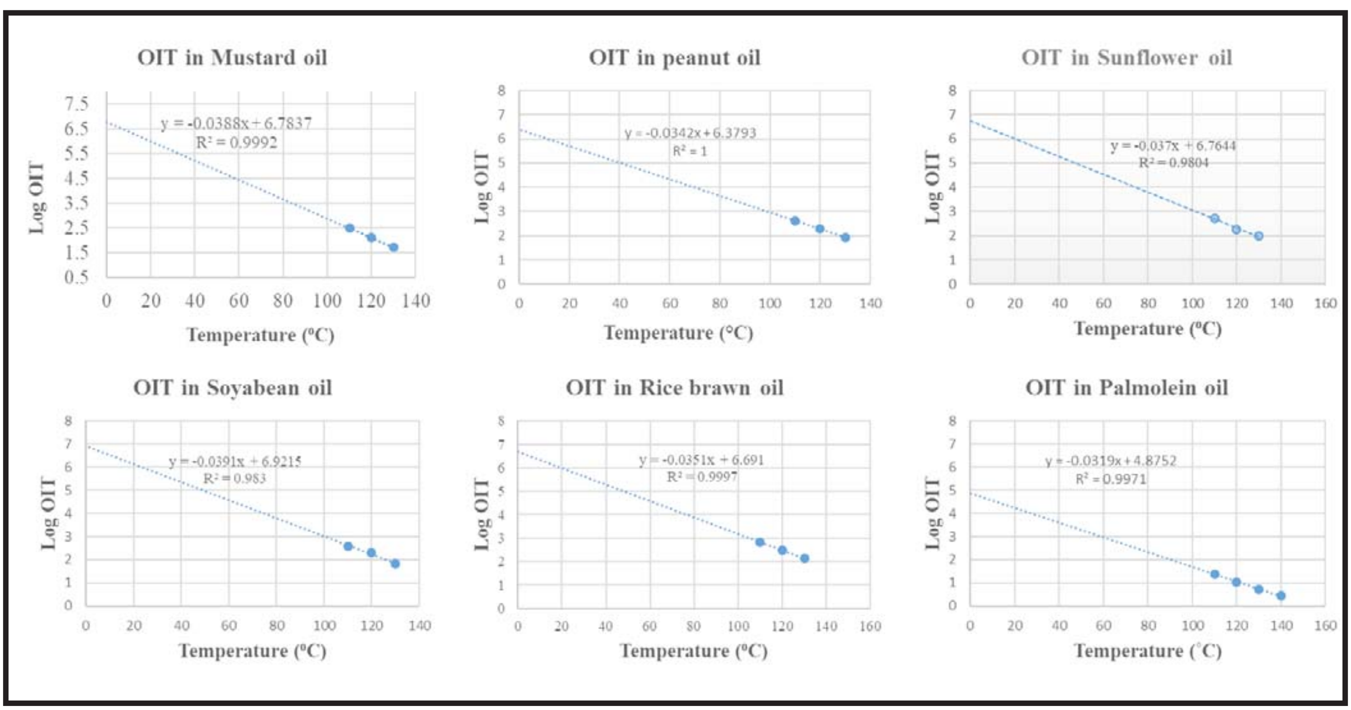


Figure 2: Linear plot in different oils and their extrapolated graph used for shelf life calculation.

Table 1: Oxidation induction time, coefficient and oxidation stability measured by DSC.

Sample	OIT (min)				Coefficient	Predicted shelf life in monthss @
	110°C	120 °C	130p C	140 °C	(R^2)	30 °C
Mustard oil	320.632	137.189	53.632	NA	0.9992	10.1
Peanut oil	570.243	257.738	110.068	NA	0.9998	10.0
Sunflower oil	525.05	181.59	95.365	NA	0.980	10.4
Soyabean oil	394.57	197.08	65.327	NA	0.983	10.1
Rice bran oil	678.23	310.1	134.98	NA	0.9997	10.6
Palmolein oil	1458	648.01	306.023	162.124	0.9971	11.1

stability of all oil samples at room temperature. The predicted oxidation stability, linearity coefficient and OIT of samples are discussed in **table1.**

Most of the other methods struggle to get the stable base line during the OIT measurement. This issue produced poor repeatability and precision of measurement in different methods **[3, 4].** However, in DSC method a stable baseline is obtained during the OIT measurement and hence, provide better precision and repeatability of the method**.** Moreover, DSC method require shorter time and measure OIT in minutes in comparison to Rancimat method which perform OIT measurement in hours.

Conclusion

Oxidation stability or shelf life prediction through the OIT analysis by DSC offers fast, precise and convenient method. Sample analysis in controlled gas flow and heat flow rate provides a stable baseline which make the correct OIT measurement possible and convenient, and improves the repeatability and precision of the measurement. Furthermore, due to its quick and reliable means of monitoring oil stability, allowing both manufacturers and consumers to make well-informed choices regarding oil selection and usage.

Reference

1. Saldana MDA, Martínez-Monteagudo SI (2013). Oxidative stability of fats and oils measured by differential scanning calorimetry for food and industrial applications. 10.5772/54486.
2. Tsao CH, Chang CW, Ho YC, Chuang YK, Lee WJ (2021). Application of OXITEST for prediction of shelf-lives of selected cold-pressed oils. Frontiers in Nutrition. 8: 763524.
3. Cross CK (1970) Oil stability: A DSC alternative for the active oxygen method. J. Amer. Oil Chem. Soc. 47:229-230.
4. Yamazaki M, Nagao A, Komomiya K (1980) High pressure differential thermal analysis of fatty acid methyl esters and triglycerides. J. Amer. Oil Chem. Soc. 57:59-60.
5. ASTM D3895-19, (2023). Standard test method for oxidative-induction time of polyolefins by differential scanning calorimetry.
6. ISO 11357-6, (2018). Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT).
7. Volponi, JE, Mei, LHI, Rosa, DS (2004). Use of oxidation onset temperature measurements for evaluating the oxidative degradation of isotatic polypropylene. Journal of polymers and the environment. 12. 11-16.

Solid fat content analysis of oils and fats by pulsed-NMR

D Mathur, CS Joshi, **Meenakshi Tripathi***, HB Singh, Praveen Kumar Yadav, Kumer Saurabh Keshari, Ayushi Shrivastava and Sapna Neolia
FARE Labs Pvt. Ltd., D-28, Infocity-II,
Sector-33, Gurugram-122002, Haryana, India
*Corresponding Author: meenakshi.tripathi@farelabs.com

Abstract

In oil and fat industries, accurate and precise measurement of solid fat content (SFC) is very important parameter for quality control. SFC values are required for product finalization and quality assessment of different products. Additionally, it also plays very critical role in processing and value addition of the products such as during the hydrogenation, blending and inter esterification process. It also regulate the flavour, texture and mouth feel of the products. Therefore, the SFC becomes very important parameter of quality control for the fat based products. The traditional methodologies like dilatometry have been used for the determination of solid fat index (SFI) with better precision and accuracy. In this work, we have determined the SFC in different oils and fats following the AOCS Cd 16b 93 method and the measurement results were not only within the repeatability and reproducibility limit but also produced very small standard deviation in comparison to the traditional method. It shows the direct method (NMR) is very effective, suitable, precise and accurate in comparison to other methods.

Introduction

The application of oils and fats has very rich historical background, it has been used since ancient period for various purposes such as for cooking, backing, eating, preservation etc. However, after the industrial revolution the invention of hydrogenation process has revolutionized and industrialized the application of oils and fats. This development has increased the application as well as the production of oil and fats which enabled the mass production of baked goods and confections in the market.

After the century of progress and understanding, quality and nutrition aspect in oils and fats has become the important criteria in current scenario. Currently, the application of oils and fats is much refined and more focused not only on the health benefits but flavour and texture, and sustainability also. Application of oils and fats in various food industries such as chocolate and bakery production etc. plays critical role for accessing the texture, quality, and overall appeal of the final products. Additionally, the application of oil and fats in backed products not only enhances the flavour but also affect the physical property of baked products.

In food industry, solid fat content (SFC) of oils and fats is very crucial parameter which affect the sensory, physical and nutritional qualities of the food products like dairy products, chocolates, margarines, baked products etc. The proportion of SFC governs the quality, texture, shelf life, mouth feel and stability of the products. Therefore, precise and accurate measurement of SFC in oils and fats became very critical parameter of quality control for manufacturers in order to meet the quality and customer demands. During the processing of oil and fat based materials, the SFC values of required materials is used to regulate blending, hydrogenation and interesterification process.

Most traditional method for the determination of SFC is dilatometry method developed by American oil chemist's society (AOCS; AOCS Cd 16b 93) **[1]**. Moreover, several other methods are also used for SFC analysis but these methods may be labour intensive, costly, cumbersome, needs regular maintenance, calibration and high chemical consumption. For instance, near infra-red (NIR) method used for SFC analysis require calibration maintenance. Calibration of NIR is very complex due to its sensitivity toward the surface measurement rather than the bulk sample measurement. In supercritical fluid extraction (SFE) method, oil is extracted by using compressed CO_2 and require high maintenance which increases the cost of measurement.

In comparison to these secondary techniques and wet chemical method for SFC analysis, nuclear magnetic resonance (NMR) technique offers eco-friendly, fast, non-destructive, direct and user-friendly method of analysis for SFC in oils and fats **[2].** Recent advancement in the NMR technology offers low magnetic field and bench top model which makes the calibration of instrument and measurement very convenient, fast and accessible for both researchers and food industries as well.

Current work discusses the determination of SFC in different oils and fats used in bakery industry using pulsed NMR technique. In this work, SFC has been determined following the AOCS Cd 16b 93 method**.** It also explains about the sample preparation procedure, method verification and collaborative work done in earlier studies.

Materials and methods

The standards (ND1645 SFC standards of 0%, 30.9% and 72.9%) used for calibration/verification of NMR is bought from Bruker. All other samples which have been used in the experiment are market samples.

Sample preparation and pre-treatment

Sample preparation has been done following the AOCS Cd 16b 93 method. A brief discussion on sample preparation procedure is provided here. However, a detailed discussion on sample preparation procedure and NMR configuration is given in AOCS Cd 16b 93 method [1]. All the fat and oil samples were heated at 100 °C to remove the previous thermal history and to make the sample homogeneous. Replicates of each sample was prepared and transferred into the 10 mm sample tubes up to the height of 4 ± 1 cm. All the samples were placed into the heating blocks at 100 °C for 15 minutes. After the storage of 15 minutes, all the sample tubes were transferred into the next temperature zone of heating block i.e., 60°C and left for 5 minutes at the same temperature. Now the sample tubes were placed at 0°C for 1 hour for the crystallization of the sample. All the sample tubes were taken out from the crystallization temperature and placed at required temperature such as 10, 15, 20, 25, 30, 40, 50 and 60°C. Samples were left for 30-35 minutes at required temperature and after 35 minutes of tempering each sample was analysed with NMR for SFC measurement **[1].**

Nuclear magnetic resonance (NMR)

Pulsed NMR (The Minispec MQ 20, Bruker) (**figure1**) with total nine tempering zone (TC6 and TC3) has been used for SFC analysis. Temperature control unit (TC3) has three temperature zone and each zone is having 60 ports for sample tempering and holding. Temperature control unit (TC6) has six compartment and each compartment has 10 ports for tempering and holding. The main unit is having 1 port for sample measurement. All the sample measured at following instrument conditions (table 1).

Figure 1: Time Domain-NMR (The Minispec MQ20, Bruker)

Table 1: Instrument (NMR) measurement conditions

S. No.	Parameters	Value
1.	Radio frequency	20 MHZ
2.	Recycle delay	1.5 sec
3.	No. of pulses	3
4.	K factor	1.001
5.	F factor	1.445
6.	Scan	4

The basic principle of NMR spectroscopy technique can be understand with the following discussion. Hydrogen nuclei itself act as a magnet when it is placed in an external magnetic field (H_O). Therefore, the alignment of the nuclei changes in presence of external magnetic field. Some nuclei aligned against the applied magnetic field and some toward the applied magnetic field in presence external magnetic field. Due to Zeeman splitting, upper and lower energy level created and the difference (ÄE) between these two energy levels, in thermal equilibrium, is given by Boltzmann equation1 [**3**].

$$\frac{N_u}{N_l} = e^{\frac{\Delta E}{k_B T}} \qquad ...1$$

Where ÄE is the difference between the upper (N_u) and lower (N_l) energy levels, k_B represent the Boltzmann constant and T is the absolute temperature. The magnitude of ÄE depend on the extent of magnetic field applied. A net magnetic moment is generated due to the energy difference between the nuclei population and this magnetic moment is aligned with the externally applied magnetic field (H_O). When an oscillating magnetic field (RF field) is applied transverse to the static magnetic field, nucleus transition or excitation takes place from lower to higher energy level which lead to the change in the net magnetic moment and hence, the thermal equilibrium. Finally, excited nuclei loses its energy and return to its ground state, and the process is called the relaxation process. Mainly, two types of relaxation takes place i.e., transverse (T_2) and longitudinal (T_1) relaxation. When nuclei loses its energy by colliding with the nearest nuclei and the time required to reach the thermal equilibrium is called the transverse relaxation (T_2) and if the nuclei loses its energy into the lattice and reaches thermal equilibrium, it is called the longitudinal relaxation (T_1). This relaxation process changes the magnetic flux which is measured by the same RF coil used for excitation of nuclei. The current induced by the RF coil due to the relaxation process is proportional to the number of hydrogen atom present in the sample. Additionally, the signal intensity obtained is used for the quantification of target element in the sample **[4].**

On the basis of the basic principle of NMR, the SFC in oil and fat samples is measured. SFC is determined by measuring the signal intensity in solid as well as liquid phase of the sample. There are two method available (such as direct and indirect method) for SFC determination by NMR method. In direct method, sample is first magnetized and signal intensity is measured after 11 µs (E11) and again measured after 70 µs (E70). The signal intensity obtained at 70 µs represent the signal intensity of liquid phase and the signal obtained at 11 µs after pulse is due to the solid and liquid phase of the sample. Due to the hardware limitation, it is not possible to measure the signal immediate after the pulse applied. The signal obtained at both time interval is used to calculate the SFC content in sample as discussed in equation 2 **[1]**.

$$SFC_{\text{Direct method}}\ (\%) = \frac{(E11-E70)\times F\times 100}{E70+[(E11-E70)\times F]+D} \qquad ...2$$

Where
E11 = Signal measured at 11 µs after magnetization
E70 = Signal measured at 70 µs after magnetization
D = Digital offset factor for detector nonlinearity correction
F = Dead time correction factor for receiver

However, in indirect method, first signal is measured at temperature (E_T) where solid and liquid both phase exist and second signal is measured at 60°C (E_{60}) only. In this case, SFC is calculated at lower temperature using the difference between these two signals (E_T and E_{60}).

Results and discussion

Earlier, it was reported that the solid fat index (SFI) measured by using the dilatometry method offers very good precision and accuracy in comparison to the other methods. Therefore, the AOCS committee has organised a collaborative study in 1992-1993 to measure the accuracy and precision (for SFC measurement) between the dilatometry and NMR method of measurement **[1]**. It was found that the direct method of measurement by NMR technique has better precision than the indirect method of the same. However, the direct method of measurement showed the similar precision as the dilatometry method. Repeatability and reproducibility limit decided on the basis collaborative measurement results from different methods are given in **table 2.**

In this work, sample preparation has been done following the AOCS Cd 16b 93 method. Sample is treated at 100 °C, 60°C and crystallized at 0°C and kept at measuring temperature (10°C) before the analysis. Sample analysis was performed following the parallel method. All the measured SFC values are discussed in **figure 2.**

Table 2: Repeatability and reproducibility limit of AOCS and dilatometry method

Parameters	AOCS method		Dilatometry method
	Direct	Indirect	
Repeatability (r)	1.3%	2 %	1.3 %
Reproducibility (R)	3.3%	4 %	2.0 %

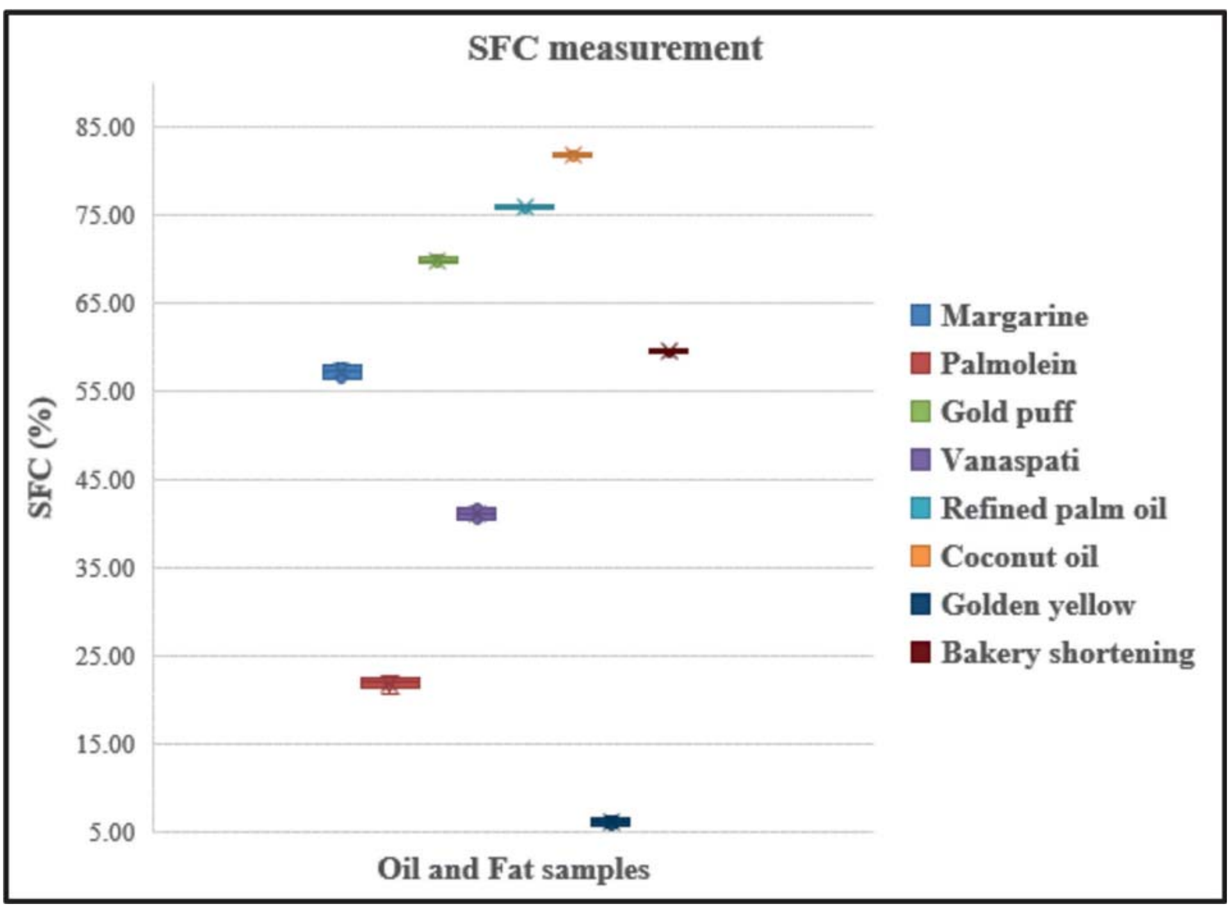


Figure 2: Box chart of SFC value measured by direct method (NMR technique) at 10ᵖ C in different samples.

Both repeatability and reproducibility measurement result showed very low standard deviation values in all the sample measured. Standard deviation of all samples were within the limit from both AOCS and dilatometry method. Measured standard deviation values for repeatability and reproducibility measurement are discussed in **figure 3 and 4**. Lower standard deviation values of measurements following the direct method showed very good precision in comparison to the indirect and dilatometry method. It shows that direct NMR method provides accurate and precise measurement results in comparison to other methods.

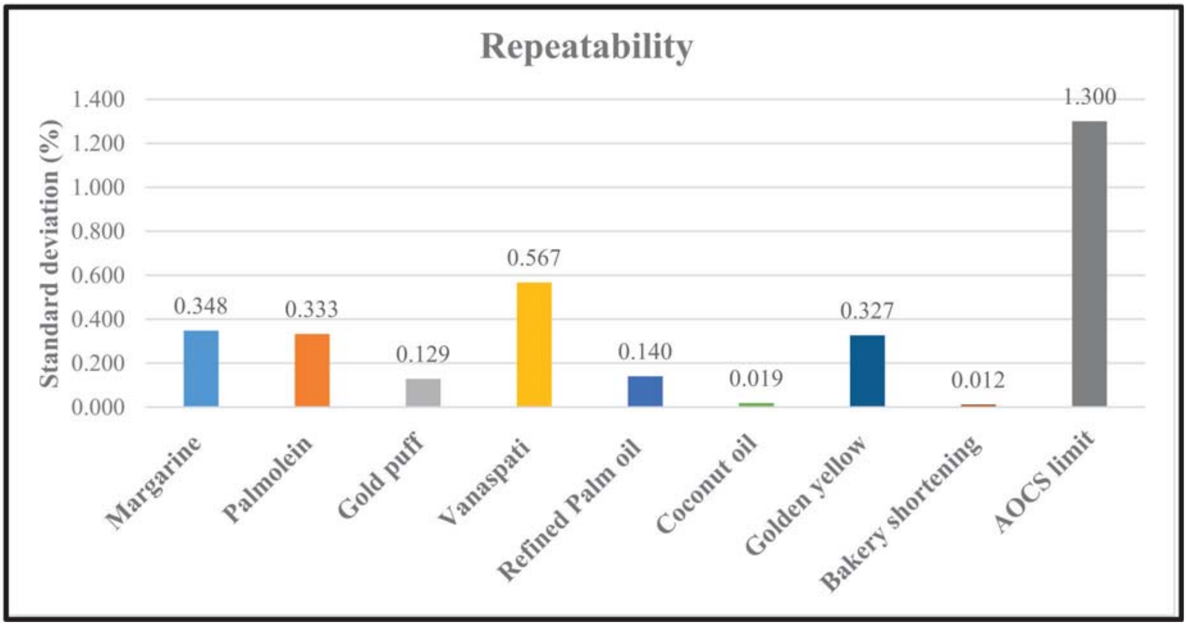


Figure 3: Standard deviation of repeatability measurement in different samples and AOCS repeatability limit.

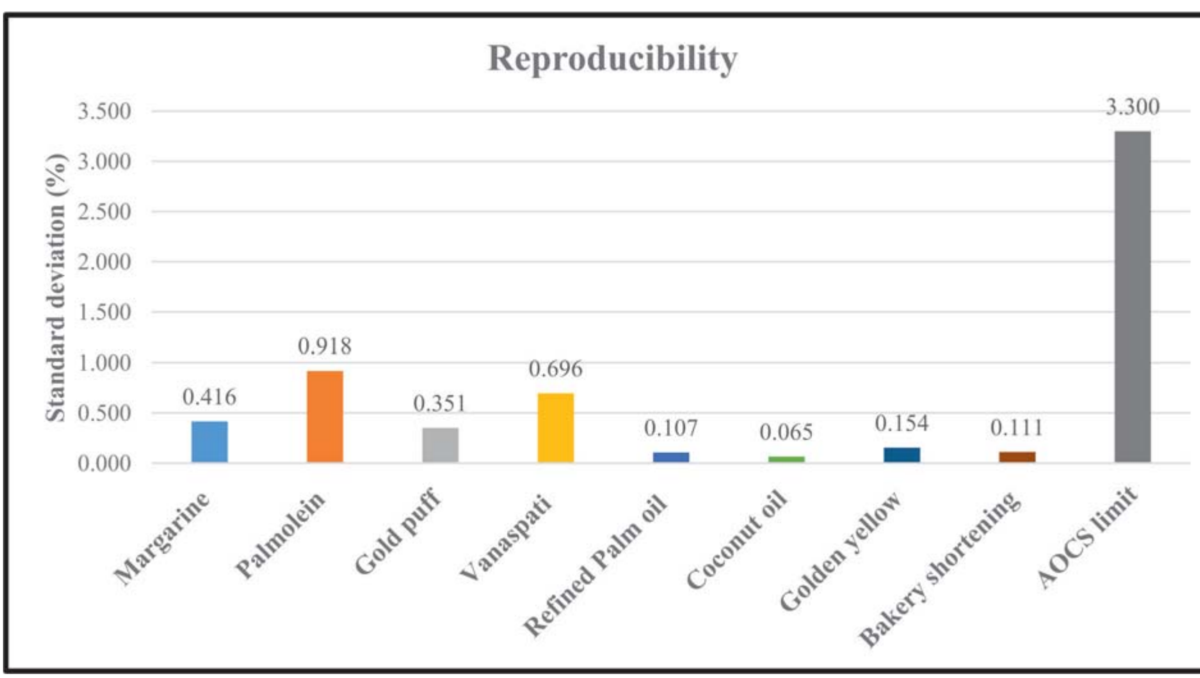


Figure 4: Standard deviation of reproducibility measurement in different samples and AOCS reproducibility limit.

Conclusion

On the basis of previous and current work, it can be concluded that the SFC measurement in oils and fats by direct NMR method provides efficient, accurate and precise measurement. This method is advantageous due to its quick analysis time, minimal sample preparation requirements, and non-destructive nature, making it particularly useful in both research and industrial contexts. Standard deviation of all measurements performed by direct method were very small from the traditional methods (dilatometry method) which highlights its better performance and reliability. Assessment of SFC within the limit for various oil and fats samples makes the method robust and suitable for wide range of food products. Overall, the direct method (NMR) marks a significant improvement in SFC analysis, offering a more efficient and accurate tool for lipid research and application.

References

1. AOAC Official Method Cd 16b 93, Solid Fat Content (SFC) by Low-Resolution Nuclear Magnetic Resonance, Direct Method (2017).
2. Martini, S., C. Bertoli, M.L. Herrera, I. Neeson, and A.G. Marangoni, In situ monitoring of solid fat content by means of pulsed nuclear magnetic resonance spectroscopy and ultra sonics, J. Am. Oil Chem. Soc. 82, 305–312 (2005).
3. Price, W. S. pulsed-field gradient nuclear magnetic resonance as a tool for studying translational diffusion: Part 1. Basic theory. Concepts in magnetic resonance, 9, 299–336 (1997).
4. Slichter, C. P. principles of magnetic resonance. Springer series in solid-state sciences: 1. Springer-Verlag (1989).

Following studies demonstrate the broad impact of oils and fats research on health, sustainability, and food technology, underscoring the potential for further innovation in lipid science:

1. Oleogels as Trans-Fat Alternatives in Food Products

Research on oleogels has shown promising results as a sustainable replacement for trans and saturated fats in food processing. Oleogels are created by structuring liquid oils with gelling agents like waxes, which mimic the texture and mouthfeel of solid fats. A study published in *Food Hydrocolloids* reported that oleogels made with sunflower oil and rice bran wax displayed ideal stability and sensory properties suitable for applications in bakery and spreads (Patel et al., 2023). This formulation approach aligns with the growing demand for healthier food fats and may reduce reliance on hydrogenated oils (Co et al., 2023).

2. Lipidomic Profiling in Olive Oil Authentication

Lipidomics is increasingly utilized to detect olive oil adulteration, addressing a major quality control concern in the industry. Using advanced mass spectrometry techniques, researchers have been able to distinguish olive oil from adulterants by identifying specific lipid profiles unique to pure olive oil. According to a recent study in *Journal of Agricultural and Food Chemistry*, triglyceride and phospholipid compositions were highly effective markers for identifying pure olive oil (Almeida et al., 2023). This development provides a robust tool for quality assurance, helping protect consumers and legitimate producers from fraudulent practices (Smith et al., 2023).

3. Enhancements in Enzyme-Assisted Oil Extraction

Enzyme-assisted extraction (EAE) has emerged as an eco-friendly alternative to traditional solvent-based oil extraction. A recent publication in *Biotechnology Advances* highlighted the efficiency of enzymes such as cellulase and pectinase in increasing oil yield and preserving bioactive compounds in sunflower and rapeseed oils (Zhang et al., 2023). EAE minimizes solvent use, aligns with green chemistry principles, and can extract oils with higher nutritional value due to the retention of antioxidants and vitamins (Mishra et al., 2023). This method shows potential for becoming a standard in sustainable oil extraction.

4. Structured Lipids for Nutritional Tailoring

The use of structured lipids, which are specifically engineered to contain beneficial fatty acids like omega-3s, offers opportunities for personalized nutrition. A recent study in *Lipids in Health and Disease* demonstrated that modified triglycerides could enhance digestion and potentially deliver health benefits in clinical nutrition, such as improving cognitive health and reducing inflammation (Gomez et al., 2023). This research suggests that structured lipids could be a powerful component in functional foods aimed at specific health outcomes (Lee et al., 2023).

5. Omega-3 Fatty Acids in Immune Modulation

Omega-3 fatty acids are well-known for their anti-inflammatory effects, but recent studies indicate they may also play a role in immune modulation. A publication in *Frontiers in Immunology* detailed how EPA and DHA, two key omega-3 fatty acids, reduce pro-inflammatory cytokine levels, which can benefit patients with autoimmune and inflammatory disorders (Nguyen et al., 2023). Further research in *Journal of Lipid Research* supported these findings, suggesting potential dietary recommendations for immune support based on omega-3 intake (Ramirez et al., 2023).

Dr HB Singh
Editor-in-Chief, JLST

Eyeing alternatives – meat companies with stakes in meat-free and cell-based meat (Andy Coyne has presented a guide on how meat manufacturers are investing in plant-based and cell-based alternatives, August 30, 2024, published in ***Just Food***)

The rise of plant-based products and the arrival of cell-cultured options as meat alternatives are trends very much on the radar of the world's largest meat companies. Here we look at what those businesses are doing to make sure they are not missing out on alternative protein solutions.

Tönnies Group

Tönnies Group is one of the largest meat processors in Germany, offering pork, beef, and convenience products. Set up in 1971, the family-owned company's "core business" centres on the slaughter, butchering, processing, and refining of pigs, sows and cattle. In 2022, the group's turnover stood at •6.82bn, with its workforce at 15,200 worldwide. However, Tönnies has interests in meat alternatives, with its Zur Mühlen Gruppe subsidiary active in the sector. Zur Mühlen Gruppe, home to meat brands including Böklunder and Eberswalder, also markets meat-free products under brands including Vevia 4 You and a meat brand, Gutfried. In 2024, the company announced it had invested in Nosh, a Berlin-based ingredients firm. Nosh uses fermentation to make non-GMO fungi to use as an ingredient in meat analogues and alternative-seafood products. The company says the ingredient can also be used in bakery, dairy, confectionery, and pet food.

JBS

The Brazil-based meat titan has had an up-and-down record in alternatives to conventional meat. In the spring of 2019, JBS, the world's largest beef processor, unveiled a plant-based version of a burger for the first time. JBS launched the vegan product under one of its flagship Brazilian brands, Seara. The company said the Incrível Burger Seara Gourmet burger contained soy, beets, wheat, garlic and onion. In March 2020, JBS announced it would launch plant-based protein brand Ozo in the US via a new subsidiary, Planterra Foods. Burgers were among the products to be rolled out. However, two-and-a-half years later, the company announced it was to close Planterra and "focus its efforts on its plant-based operations in Brazil and Europe, which continue to gain market share and expand their respective customer bases". In Europe, JBS is present in plant-based meat through its ownership of Dutch business Vivera, which it acquired in 2021. In November of that year, JBS announced it taken a stake in Spain-based cultivated meat firm BioTech Foods. JBS announced in September 2023 that it had started construction work on an R&D site that will develop cell-based protein, marking its latest investment in the early-stage industry.

Tyson Foods

The US meat giant, one of the largest companies in the sector, has perhaps done more than any of its rivals to position itself in alternatives to its core product. Tyson Foods previously invested in US plant-based burger firm **Beyond Meat** and has backed two lab-based meat firms – **Memphis Meats** from the US and **Future Meat Technologies**. In May 2018, it co-led a US$2.2m seed investment round in the Israeli firm through its Tyson Ventures arm. It described the target of its investment as a "ground-breaking start-up developing affordable, non-GMO technology for cultured meat production". Future Meat Technologies is a Jerusalem-based biotechnology company advancing a distributive manufacturing platform for cost-efficient, non-GMO production of meat directly from animal cells, without the need to raise or harvest animals.

The investment built on its previously taking a minority stake in US-based Memphis Meats, again through its Tyson Ventures arm. Memphis Meats, based in the San Francisco Bay area and since renamed Upside Foods, said it planned to use the new funds to accelerate product development. In April 2019, it emerged Tyson had exited its investment in US firm Beyond Meat, ahead of the Beyond Burger maker's IPO. In June that year, Tyson launched a brand – Raised & Rooted – in the US, under which plant-based products and so-called 'blended' food (containing meat and plant ingredients) were sold. By the autumn of 2020, the company rolled out the brand to Europe, targeting the foodservice market.

In December 2020, Tyson announced it was making changes to the Raised & Rooted plant-based range it sells in the US – including pulling the hybrid burger on offer since the brand's launch last year. Tyson started 2021 with the unveiling of plant-based breakfast patties under its Jimmy Dean brand, products it said would help meet demand for meat-free options at breakfast. In June of that year, the company continued its push into meat alternatives launched its first plant-based meat brand in Asia.

Marfrig

Another Brazil-based meat major, **Marfrig**, announced in August 2019 plans to enter the plant-based category in an exclusive tie-up with **Archer Daniels Midland**. ADM produces the base raw materials while Marfrig manufactures and sells the end products. Marfrig's meat-free burgers – sold under the Revolution brand – launched in December 2019 and since then they have largely been targeted at the foodservice market where they are sold by the likes of fast-food giant Burger King and local chain Outback Steakhouse, which brands its meat-free offering the Aussie Plant Burger and sells it for around US$8. In November 2021, the Marfrig-ADM venture, Plant Plus Foods, announced a pair of acquisitions in the sector. The JV snapped up Sol Cuisine in Canada and Chicago-based Hilary's for a joint consideration of US$140m.

BRF

Another Brazil-based meat giant has invested in alternatives to the conventional industry. In the plant-based area, BRF markets products under its Sadia Veg & Tal brand, while the company has a contract with **Aleph Farms**, an Israel-based start-up focusing on cell-cultured meat. Their tie-up, announced in March 2021, will see the companies work together on developing cell-based meat for sale in Brazil. "BRF is ready and charged to play a leading role in this food revolution and be an active participant in one the greatest industry transformations of this generation," Lorival Luz, the CEO of BRF, said at the time. In July 2021, BRF invested in Aleph Farms as part of a US$105m funding round. Its contribution was $2.5m.

Cargill

US agri-food giant Cargill has also backed 'clean' meat company **Memphis Meats**. In August 2017, Cargill joined a wide group of investors including Microsoft founder Bill Gates and Virgin founder Richard Branson in a Series A fundraising round in the business, which has since been renamed Upside Foods. "Our goal is to provide a complete basket of goods to our customers. We will do this by growing our traditional protein business, entering into new proteins and investing in innovative alternatives," Brian Sikes, group leader of Cargill's protein business, said at the time. Cargill has continued to invest in conventional meat products but, alongside building that side of its business, has backed others offering alternatives. In May 2019, it was announced Cargill had also become an investor in **Aleph Farms**. In February 2020, Cargill announced it would launch its own meat-free patties and ground products aimed at the private-label and foodservice channels.

Smithfield Foods

In August 2019, the US meat major, owned by China's WH Group, launched its own meat-free range. Smithfield Foods rolled out meat alternatives in the form of breakfast patties, 'meatballs', burgers and starters, all marketed under the Pure Farmland brand. The line-up from Smithfield covered eight soy-based products made with natural ingredients and are dairy and gluten free. Pure Farmland products were set to hit the fresh, refrigerated sections of grocery retailers in the US in mid-September 2019.

Maple Leaf Foods

Canada's Maple Leaf Foods has also been busy in meat alternatives. In February 2017, it moved to acquire US plant-based protein manufacturer **Lightlife Foods** from private-equity firm Brynwood Partners for US$140m. Announcing the deal, Maple Leaf claimed the acquisition establishes it as a "leader" in the US plant-based protein category through the Lightlife brand, which offers refrigerated products such as plant-based hot dogs, breakfast foods and burgers. And it built on this in December 2017 when it entered an agreement to buy US-based **Field Roast Grain Meat Co.** for US$120m. Seattle-based Field Roast supplies grain-based meat and vegan cheese products to the North American market. Its range includes sausages, frankfurters, burgers and deli slices.

In 2018, Maple Leaf created Greenleaf Foods, a new division to head the acquired Lightlife and Field Roast Grain Meat assets. In 2020, through Greenleaf, Maple Leaf invested in **Gathered Foods**, the US company behind the plant-based seafood brand Good Catch. However, by 2021, the company was warning about the level of sales seen in the wider category. In November that year, Maple Leaf announced a review of its plant-protein business after a third quarter of declining sales. Three months later, the group said it would "recalibrate" its investment in the division to "align with the market opportunity". It added: "The [financial] results to date confirm that the very high category growth rates previously predicted by many industry experts are unlikely to be achieved given current customer feedback, experience, buy rates and household penetration." In 2022, Maple Leaf emerged as an investor in **Evolved Foods**, a Canada-based outfit developing cell-cultivated meat. Previously trading as CaroMeats, Evolved Meats announced it had raised CAD2m (US$1.5m) in seed funding, with Big Idea Ventures, an alternative-protein venture fund and accelerator that has invested in plant-based and cell-cultured protein start-ups, joining Maple Leaf in the round.

In February 2024, Maple Leaf revealed it is to merge its meat and plant-based protein businesses after breaking even in its meat-free division. It revealed the reorganisation alongside its full-year results for 2023, when, in the fourth quarter, it achieved its goal from 2022 "to deliver neutral, or better, adjusted EBITDA within the next 18 months" in its plant protein division. Sales from the division, however, fell in the fourth quarter and for the year as a whole.

OSI Group

The US-based meat supplier – with more than 60 facilities across 17 countries – announced in July 2019 a deal to produce the Impossible Burger, the flagship product of another Californian plant-based upstart, **Impossible Foods**. The contract added capacity to Impossible's own plant in Oakland, California. It came as Impossible claimed it had seen "unprecedented demand" for the burger, which made its debut in selected restaurants in 2016.

Sigma Alimentos

Further south in Mexico, **Sigma Alimentos**, one of the country's largest suppliers of meat and dairy products, has invested in plant-based meat alternatives. In 2021, the company announced it had acquired a minority stake in **The Live Green Co.** (TLGC), a Chile-based supplier of plant-based meat and dairy products. Sigma described TLGC as "one of the most exciting plant-based start-ups in Latin America". The Santiago-based firm, set up in 2018, has a product range that includes plant-based burger and pancake mixes, as well as ice cream. The company has also made moves in plant-based meat via its Spain-based business **Campofrio Food Group**.

Nestlé

The world's largest food maker, which owns a minority stake in European meats business Herta and buys in meat for a variety of ready meals and convenience-food products, has a growing presence in the market for meat alternatives. In September 2017, the company entered the US market for plant-based food with the acquisition of Sweet Earth.

In Europe, Nestlé's has made a series of moves to try to tap into growing demand for plant-based alternatives to meat. In the spring of 2018, the company launched the Garden Gourmet brand in the UK but, by April 2019, had confirmed the product was no longer on sale in that market. April 2019 also saw Nestlé launch the Incredible Burger under the Garden Gourmet brand in select European markets.

In June 2020, Nestlé lost a trademark spat with US plant-based burger maker Impossible Foods and was forced to drop the Incredible Burger name, adopting the designation of the Sensational Burger instead. In Australia, the Swiss giant markets its plant-based meat products under the name Harvest Gourmet, which was launched in that market in 2019.

The Harvest Gourmet brand was launched in China in the autumn of 2020. In July 2021, Nestlé confirmed it was "evaluating innovative technologies to produce cultured meat or cultured-meat ingredients with several external partners and start-ups". Nestlé said an example was its work with Israeli cell-based meat start-up **Future Meat Technologies**. The company said it was partnering with Future Meat Technologies to "explore the potential of cultured-meat components that do not compromise on taste or sustainability". Four months later, the company took part in the seed funding of **Sundial Foods**, a US start-up developing a vegan alternative to chicken wings.

Campofrio

Campofrio announced its first move into the plant-based protein category in June 2020. The move came three years after it launched its Campofrío Vegalia unit with the aim of "responding to the needs of the vegetarian or flexitarian consumer". The Madrid-based company launched a vegan burger made with ingredients including soy and pea vegetable protein, mushrooms and sunflower oil. Magic Burger is made at the Campofrío Frescos plant in Burgos.

Thomas Foods International (TFI)

In April 2022, the Australia-based meat and seafood processor, which serves retail customers worldwide, announced it had joined a project to develop a plant-based protein and foods hub in the country. **Thomas Foods International (TFI)**, a processor of lamb, mutton, beef, goat and seafood, will build meat-alternative and plant-based extraction facilities in Australia. At the time, Darren Thomas, TFI's managing director, said in a statement: "For Thomas Foods International, we see plant-based protein as a natural complement to our traditional product offering and allows us to reach new markets and customers. "The market for plant-based products is also expanding rapidly and we see great opportunity to leverage our experience and expertise into this exciting new opportunity for local farmers and consumers across the globe."

Unilever

The owner of the Unox meats brand made a splash in alt-meat in 2018 with the acquisition of Netherlands-based **The Vegetarian Butcher**. Unilever's sales of plant-based meat and dairy products (also including ice cream) were circa EUR200m in 2019. In November 2020, the FMCG giant announced a target of generating annual sales of meat- and dairy-alternative of EUR1bn in the next "five to seven years". Announcing the target, Unilever said it had grown The Vegetarian Butcher's presence to "more than 20,000 points of sale in 30 countries".

In May 2021, Unilever announced a "partnership" with UK-based Enough, which produces the Abunda myco-protein using a zero-waste fermentation process where natural fungi are fed with renewable feedstock, such as wheat and corn.

Fleury Michon

In 2023, France-based charcuterie supplier **Fleury Michon** entered the plant-based meat sector through a partnership with Planted, a Swiss specialist. The two companies launched a range of mince-type products in France. They secured listings at retailers including Carrefour, Intermarché and Casino.

Noel Alimentaria

The company, a major name in Spain's meat industry, has made a foray into the market for meat-free products. The family-owned business launched its first meat-alternative items, a substitute for a veal burger, in 2019. In the summer of 2020, **Noel Alimentaria** announced the development of more products, all sold under the Nature sub-brand.

HKScan

The Nordic meat processor's presence in meat-free includes the manufacturing and marketing of meat-free products under its Pärsons brand in Sweden in 2016. In November 2019, the company teamed up with **Hes-Pro (Finland)** to develop plant-based protein products, with the first foods from that partnership launched the following autumn under the HK Vihreät brand.

In May 2020, **HKScan** expanded further into the plant-based market with a joint venture with Finland-based private bakery business **Leivon Leipomo**. Six months later, the group inked a deal to sell **Apetit's** plant-based products in the Swedish foodservice channel, with distribution starting in February 2021. That same month, HKScan said it wanted to continue to build its presence in the market for plant-based alternatives.

Speaking to *Just Food*, Tero Hemmilä, HKScan's Chief executive, said he had seen the growth in the plant-based meat category "slow" during the Covid-19 pandemic but added that he expects interest to rise again once the dust settles on the virus.

Bell Food Group

European packaged meats supplier **Bell Food Group** is another to have invested in lab-grown meat. In July 2018, the convenience food supplier invested EUR2m (US$2.4m) in **Mosa Meat**, a cultured-beef start-up based in the Netherlands. "The objective of the upcoming development phase is to successfully bring cultured beef to market by 2021," Bell said. "The Bell Food Group supports the development and research work [at Mosa Meat] with its expertise and know-how as one of the leading producers of meat and charcuterie products in Europe." Mosa Meat also attracted investment from M Ventures, the corporate venture capital arm of science and technology company Merck. Bell has invested further in Mosa Meat since, most recently in July 2020. The company also has plant-based meat alternatives in its product range. Bell sells products in Switzerland and Germany, marketing plant-based options under its The Green Mountain brand.

Hilton Food Group

In October 2018, the UK-based meat processor Hilton Food Group struck a deal to buy 50% of **Dalco Food**, a supplier of vegetarian products in the Netherlands. The transaction, agreed for an undisclosed sum, gives Hilton an option to buy the rest of Dalco Food in 2024. According to the Dalco Food website, the company started life as a butcher's shop in the centre of Oss, a city in the east of the Netherlands, in 1975. Dalco Food's product line includes meat substitutes such as vegetarian burgers. It also includes products like chicken nuggets and meatballs. The business' customer base takes in retailers on a private-label basis, the foodservice channel and food manufacturers.

In September 2023, Hilton announced it was consolidating its factory operations for meat-alternatives as a proactive measure against the "market restructure" in the category. It said it planned to close its Dutch facility in the city of Oss and move production of meat-free sausages, chicken and burgers – marketed internationally – to Hilton's remaining site in the country based at Oosterhout.

In April 2024, CEO Steve Murrells told *Just Food*: "We remain a fan of that sector. It remains an important market for our partners around the world. "Two of the reasons why I think there's a global resetting in this marketplace was around how do we make it more affordable for more people and how do we improve the experience around taste and flavour." Hilton Food has now "started to rightsize the business", he said.

Rastelli Foods Group

In the autumn of 2019, US-based meat and seafood supplier **Rastelli Foods Group** was signed up by **Moving Mountains** as the UK-based meat-free business' importer and "key distributor" in the country. At the end of the year, Rastelli Foods Group also agreed to act as US distributor for UK meat-free start-up **Daring Foods**. In February 2020, Daring Foods is also planning to launch a direct-to-consumer service in the US in February supported by Rastelli Foods.

Izico Food Group

In November 2017, Dutch frozen snack company **Izico Food Group**, which includes chicken skewers, mini burgers and meat croquettes in its range, added to its business in the UK with the acquisition of vegetarian foods supplier **Goodlife Foods**. Goodlife's range includes vegetarian sausages and burgers supplied to the retail and foodservice channels. Izico, which manufactures branded and private-label frozen food products, also has its own range of vegetarian and vegan products. It said the "addition of Goodlife confirms the organisation's strategy to develop their UK business going forward and to cement their position as a leading supplier in their chosen categories".

PHW-Gruppe

The company, one of Europe's largest poultry processors, has made – or been involved in – a number of investments in businesses offering meat alternatives. In January 2018, PHW formed a strategic partnership with Israeli 'clean meat' business **SuperMeat**. It provided financing that will enable the Tel Aviv-based, bio-tech start-up to bring its "clean-chicken products" to market. SuperMeat produces meat by growing cells extracted from chickens. The cells are then grown in conditions that allow them to thrive, forming poultry cuts. SuperMeat said of its business: "This process puts an end to the industrial need to mass produce animals for slaughter, while eliminating exposure to animal waste and food-borne illnesses; the potential benefits for public health and animal welfare are therefore considerable."

In September 2019, PHW was part of a consortium investing in Israel-based 3D printer alternative meat producing firm **Redefine Meat**. In February 2020, **Foods United**, a US-based business set up to invest in the plant-based market, bought a majority stake in German vegan business **LikeMeat**. PHW-Gruppe owns a minority stake in Foods United. A month later, Foods United was renamed **The LiveKindly Collective** after acquiring plant-based digital media platform, LiveKindly Media. The LiveKindly Collective also has South Africa-based business **The Fry Family Food Co.** in its portfolio, as well as the Nordic brand **Oumph**, which was acquired from Sweden's Food for Progress in the summer of 2020.

In 2021, The Livekindly Collective snapped up **No Meat**, the branded alternative-protein line owned by UK frozen-food retailer Iceland Foods. The same year, the company also bought Amsterdam-based **The Dutch Weed Burger**, which makes alt-meat products from seaweed. In October 2020, meanwhile, PHW launched its own vegan brand, Green Legend.

RCL Foods

Another investor in The Livekindly Collective is South Africa's **RCL Foods**, a major local supplier of poultry products. RCL, the owner of the Rainbow chicken brand, invested in The Livekindly Collective in January 2020, acquiring a minority shareholding. Terms have not been disclosed. A year later, RCL and The Livekindly Collective announced the formation of a joint venture to market the latter's products in South Africa and elsewhere in sub-Saharan Africa. The venture, Livekindly Collective Africa, was launched in May 2021 and is markets the US firm's brands, including Fry's, Oumph and Like Meat, in the region.

Nortura

Norway's **Nortura** is among those meat companies to have launched their own ranges of meat-free products. In 2017, Nortura launched a line of vegetarian alternatives to meat called MEATish. The line included MEATish bowls, nuggets, bites and burgers. It is made from GMO-free soybeans and Norwegian eggs. The company said the products have "equivalent or higher" protein and less saturated fat than meat options. Nortura said at the time it is one of "several" vegetable-based projects it is working on.

Wiesenhof

In 2015, German meat processor **Wiesenhof** continued its push into meat-free with the launch of two vegan products. The company, which already sold vegetarian lines under its Paul's Veggie brand, introduced a vegan sausage and a vegan mortadella – an Italian sausage. The products are made with pea and soy protein. Wiesenhof pointed to data from the Vegetarierbund, Germany's vegetarian association, that it said showed 10% of German consumers are vegetarians.

Finnebrogue Artisan

In early 2019, the sausage, bacon and ham supplier, based in Northern Ireland, opened a new facility to make vegetarian and vegan products. Announcing the investment, managing director Brian McMonagle said: "We are determined not to stand still and are always looking to make food the best it can possibly be, without being bound by the way it's always been done. "More and more people are switching to a vegan or vegetarian diet – and even meat eaters are increasingly seeking a day or two off a week." In May 2020 it launched a new plant-based range, consisting of Naked 'made without the moo' burgers, meatballs and mince products and Naked 'made without the oink' sausages.

The Black Farmer

In April 2018, **The Black Farmer**, a UK food business best known for sausages and other meat products, launched The Hatchery, a collaborative incubator for food entrepreneurs. The first cohort was made up of three businesses, one of which is London-based Planet Jason which makes vegan burgers and sausages. meatless mince and chicken-type products.

ABP Food Group

Ireland-based meat processor **ABP Food Group** announced it was moving into the plant-based arena in February 2019. The County Louth business launched its first fresh plant-based, meat-free brand for distribution in the UK. Its brand is called Equals and is being sold through major UK retailers including Asda. The company said the move was part of its "multi-million pound" investment in branded and ready-to-cook meat and meat-free products which complement its core processing business. Equals' launch product was a pack of two meat-free quarterpounder burgers, made from a mix of seasoned pea and soy proteins.

The brand was delisted and, in 2021, ABP launched another brand, Dopsu, in the UK. ABP rolled out a range of frozen products under the Dopsu brand, which was a portmanteau of the words doppelganger and substitute.

Danish Crown

In August 2019, Denmark-based co-op **Danish Crown** announced it was to launch plant-based products. The company said it would be ready to introduce plant-based alternatives to beef burgers before the end of the year. Finn Klostermann, CEO of Danish Crown Beef, said: "Danish Crown Beef already has several hybrid products composed of minced beef and root vegetables in the chilled cabinets, they will soon be joined by products made entirely of plants. Before the end of the year a plant-based burger will be a part of our product range." Klostermann said the co-op was responding to consumer demand. In autumn 2020, Danish Crown confirmed it had acquired a stake in a local business making steak products targeted at flexitarians and vegetarians. The company invested in **INFoods**, a new business set up by the founders of DK-Foods, the Danish pepperoni manufacturer Danish Crown acquired in 2018.

Hormel Foods

US-based **Hormel Foods** launched a meat alternative brand in the shape of Happy Little Plants in September 2019. The Austin, Minnesota-based branded food company – behind products such as Skippy, Spam and Applegate – announced the launch at the Barclays Global Consumer Staples Conference in Boston. It said the initiative, mooted back in June, is the first project under its Cultivated Foods umbrella. It had previously launched blended meat and vegetable products.

Vion Food Group

Netherlands-based meat business **Vion Food Group** announced in October 2019 it was to establish an arm manufacturing plant-based meat alternatives. ME-AT was to provide products on a private label basis to retailers, most likely in its home market and in Germany.

There were no plans to bring out branded products using the ME-AT label. Vion did not disclose which proteins will be used in its five planned products.

Kepak Group

Ireland's **Kepak** is another company to seek to tap into the interest in vegetarian brands. In January 2020, Kepak announced it was rolling out a vegetarian product under its ready-to-cook burger brand Rustlers. The Rustlers Moroccan Vegetarian Burger – which had a recommended retail price of GBP2 (US$2.60 at the prevailing exchange rate) – is made with chickpeas, carrot and coriander. Every Rustlers comes with a sachet of sauce and the veggie product is sold with mango chutney and a yogurt-and-mint sauce. In October 2021, Kepak launched a product it described as a "meat mimicking" burger. Made with pea protein and launched under the company's Rustlers brand, the Meatless Maverick burger was launched at Tesco stores and at the retailer's One Stop and Booker outlets. "The meat-free movement has rapidly accelerated growth of the category, which is being driven by flexitarians as consumers seek more balance in their diets," Adrian Lawlor, Kepak's chief marketing officer, said at the time. "It's important for a brand like Rustlers which has built its success on meeting clear consumer needs to recognise this trend and provide solutions to meet it. For meat reducers, Meatless Maverick provides an easy swap while behaviourally fitting existing habits, therefore requiring less of a conscious shift."

NH Foods

In the spring of 2020, the Japanese group, home to businesses including Nippon Ham, was announced as among a group of investors taking part in a Series A round of funding in **IntegriCulture**, a Japanese firm developing cell-based foods. A spokesperson for **NH Foods** told just-food at the time: "By strengthening the collaboration through this investment, we will accelerate technological research for the realisation of clean meat and verification of future business possibilities. IntegriCulture is a start-up company that has useful technology in developing clean meat and is actively taking on the challenge of market creation." IntegriCulture's key aims are to bring cell-based foie gras to market in 2021 and processed meat in 2023. It hopes to then start marketing cell-based beef in 2025.

Hanegal

The Danish manufacturer, which sells a range of meat products, also offers organic, meat-free meals and, in 2020, stepped up its presence in the market for meat alternatives by acquiring local plant-based ready-meals manufacturer **Fairdig**. Cees Kuypers, the commercial director and co-owner of **Hanegal**, said at the time: "The acquisition is strategically important to us as we thereby strengthen our position in plant-based ready meals. The acquisition gives us a good starting point for further expansion – and especially in the frozen category and in export markets where Lise-Lotte has extensive experience."

Scandi Standard

The Nordic chicken group, formed in 2013 by private-equity house CapVest through the combination of processors Kronfågel and Cardinal Foods, owns poultry brands across western Europe. In the autumn of 2020, **Scandi Standard** announced a plan to work with local food-development firm Veg of Lund in R&D projects centring on plant-based protein.

Century Pacific Food

Century Pacific Food, a meat and seafood products manufacturer in the Philippines, moved into alt-meat in 2020. The publicly-listed business started off with plant-based burgers, which were rolled out in the company's foodservice operation – Shakey's Pizza Asia Ventures – in October. Century Pacific then launched a brand, UnMeat, into the country's retail sector.

Charoen Pokphand Foods

In May 2021, the Thailand-based pork and poultry heavyweight unveiled plant-based brand Meat Zero and announced an ambition for it to become a top-three alt-meat brand globally within five years. On its way to that goal, Charoen Pokphand Foods wants the brand to be the top alternative meat brand in Asia "within 2022". Five months later, CPF announced the acquisition of 50% of Poland-based Well Well, which manufactures a range of plant-based meat substitutes.

Al Islami Foods

Middle East manufacturer **Al Islami Foods** made its meat-free debut with the launch of a plant-based burger in January 2021. The United Arab Emirates-based company, one of the largest frozen food companies in the region, said it had launched the product in response to the growing appetite for healthier vegan options and in time for Veganuary, a global campaign that encourages people to try a plant-based diet in the New Year. Its burger is made using sunflower protein, fava beans and peas and is the first in a series of plant-based products that the company planned to roll out.

Jensen Meat Co.

In 2021, the California-based beef processor broke ground on a dedicated facility for meat alternatives due to be operational in April that year. The project came under a year after Gregg and Jeff Hamann, who have owned **Jensen Meat Co.** since 2011, acquired a controlling interest in local plant-based business Before the Butcher.

Van Loon Group

The Netherlands-based business, which is centred on meat and ready meals, has a presence in alt-meats. In 2019, the company launched meat-free brand The Blue Butcher, which sells into retail and foodservice. Two years later, **Van Loon** set up **The No Meat Today Company**, a dedicated meat-free arm, to try to expand its business in the meat-alternatives sector.

Country Archer Provisions

In August 2021, the US jerky firm Country Archer Provisions launched a plant-based option, made from oyster mushrooms. The jerky was rolled out in BBQ, teriyaki and spiced bacon variants. Country Archer Provisions, based in San Bernardino, California, is best known for its grass-fed beef jerky and meat sticks. The company suggested its plant-based line is a "clean-label snack that both flexitarians and vegetarians will love".

Harvest Road

Australian beef and seafood processor **Harvest Road** is a shareholder in **Proform Foods**, a local plant-based meat business. Harvest Road acquired its minority stake in Proform Foods in 2021. Based in Sydney, Proform Foods was set up in 2008 as an R&D business, providing protein ingredients. The company is still an ingredients supplier but has branched out into brands, selling the Meet range (stylised as 'MEET') of plant-based meat alternatives.

Baiada

Staying in Australia, another major local meat group that offers meat-alternatives is **Baiada**, the poultry processor. The company markets a range of products, including nuggets, kievs and tenders, under the Greens & Goodness brand. Baiada says it uses a pea-based protein for its meat alternatives for "an improved taste, flavour, texture and nutrition". The Greens & Goodness range comprises frozen and chilled products. Upon the launch of the frozen SKUs in July 2022, Baiada said: "According to the research of 2,000 Australian consumers conducted by Baiada, one-in-four households now include at least one vegetarian, vegan or meat reducer, representing nearly AUD26bn in household consumer spending. "While existing plant-based protein offerings focus on wellness, research suggests that consumers are looking for greater convenience and improved taste and texture from current plant-based offerings."

Orkla

In April 2021, Orkla, the Nordic food manufacturer, announced the launch of a new dedicated alt-protein division. And in November that year, it revealed it was expanding a factory in Sweden that produces plant-based meat alternatives. The company saaid it was spending SEK70m ($81.2m at the time) on its facility in the southern town of Eslöv to up its capacity to make foods sold under the Anamma, Frankful and Naturlí brands. As well as serving the Swedish market, the Eslöv site exports to other Nordic countries and the Baltic states. "We have had an incomparable development since 2015 when we started the vegan factory in Eslöv. The production volume is about seven times higher than five years ago," Erik Wendel, the manager of the Eslöv factory, said. But soon afterwards, it dialled back its plant-based M&A strategy, suggesting it will need to fast-track innovation to deliver on its category pledge.

1950-2023

Dr. Vijay Kale (Late)
Former Chief Scientist & Head
Lipid Science & Technology Division
CSIR-Indian Institute of Chemical Technology
Hyderabad – 500007, India

Dr Vijay Kale, Chemical Engineer by profession obtained his BTech, MTech and Ph.D from Osmania University. He joined the Lipid Science & Technology (then Oils & Fats) Division of CSIR-IICT (then RRL), Hyderabad in the year 1977 and retired from there in 2010 as Director Grade Scientist (Sci. G). He strongly believed in **“Concept to Commercialisation”** with this motto, he developed many processes from lab scale to pilot scale and finally to commercial scale.

Although India is the largest producer of castor oil, most of the castor derivatives are imported. During his tenure at IICT for first time in the country, he developed novel technologies or improved existing technologies for many castor oil derivatives, green technologies such as Enzymatic Degumming of Rice Bran Oil, Biodiesel from Non-edible oils, use of membrane in refining of vegetable oils and Synthetic Aviation Lubricants. The technologies at 50 tons per day of Enzymatic Degumming of Rice bran oil, Hydrogenated Castor Oil (HCO), 12-Hydroxy Stearic Acid (12-HSA) and and 2 tons per day of Undecenoic Acid (UDA) were successfully demonstrated and transferred to Industries.

In recognition of his research work he was conferred many prestigious Awards, notably among them are **- CSIR Technology Award (2005)** from Sri Somnath Chatterjee, the Honourable Speaker of Lok Sabha, **National Award for Technology Development Board (2009)** for Enzymatic Degumming Technology.

He was deputed to University of Illinois, USA to obtain ‘Hands on Application Training in Membrane field’ and was invited as a visiting Scientist by University of Saskatchewan, Canada.

He has published 25 research papers in National and International Journals and has 8 patents to his credit. He presented 10 research papers in International seminars and has delivered 23 Invited lectures organised by various Indian and International Organisations in USA, Canada, Malaysia and Singapore. He has guided several PhD, MTech and BTech Chemical Engineering students. During his tenure in IICT, he was member of many National Committees such as DBT, DST, Bureau of Indian Standards. He was a Life member of many professional bodies such as Telangana Academy of Sciences, Indian Science Congress, Association of Food Scientists and Technologists' India, Indian Catalysts' Society and Indian Society of Analytical Scientists, Indian Institute of Chemical Engineers (IIChE)

Dr Kale served as **Chairman** of IIChE, Hyderabad Regional Centre for 2 years, as **President** Oil Technologists' Association of India, South Zone for two consecutive terms.

Prabhavathi Devi

1938-2024

Dr Nori Krishnamurthy (Late)
Former Deputy Director & Head
Paints & Polymers Division
CSIR-Indian Institute of Chemical Technology
Hyderabad - 500007, India

Dr N Krishnamurthy, Polymer Chemist by profession and obtained his BSc (Hons), BSc (Tech), MSc (in Oils & Fats Technology) and PhD (Tech) from UDCT, Bombay University. He joined as Scientist B in Paints & Polymers Division of CSIR-IICT (then RRL), Hyderabad in April 1965 and retired from there in August 2000 as Deputy Director. He served IICT for > 35 years and developed >70 adhesives products of commercial importance and transferred to 70 industries all over the country. Many products which were developed during those days are still in the market and no substitutes were found yet in the market. These industries have generated an employment to more than 500 persons.

After his retirement from IICT, he served as consultant for Pidilite for 17 years and helped Pidilite to get turnover more than Rs 8000 crores. Because of his successful stint at Pidilite, this firm has sponsored three projects to IICT worth of Rs 55 lakhs. IICT also earned another Rs 35 lakhs by transfering the know-hows for octyl cyanoacrylates, neoprene based contact adhesive, rat trap adhesive etc., that were developed by him when he was in service.

He developed about 18 high tech adhesives for Agni, Aakash,Trishul and BrahMos missiles. Out of these 10 adhesives are now being manufactured commercially by Pidilite and supplying to RCI-DRDO on regular basis since 2011. He has received a certificate of appreciation from our Prime Minister Shri Narendra Modi in the year 2015 for developing an adhesive for Fiber Optic Gyro used to navigate an unmanned fighter aircraft.

In addition, he also served as consultant for RCI Missile centre, Ministry of Defence, at Hyderabad, Johnson and Johnson ltd., Aurangabad, Ex. RAC Chairman of Indian Institute of Natural Resins and Gums, Indian council of Agriculture Research, Ranchi, Jharkhand.

In recognition of his research work he was conferred many prestigious Awards, notably among them are - RGBV Swaika awards (1981,1991 & 1995), Hussain Zaheer award (1983) & JG Kane Memorial Award (2003) from OTAI in addition to IPA first prize (1982) and Life time Achievement Award from IICT in 2011.

He published more than 115 research papers in Polymers, paints and adhesives. He had more than 22 Patents, and one is world patent on adhesives used for communication devices. He guided 21 Ph.D students. He served as a member of several Research Advisory Committees for ILRI - Ranchi, IPI - Bangalore, BIS - New Delhi. He was a Life member of many professional bodies such as OTAI (SZ), Colour society, Biomaterials, Analytical Society and UDCT alumini and also served as **President**, OTAI-SZ. He gave UGC TV Educational programmes to popularize science for more than 180 min.

He was deputed as a visiting scientist to Sttutgart, Kaiserslatern and Erlangen universities in Germany and also visted Switzerland and USA.

Prabhavathi Devi

1939-2024

Shri Raghu Nandan Mody (Late)
Former Chairman, Rasoi Ltd.
Rasoi Court, 20 Sir RN Mukherjee Road,
Kolkata-700001, India

Raghu Nandan Mody and RASOI Vanaspati are synonymous. He was an outstanding human being who steered an industry to its heights. He was my boss, but our relationship was founded in deep mutual respect, and sustained over five decades with the bond of affection and friendship.

In the decades of 1970 and 1980, there were five vanaspati factories in Calcutta. All were proprietary concerns run directly by their respective owners. Mr. Mody commanded special respect from his peers. He was President of the VMA Eastern Zone, at least twice during this period when the vanaspati industry was at its peak.

My almost 30 year tenure at Rasoi began in 1973, and it has been an unforgettable experience. What I remember most of my professional relationship is Mr. Mody's poise in handling tricky situations, especially in West Bengal of those days, with its unforgiving labour situation. He always showed a sporting spirit in all his dealings, be it with the office staff or the workmen at the factory.

He understood the importance of collective action with peers, as well as in social outreach, and encouraged me in my activities with the Oil Technologists Association of India and the Rotary Club activities. It was at his insistence that I become a member of the American Oil Chemists Society (AOCS). It was the respect he commanded that resulted in the AOCS president visiting our factory, as did several distinguished scientists from India and abroad. His social contacts were enormous. I hold memories of his friends, including Farooq Abdullah and Dr. Karan Singh visiting our factory, and participating in various Rasoi events.

Raghu Mody's personal attachment to OTAI is a long saga. He was President of the Eastern Zone in 1977-1979. His encouragement and contributions resulted in the OTAI International Conference being held in Calcutta in 1998. It was a memorable event. He was President of the All India Body of OTAI in 2003, and closely associated with the conferences held in 2003 and 2008. He was also President of the ASSOCHAM and IVPA, in different periods.

Retirement was not for him. With the vanaspati industry moving into its twilight years, Mr. Mody seamlessly ventured into other industries, and successfully negotiated the acquisition of J.L. Morison and Hindustan Ferrodo Ltd. and ran them profitably.

He was a keen sportsman, with a special bias to golf. The sporting spirit in his day-to-day dealings possibly stemmed from his love for sport.

I remember Raghu Mody as a friend, an astute businessman and a kind human being. May His Soul Rest in Peace.

RS Vaidyanathan

Journal of lipid science and technology

Published by Oil Technologists' Association of India (OTAI)
ISSN 0973 - 6379

REGULAR ARTICLES

All portions of the manuscript must be typed **double-spaced** and all pages numbered starting from the title page. The **Title** should be a brief phrase describing the contents of the paper. The Title Page should include the authors' full names and affiliations, the name of the corresponding author along with phone, and E-mail information. Present addresses of authors should appear as a footnote.

The **Abstract** should be informative and completely self-explanatory, briefly present the topic, state the scope of the experiments, indicate significant data, and point out major findings and conclusions. The Abstract should be maximum 250-300 words in length. Complete sentences, active verbs, and the third person should be used, and the abstract should be written in the past tense. Standard nomenclature should be used, and abbreviations should be avoided. No literature should be cited.

Following the abstract, about 3 to 10 **key words,** that will provide indexing references, should be listed. A list of non- standard **Abbreviations** should be added. In general, non-standard abbreviations should be used only when the full term is very long and used often. Each abbreviation should be spelled out and introduced in parentheses the first time it is used in the text. Only recommended SI units should be used. Authors should use the solidus presentation (mg/ ml). Standard abbreviations (such as ATP and DNA) need not be defined.

The **Introduction** should provide a clear statement of the problem, the relevant literature on the subject, and the proposed approach or solution. It should be understandable to colleagues from a broad range of scientific disciplines.

Materials and methods should be complete enough to allow experiments to be reproduced. However, only truly new procedures should be described in detail; previously published procedures should be cited, and important modifications of published procedures should be mentioned briefly. Capitalize trade names and include the manufacturer's name and address. Subheadings should be used. Methods in general use need not be described in detail.

Results should be presented with clarity and precision. The results should be written in the past tense when describing findings in the authors' experiments. Previously published findings should be written in the present tense. Results should be explained, but largely without referring to the literature. Discussion, speculation and detailed interpretation of data should not be included in the Results but should be put into the Discussion section.

The **Discussion** should interpret the findings in view of the results obtained in this and in past studies on this topic. State the conclusions in a few sentences at the end of the paper. The Results and Discussion sections can include subheadings, and when appropriate, both sections can be combined.

The **Acknowledgments** of people, grants, funds, etc should be brief.

Tables should be kept to a minimum and be designed to be as simple as possible. Tables are to be typed double- spaced throughout, including headings and footnotes. Each table should be on a separate page, numbered consecutively in Arabic numerals and supplied with a heading and a legend. Tables should be self-explanatory without reference to the text. The details of the methods used in the experiments should preferably be described in the legend instead of in the text. The same data should not be presented in both table and graph form or repeated in the text.

Figure legends should be typed in numerical order on a separate sheet. Graphics should be prepared using applications capable of generating high resolution GIF, TIFF, JPEG or Powerpoint before pasting in the

Microsoft Word manuscript file. Tables should be prepared in Microsoft Word. Use Arabic numerals to designate figures and upper-case letters for their parts (Figure 1). Begin each legend with a title and include sufficient description so that the figure is understandable without reading the text of the manuscript. Information given in legends should not be repeated in the text.

References, in the text, a reference identified by means of an author‘s name should be followed by the date of the reference in parentheses. When there are more than two authors, only the first author‘s name should be mentioned, followed by ’*et al*‘. In the event that an author cited has had two or more works published during the same year, the reference, both in the text and in the reference list, should be identified by a lower case letter like ’a‘ and ’b‘ after the date to distinguish the works.

Examples:

Abayomi (2000), Agindotan *et al*. (2003), (Kelebeni, 1983), (Usman and Smith, 1992), (Chege, 1998; Chukwura, 1987a,b; Tijani, 1993,1995), (Kumasi *et al*., 2001) References should be listed at the end of the paper in alphabetical order. Articles in preparation or articles submitted for publication, unpublished observations, personal communications, etc. should not be included in the reference list but should only be mentioned in the article text (e.g., A. Kingori, University of Nairobi, Kenya, personal communication). Journal names are abbreviated according to Chemical Abstracts. Authors are fully responsible for the accuracy of the references.

Examples:

Ogunseitan OA (1998). Protein method for investigating mercuric reductase gene expression in aquatic environments. *Appl. Environ. Microbiol.*, 64: 695–702.

Gueye M, Ndoye I, Dianda M, Danso SKA and Dreyfus B (1997). Active N2 fixation in several *Faidherbia albida* provenances. *Ar. Soil Res. Rehabil.*, 11: 63-70.

Charnley AK (1992). Mechanisms of fungal pathogenesis in insects with particular reference to locusts. In: Lomer CJ, Prior C (eds) Biological Controls of Locusts and Grasshoppers: Proceedings of an international workshop held at Cotonou, Benin. Oxford: CAB International, pp 181-190.

Mundree SG and Farrant JM (2000). Some physiological and molecular insights into the mechanisms of desiccation tolerance in the resurrection plant *Xerophyta viscasa* Baker. In Cherry *et al*. (eds) Plant tolerance to abiotic stresses in Agriculture: Role of Genetic Engineering, Kluwer Academic Publishers, Netherlands, pp 201-222.

Membership, proofs, colour plate charges, mode of payment

Once a manuscript is accepted, the corresponding author and co-authors must sign the copyright form. One of the authors should be a life member of the OTAI (membership form attached).

Color plates will be charged extra @ Rs. 2,500 for India and US$ 100 per page for rest of the world. Besides, Rs. 500.00 will be charged per page of print manuscript as processing and handling charges. Mode of payment will be bank transfer in favor of OTAI - Publication Committee; Account no.: 048794600000653; IFSC Code: YESB0000487; Yes Bank Ltd, Branch: Phase 4, DLF Cross Point, DLF City, Gurugram.

After the journal is printed the corresponding author will receive a hard copy of ‘JLST’ for which please mention your complete postal address (residential/ professional) along with pin code and contact number for dispatching the journal.

Dr HB Singh
Editor-in-Chief
Journal of Lipid Science and Technology
Email: editorinchief-jlst@otai.org

Journal of lipid science and technology

Published by Oil Technologists' Association of India (OTAI)
ISSN 0973 - 6379

Dear researcher,

Journal of Lipid Science and Technology (JLST) is an open-access peer-reviewed 52 years old journal published by Oil Technologists of India.

JLST is a quarterly journal that accepts review articles, original research articles, short communications, case reports, and letters to the editor, and book reviews covering recent experimental findings pertinent to advancement in lipid science and technology. Our diversified editorial board provides rapid evaluation of submitted manuscripts without compromising on the scientific quality.

On behalf of the editorial team of JLST, we would like to invite manuscript submissions from authors across the journal's scope. The submitted manuscripts should not be either published or under consideration for publication elsewhere.

Accepted papers are published ahead of print in an accelerated online-only format for immediate visibility within the scientific community.

Each accepted manuscript is subjected to an article processing charge (APC) to meet the administrative publication expenses. The editorial board wants all authors to submit their manuscripts to JLST and supports authors who are unable to meet the entire APC.

You may submit your manuscript as per 'Instruction to Author' attached herewith through mail to the Editor-in-Chief.

For further information, please have a look at the journal's website http://www.otai.org/otai-journal/ and do not hesitate to contact us at our Editorial Office (editorinchief-jlst@otai.org).

We hope to receive your contributions soon.

Sincerely and with kind regards:

Editor-in-Chief

Aims and scope of JLST:

The Journal of Lipid Science and Technology (JLST) is a peer reviewed international journal that publishes research and review on oilseeds, oils & fats, and derivatives, such as, oleochemicals, soaps, detergents, lubricants, toiletries, and cosmetics. In addition to its full length and short papers on original research, the journal also covers regular feature articles, reviews, comments, scientific correspondence, etc. The journal's scope includes:

- Oils and fats, speciality oils and fats for specific industrial applications.
- Industrial shortenings, table margarine and cocoa butter substitutes.
- Wheat germ oil, corn oil and millet oils.
- Processed food including breakfast cereals.
- Dairy industry including cheese and its derivatives.
- Prepared meals, ready to eat meals (RTE) and ready to cook (RTC) meals.
- Beverages and energy drinks.
- Bakery products: biscuits, cookies, croissants, bagels, etc.
- Fresh foods, frozen foods, and dehydrated eatables.
- Essential oils products: balm, ointment, massage oils, pesticide formulations, etc.
- Home care products.
- Cosmetics and personal care products.
- Confectionary products.
- Savoury and snacks industry.
- Soap and detergents.
- Nutraceuticals and pharmaceuticals.
- Meat and meat products.
- Biodiesel and biofuel, lubricants, and greases.
- Waxes, lecithin, and other co-products.
- Dry fruits, nuts, and soaps.
- Modern analytical techniques.
- Quality and sustainable packaging.