LIPID UNIVERSE

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Tree-Borne Oilseed Cultivation: Research Gaps and Future Perspective Waste

Trade News

Important Figures

Physicochemical and Sensorial Properties of Chocolate Spread Substituted with Oleogel based on Palm Oil and Coconut Oil

Health News

Dill (*Anethum Graveolens Linn.*) Essential Oil

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Editor-in-chief desk.....



Dear Friends,

Welcome to the April-June 2026 issue of Lipid Universe. This issue looks at how the world's oils and fats are grown, traded, formulated and consumed, and what that means for India.

Our lead article reviews tree-borne oilseeds (TBOs), a resource India has not fully used. With about 67% of our vegetable oil consumption met through imports, domestic alternatives such as Mahua, Neem, Karanja, Simarouba and Jojoba deserve serious attention. The author points out that the real bottleneck is quality planting material, backed by seed testing and certification. India still has no legal framework for certifying forest tree germplasm. Without that foundation, large-scale TBO plantations will struggle to deliver.

The USDA figures in Important Figures show why these matters. World oilseed production for 2025/26 is estimated at 701 million tonnes and vegetable oil production at 240 million tonnes. India's vegetable oil imports are projected at about 16.75 million tonnes, the largest of any country.

Trade News is a reminder that markets respond to policy as much as to weather. U.S. soybean exports have rebounded strongly this year, but the article is right to call it a recovery from a weak base, as Brazil continues to gain ground. Other items cover the new ASTM D396-26a specification allowing biodiesel blends up to B50 in heating oil, Goodyear's use of soybean oil in tyres, and how AI-driven fermentation and certifications such as FSSC 22000, Halal and Informed Sport are redefining ingredient integrity. For those of us in testing, accreditation and quality assurance, these trends show that data, traceability and independent verification are now basic expectations of the supply chain.

On the technical side, the research paper on palm-coconut oleo gel as a partial fat replacement in chocolate spread is worth a careful read. Substituting 25% of the fat gave the best balance of sensory acceptance and physicochemical properties, while higher levels compromised spreadability. Health News adds a simple bleaching-earth treatment that keeps flaxseed oil from turning bitter, and the progress of cultured chocolate as cacao faces climate pressure. We also feature the chemistry and uses of dill essential oil, and a practical Members' Page piece on bone health.

I thank all our authors, the Editorial Board and our advertisers for their continued support. I also invite our members and readers to send us articles, research notes and industry updates, so that Lipid Universe remains a useful platform for the oils and fats community.

Warm regards,

Yours truly

C.S. Joshi

Editor-in-Chief, Lipid Universe

Editor-in-chief desk.....

Editor's desk.....



Dear Readers,

Why tree borne oil seeds (non- traditional oils) matter today ? Because India can not afford to divert edible oil crops (like soybean, groundnut or mustard) toward bio-diesel production. Non- edible TBOs such as neem, karanja, mahua, Jatropha provide an alternative raw materials for bio-diesel and industrial applications without cutting into the human food supply. As a result, unproductive land can be transformed into a productive bio- energy asset, thus creates rural employment and cash generation.

In the chocolate industry, fat plays an important role in the texture and structure of chocolate spread. Substituting the fat in the chocolate spread with a palm- coconut oleogel at an optimal level of 25% improves physical, textural and sensory characteristics; and balancing firmness and smooth mouth feel. This is due to the formation of the crystal behaviour predominantly governed by the stable beta- prime crystal polymorph.

The noteworthy issues in the trade and health news are - (a) why technology- driven validation is becoming the new standard for ingredient integrity - because it replaces slow, mannual paper trails and periodic lab tests with real- time, automated verification; (b) U.S. soybean exports in early 2026 jumped 27.09% year- over- year, rebounding from a sluggish 2025 mainly due to the China's share of U.S. soybean exports; (c) fresh flax seed oil tastes plesantly mild, but naturally occuring peptides called cyclolinopeptides cause it quickly develop bitter notes and spoil during storage. Using bleaching earth, a mineral based cleaning agent removes the peptides from flaxseed oil, eleminating bitter testing compounds while preserving its omega-3 fatty acid content and mild flavour.

Dill essential oil attracts the essential oil and wellness industries due to its rich active chemical profile, potent therapeutic (natural antibacterial and antifungal) properties, and wide ranging commercial uses in soaps, cosmetics and cleansing formulas.

Our Members' page speaks about how to improve our bone health and for this, we must combine targetted nutrition and top 3 vitamins and minerals like calcium, vitamin D and magnesium.

Concluding, this issue discussed the latest trends and innovations in the lipid research and trust our readers will find these insights interesting.

With Festival Greetings and Heartiest regards,

Dr. S. Adhikari
Editor

Editor's desk.....

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(North Zone)

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TREE-BORNE OILSEED CULTIVATION: RESEARCH GAPS AND FUTURE PERSPECTIVE

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ABSTRACT

Tree-borne oilseeds (TBOs) are emerging as a pivotal resource for sustainable oil production, biodiesel, and industrial applications, offering a promising alternative to conventional sources. However, despite their potential, TBOs face significant challenges that hinder their widespread adoption, primarily related to seed quality and availability. With the rising domestic demand for edible oils and energy, India's reliance on imports has become increasingly pronounced, emphasizing the need to explore and enhance alternative domestic sources such as TBOs. TBOs are distributed across various ecological zones, yet their scattered distribution, suboptimal collection practices, and low-quality seeds present substantial barriers. Compounded by climate change, overexploitation, and inadequate infrastructure for storage and collection, these challenges restrict the effective utilization of TBOs. Expanding TBO cultivation beyond forested areas through agroforestry and reforestation is essential to meet the growing demand for oilseeds. However, the lack of high-quality planting material remains a critical impediment. This review provides a comprehensive analysis of the current state of TBOs, with a focus on technological insights and future perspective. It examines significant TBO species in India, highlights research efforts by various ICFRE institutes aimed at TBO improvement, and assesses the status of seed testing and certification both nationally and globally. The paper identifies key challenges and explores potential solutions, offering strategic recommendations for advancing TBO cultivation. By addressing these issues, the review aims to support policy advocacy efforts to enhance TBO production, reduce import dependency, and contribute to sustainable development in the sector.

Keywords: Tree- borne oil seeds, Seed Testing, TBO Research, Biodiesel, Edible oil.

INTRODUCTION

India is one of the major growers and importers of oilseeds globally, ranking fourth in the vegetable oil economy after the USA, China, and Brazil. Oilseeds constitute approximately 13% of India's gross cropped area, contribute 3% to the Gross National Product, and account for 10% of the value of all agricultural commodities. Over the last decade (1999-2009), this sector has seen an annual growth rate of 2.44% in area, 5.47% in production, and 2.96% in yield. In recent years, domestic consumption of edible oils has significantly increased, reaching 18.90 million tonnes in 2011-12, with further growth expected. According to the OECD-FAO Agricultural Outlook (2021-2030), India's per capita vegetable oil consumption is projected to grow at 2.6% per annum, reaching 14 kg per capita by 2030. This rise, driven by urbanization and shifts toward highly processed foods rich in vegetable oils, necessitates an import growth rate of 3.4% per annum [1]. To ensure edible oil security, it is crucial to optimize domestic production.

India's growing demand for edible oils and energy sources, coupled with a heavy reliance on imports, highlights the need to utilize alternative domestic resources. Approximately 67% of India's vegetable oil consumption is met through imports. In addition, conventional petroleum energy presents challenges, including fluctuating global prices, depletion of reserves, import dependency, environmental degradation, and geopolitical conflicts like the Ukraine-Russia war. To bolster national energy and food security, it is essential to enhance domestic production of TBOs, which can be cultivated in various agro-climatic conditions,

including wastelands, deserts, and hilly areas. TBOs are naturally shed by trees and typically collected by indigenous communities.

To address the country's edible oil demand, the Ministry of Agriculture, Cooperation, and Farmers' Welfare, Government of India, launched the National Mission on Oilseeds and Oil Palm (NMOOP) in April 2014. Under NMOOP, Mini Mission-III focuses on enhancing the area under TBOs, particularly in wastelands. This mission promotes interventions such as nursery development, plantation maintenance, intercropping incentives, research and development, equipment distribution for processing, support for TRIFED, training for farmers and extension workers, and local initiatives [2]. The objective is to increase TBO seed collection from 9 lakh tonnes to 14 lakh tonnes and supply elite planting materials to expand cultivation in wastelands across 28 states [2].

Tree-borne seed oils, defined as oils extracted from the seeds (endosperm) of certain trees rather than the fruit (pericarp), offer a significant source of vegetable oil [3, 4, 5]. Tree-borne oilseeds (TBOs), an essential non-timber forest product, are species-specific and vary across agro-climatic zones. In India, Sal (*Shorea robusta*), Mahua (*Madhuca longifolia*), Simarouba (*Simarouba glauca*), Kokum (*Garcinia indica*), Olive (*Olea europaea*), Karanja (*Pongamia pinnata*), Jatropha (*Jatropha curcas*), Neem (*Azadirachta indica*), Jojoba (*Simmondsia chinensis*), Cheura (*Diploknema butyracea*), Wild Apricot (*Prunus armeniaca*), Walnut (*Juglans regia*), Tung (*Aleurites fordii*) and many other minor TBOs are cultivated under diverse agro-climatic conditions, both in forest and non-forest areas, as well as in wastelands, deserts, and hilly regions. Some of these TBOs are utilized for edible oil production. In India, oilseeds of tree and forest origin, primarily found in tribal areas, are estimated to produce about 11-15 lakh tonnes of oil for edible and industrial purposes. Currently, around 5 lakh tonnes of TBO seeds are collected and processed, yielding approximately 1 lakh tonne of oil. According to a 2012 survey by the Indian Council of Forestry Research & Education (ICFRE), Dehradun, TBOs such as Neem, Karanja, Sal, Mahua, Cheura, Kokum, Simarouba, Jatropha, Jojoba, and Wild Apricot are cultivated across 14.7 lakh hectares of government or private lands, with only 7.5 to 10% of the potential being utilized [2].

TBOs serve both domestic and industrial purposes, including agriculture, cosmetics, pharmaceuticals, diesel substitutes, and cocoa-butter alternatives. National policies such as the National Biofuel Policy (2009) and the National Agroforestry Policy (2014) aim to replace fossil fuels with biofuels and promote integrated land use for livelihood, environmental, and energy security. While all oils can be used as biofuels, edible oils are primarily reserved for food, making non-edible oils the main raw material for biodiesel production in India. The country has significant potential, with over 100 tree species capable of producing seed oil suitable for biodiesel.

Despite their abundance, TBOs are often scattered and underutilized due to factors such as poor seed quality, lack of awareness, climate change, overexploitation, and unsustainable harvesting. Additional constraints include inadequate facilities for storage and seed collection, long gestation periods, harvesting during the rainy season, and limited availability of quality tree germplasm. To meet future demand, it is imperative to cultivate TBOs outside forest areas in plantations (agroforestry systems or Trees Outside Forests [TOF] plantations) while actively restoring natural forests to bridge the gap between oil production demand and supply in India.

IMPORTANT TBOS IN INDIA

India possesses significant potential for TBO cultivation, with species such as Mahua, Neem, Simarouba, Karanja, Ratanjyot, Jojoba, Cheura, Kokum, Wild Apricot, Wild Walnut, Kusum, and Tung, suitable for diverse agro-climatic conditions [6]. Screening of lesser-known TBO species from Northeast India, including *Cinnamomum impressinervium*, *Garcinia xanthochymus*, *Litsea coriacea*, *Croton joufra*, *Albizia procera*, *Cryptocaria andersoni*, and *Kayea assamica*, revealed their potential for edible oil production due to favorable omega-6/omega-3 and PUFA/SFA

ratios [3]. These findings suggest that these lesser-known oilseeds could be valuable raw materials for various commercial applications, contributing to India's self-sufficiency in the vegetable oil sector. Below table provides a concise overview of each particularly focusing on the production of edible and non-edible oils and other valuable applications [3,6, 8-21].

RESEARCH STATUS OF TBOS IN INDIA

Various ICAR and ICFRE institutes in India are actively involved in the conservation, plantation, propagation, post-harvest seed handling, seed storage studies, longevity, and long-term storage using cryopreservation of Tree-Borne Oilseeds (TBOs). The National Oilseeds and Vegetable Oils

Table 1. Details of important TBOs in India

Species	*Scientific Name*	Distribution	Characteristics	Uses
Dhupa	*Vateria indica*	Western Ghats, Kerala, Tamil Nadu (India)	Indigenous tree with seeds containing 20-22% oil.	Edible after refining, used in confectionery, soap, candle manufacturing, substitute for cocoa butter.
False Sandalwood	*Ximenia americana*	Deccan Peninsula, Andaman Islands (India)	Valuable wild edible plant, seed kernels contain 49-60% oil.	Edible oil, suitable for soap making, lubrication, and other industrial uses.
Jojoba	*Simmondsia chinensis*	Rajasthan, Gujarat, Haryana, Andhra Pradesh (India)	Hardy desert shrub. Seeds contain about 50% oil.	Used in cosmetics, pharmaceuticals, lubricants, food, waxes for polishing, cake used as cattle feed.
Indian Jujube (Ber)	*Ziziphus mauritiana*	Yunnan (China) to Afghanistan, Malaysia, Queensland (Australia), India (commercially grown)	Medium-sized tree with varying height. Adapted to drought conditions.	Fruit eaten raw or pickled, seed oil used in biodiesel production, seeds used medicinally.
Tung	*Aleurites spp.*	Eastern Asia, Malaysia, Mizoram (India)	Deciduous tree known for its quick-drying oil.	Tung oil used for industrial purposes, including paint and varnish. Seeds used for biodiesel production.
Indian Tulip Tree	*Thespesia populnea*	Coastal regions, possibly indigenous to India and Hawaii	Small tree or shrub. Pan-tropical distribution.	Pharmaceutical applications, biodiesel production.
Indian Rose Chestnut	*Mesua ferrea*	Sri Lanka, Assam (India)	Tall tree with heavy, hard wood.	Timber used for railroad ties, medicinal uses, seed oil used in pharmaceuticals.
Neem	*Azadirachta indica*	Entire India, thrives in drier climates, wild in Deccan forests, scattered in Northern and Central India	Medium to large tree	Bio-pesticides, soap, cosmetics, manure, biodiesel, pesticide
Karanja	*Pongamia pinnata*	Throughout India, drought-resistant, salinity-tolerant, found along roadsides, railways, and	Medium to large tree	Soap making, leather dressing, lubrication, illumination, green manure, bio-diesel production
Jatropha	*Jatropha curcas*	Semi-arid regions, Andhra Pradesh, Gujarat, Rajasthan, Karnataka, Maharashtra	Shrub to small tree	Biodiesel, illumination, soap, candles, lubricant, hair oil, manure
Tamanu	*Calophyllum inophyllum*	Coastal areas, tropical regions	Large tree	Skin care, medicinal purposes, biodiesel, UV-absorption properties, wound healing, antibacterial properties
Tejpat	*Cinnamomum impressinervium*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio

Species	*Scientific Name*	Distribution	Characteristics	Uses
Tapor Tenga	*Garcinia xanthochymus*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio
Bagh-nola	*Litsea coriacea*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio
Mahunda	*Croton joufra*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio
Koroi	*Albizia procera*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio
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		Haryana, Andhra Pradesh (India)	50% oil.	lubricants, food, waxes for polishing, cake used as cattle feed.
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Koroi	*Albizia procera*	Northeast India	Medium to large tree	Edible oil based on ω6/w3 and PUFA/ SFA ratio
Sia-nahor	*Kayea assamica*	Northeast India	Medium to large tree	Edible oil based on ω6/w3 and PUFA/ SFA ratio
Sia-nahor	*Keyea assamica*	Northeast India	Medium to large tree	Edible oil based on ω6/ω3 and PUFA/SFA ratio

Development (NOVOD) Board is particularly renowned for exploring and enhancing the potential of TBOs in India through activities such as nursery raising, plantation establishment, installation of processing facilities, and capacity building initiatives. NOVOD has launched research and development programs on Jatropha and Karanja for biodiesel production, involving a network of 25 institutions across the country to achieve these objectives. Additionally, national networks have been established for the promotion of other TBOs like Wild Apricot and Cheura in suitable states. Integrated efforts for TBO development are being facilitated through the exchange of planting materials and technical know-how among these institutions [7]. A summary of completed projects and significant findings on TBOs conducted by various ICFRE research institutes is provided in Table 2.

The germplasm of TBOs can be conserved through both in situ and ex situ conservation methods. Ex situ conservation involves plantations, gene banks, in vitro techniques, and cryopreservation to preserve diverse germplasm for varying durations. Several projects, including the All India Coordinated Research Projects and National Programs on the Conservation of Forest Genetic Resources, are ongoing in collaboration among various ICFRE institutes.

The Challenge of Quality Seed Availability for TBOS and Forestry Species: A Key Issue

Challenges in seed quality for TBO (Tree-Borne Oilseed) cultivation include several key factors. Genetic variability within wild TBO populations often results in seeds with inconsistent size, oil content, and germination potential, further compounded by the lack of improved cultivars and standardized seed production techniques. Environmental conditions such as drought, high temperatures, and soil salinity can adversely affect seed development, leading to poor seed filling, reduced viability, and lower oil content. Improper seed handling and storage—exposed to high humidity and temperatures—can cause seed deterioration, while inadequate post-harvest processing and storage facilities exacerbate the issue. Additionally, seeds are vulnerable to pest and disease infestations both in the field and during storage, which can significantly impair seed quality and viability.

Tree-borne oilseeds (TBOs) from forest origins face many hurdles. One major problem is collecting seeds from scattered locations, which is time-consuming and inefficient. Additionally, high seed dormancy and difficulties in harvesting from avenue and forest plantations pose significant challenges. There is a notable lack of quality planting material and seeds, which are only available for limited periods. Marketing channels for TBOs are often unreliable and improper, which further complicates their distribution. Post-harvest technologies and processing methods are scarce, leading to poor handling and storage. As a result, prices are low, and there is a wide gap between potential and actual production. The absence of state incentives to promote biodiesel as a fuel

Table 2. Summary of Completed Projects and Significant Findings on Tree-Borne Oilseeds (TBOs) Conducted by Various ICFRE Research Institutes

S. No.	Institute	Project Name	Significant Findings
1	Tropical Forest Research Institute (TFRI), Jabalpur	Processing techniques of NWFPs in Chhattisgarh TBOs	Quality of oil seeds is affected by drying temperature, method, and storage containers. Jute bags are unsuitable due to increased moisture. Polyethylene bags and jars are recommended. Hot air drying at 60°C is better for maintaining seed quality.
2	Tropical Forest Research Institute (TFRI), Jabalpur	Integrated development of TBOs	Collaborated with local communities for planting Jatropha, Pongamia, and Madhuca on degraded lands. Provided technical training and raised awareness about TBOs' economic potential.
3	Arid Forest Research Institute (AFRI), Jodhpur	Development of a database on TBOs in India (Funded by NOVOD Board through ICFRE)	Compiled data on TBO cultivation in Gujarat and Rajasthan, focusing on species like Jatropha, Karanja, Neem, Mahua, Mango kernel, Jojoba, and Piloo.
4	Arid Forest Research Institute (AFRI), Jodhpur	Fatty oil studies of important oil-bearing plants of the arid region	High oil content was observed in Salvadora persica and S. oleoides from specific regions. Oil content varied across neem and Pongamia pinnata seeds from different locations, with some international provenances showing even higher oil content.
5	Institute of Wood Science and Technology (IWST), Bangalore	Fatty oil composition of lesser-known TBOs	Madhuca insignis seed oil identified as edible; Givotia oil showed antifungal activity; Hopea seed oil demonstrated antibacterial properties.
6	Institute of Forest Productivity (IFP), Ranchi	TBOs in community lands for improving livelihoods	Evaluated Pongamia pinnata clonal trials; significant growth observed in selected clones, indicating potential for community-based plantation initiatives.
7	Forest Research Institute (FRI), Dehradun	R&D on Jatropha under National Network Programme (Sponsored by NOVOD Board)	Conducted growth analysis, oil content studies, and pruning impact assessments on Jatropha.
8	Forest Research Institute (FRI), Dehradun	Studies on oilseeds of forest origin for oil and wetting agents	Five species, including Cedrela serata and Garuga pinnata, were identified with high fatty oil content. Sulphated oils were evaluated as substitutes for Turkey Red Oil.
9	Forest Research Institute (FRI), Dehradun	Studies on fungal infestation, mycotoxin elaboration, and biochemical changes in edible oilseeds	Aspergillus, Penicillium, and other fungi were found in stored samples, with aflatoxin presence varying by species. No fungal infestation in fresh samples of Prunus armeniaca.

adds to the economic challenges, making it hard to achieve a favorable cost-benefit ratio. Currently, TBOs contribute only a small portion of the country's vegetable oil production.

To address these issues, research and development efforts are needed. Focus areas should include germplasm resources, identifying elite planting material, developing propagation techniques, and establishing production technologies for large-scale plantations. Studies on how different TBO progenies perform under various agro-climatic conditions are essential. Additionally, effective pest and disease management strategies and quality assessment protocols are needed to improve overall productivity and sustainability.

In light of ongoing climate change and shrinking forest areas, it's crucial to restore TBO availability through forest restoration and cultivation outside forest areas using agroforestry models. Forest restoration involves bringing back degraded or damaged landscapes to their original state, helping to achieve climate mitigation, biodiversity conservation, and socio-economic benefits. Over the past few decades, emphasis has been placed on large-scale plantations under various schemes, which require a significant amount of seeds.

Numerous national and international programs have committed to restoration, conservation, sustainability, and biodiversity.

Initiatives like social forestry, community forestry, and various national policies (e.g., National Forest Policy 1988, National Agroforestry Policy 2014) emphasize massive plantation efforts, especially in areas outside the forest. The Bonn Challenge, launched in 2011, aims to restore millions of hectares of degraded and deforested landscapes globally. India joined this initiative in 2015, pledging to restore 26 million hectares by 2030.

In India's Nationally Determined Contribution (NDC), a commitment was made to create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through forest and tree cover by 2030. The Indian government's 2022 Union budget highlights agroforestry and private forests as tools for decarbonizing the economy. With only 24.62% forest cover, far below the recommended 33%, there is little scope for increasing the area under natural forests. However, Trees Outside Forests (TOFs) offer tremendous opportunities for enhancing productivity and sustainability.

Certified Forest Reproductive Material (FRM) is vital for forestry and agroforestry functions, including timber production, food security, and climate change mitigation. FRM can significantly impact forest health, productivity, and resilience against climate changes, pests, and diseases. Promoting agroforestry through legislative changes and financial support is part of the government's broader goal of gradually moving towards a carbon-neutral economy.

However, one major constraint to scaling up agroforestry with tree components, including TBOs, is the unavailability of high-quality planting material. Ensuring the availability of quality planting material is essential before undertaking large-scale TBO plantations, as these species are perennial and can yield for 30-40 years once established.

The "Green Revolution" in agriculture was largely due to the use of quality seeds. The agricultural seed industry has well-established guidelines, rules, and protocols for testing seed quality. These are regulated by various bodies and legislation, such as the Seed Act of 1966 and Seed Control Order of 1983, and supported by organizations like the International Seed Testing Agency (ISTA) and the OECD. In contrast, the forestry sector lacks similar standards, policies, and infrastructure. Most genetic material in forestry, including TBOs, is obtained from unspecified sources, leading to poor seed quality and inconsistent results. A lack of control systems, such as minimum seed standards, testing protocols, and certification policies, further exacerbates the issue. Establishing uniform standards for tree seed testing and a "Seed Act" specific to forestry is essential to ensure the availability of high-quality seeds and planting material.

Quality Control of Forestry Seed Including TBOS

Quality control for seeds involves ensuring guaranteed germination rates and purity through a system of seed testing and certification [22-26]. Testing assesses physical purity, moisture, genetic purity, germination, vigor, and seed health. Recent advancements in non-destructive technologies, such as machine vision, spectroscopy, and thermal imaging, are enhancing seed quality assessment. Certification verifies the origin and quality of seeds, akin to a guarantee for manufactured goods, and is crucial for maintaining high-quality forest tree seeds and propagating materials. The OECD Scheme, established in 1967, sets international standards for forest reproductive material, categorizing them into four classes: source-identified, selected, qualified, and tested. This scheme promotes the production and use of forest seeds and plants in compliance with standards to ensure their trueness to name. The OECD's internationally recognized certification process, which 29 countries participate in, helps standardize and ensure quality across global seed exchanges and forestry functions. Many countries globally have established seed zone systems for their indigenous species and various schemes of seed certification have been designed (NWFTSCA-Forest Reproductive Material Certification

Standards: Oregon-Washington Interagency, OECD- Control of Forest Reproductive Material Moving in International Trade, European Union (EU) - Council Directive 1999/105/EC, etc.) (Table 3).

This table compares the different forest reproductive materials certification schemes employed in the USA, OECD countries, the European Union, and India, highlighting their origin, general overview, and classification of forest reproductive materials.

In India, at present no legal framework exists. The first attempt to certify tree germplasm in India began in 1979 under an Indo-Danish project on seed procurement and tree improvement. Indian Council of Forest Research and Education (ICFRE) lobbied for the certification of tree germplasm and the Indian government reinitiated the process of developing a certification scheme for forest and agroforestry tree germplasm in 2008 but it is still pending. Currently, few states in India have developed their own testing and certification standards for some commercially important tree species, but these are not up to mark to be used across the country.

Opportunities for Improvement

To tackle the challenges in TBO cultivation and enhance seed quality, a range of innovative strategies can be employed. Imagine a world where breeding programs are the heart of transformation, creating cultivars with not only higher genetic uniformity but also with enhanced oil content and resilience to environmental stresses. Advanced techniques like marker-assisted selection and biotechnology speed up the journey to developing superior TBO varieties. Pre-sowing treatments act as a protective

Table 3. Comparison of Forest Reproductive Materials Certification Schemes around the globe

Region	USA - Northwest Forest Tree Seed Certifiers Association (NWFTSCA)	OECD (Organization for Economic Cooperation and Development)	European Union (EU)	India
Name of Scheme	Forest Reproductive Material Certification Standards: Oregon-Washington Interagency	Control of Forest Reproductive Material Moving in International Trade	Council Directive 1999/105/EC (later EU 2000: Directive 199/105/CE)	No legal framework currently exists
General Overview	- Formed in 1966 - Provides certification for a wide range of forest reproductive materials (FRM) including seeds, scions, cuttings, seedlings, and pollen - Certification also covers FRM sources such as seed orchards, seed production areas, plantations, and evaluation tests - Recognizes four classes of reproductive material sources	- First published in 1967, amended in 1974 - Currently under revision - Approves reproductive material from seven types of "basic material": seed source, stand, seed plantation, seed orchard, parents of families, clonal mixtures, and clone - All materials tagged and accompanied by a certificate of provenance	- First enacted in 1966 - Substantially amended to incorporate advances in tree improvement	- First attempt to certify tree germplasm began in 1979 under an Indo-Danish project on seed procurement and tree improvement - Indian Council of Forest Research and Education (ICFRE) has lobbied for certification - Efforts to develop a certification scheme were reinitiated in 2008, but no national scheme has been established yet - Some states have their own testing and certification standards for commercially important species
Classes of FRM	1. Audit Class 2. Source-Identified Class 3. Selected Class 4. Tested Class	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material

shield, preparing seeds for the rigors of germination with methods such as priming and coating with bio-fertilizers. These treatments also guard against pests and diseases, ensuring robust seedling growth. The evolution of storage practices introduces modern techniques like controlled atmosphere storage and vacuum packing, which preserve seed vitality by preventing deterioration. Meanwhile, Integrated Pest and Disease Management (IPDM) strategies deploy biological control agents and resistant varieties to keep pests and diseases at bay. Looking ahead, the potential of oils and fats from tree-borne oilseeds as vital resources for food, fuel, and industrial applications drives ongoing research. Institutions like IICT are exploring new oil sources, while the development of bio-lubricants aims to reduce reliance on petroleum-based products. ICAR and ICFRE are at the forefront of improving collection and processing technologies, identifying valuable germplasm, and integrating TBOs into agroforestry systems. Additionally, the introduction of exotic species like the Shea butter tree and Argania spinosa offers new opportunities. Future efforts will focus on developing technologies and mechanisms to ensure that TBOs not only thrive but also contribute significantly to sustainable and profitable agroforestry systems.

Conclusion

In a world grappling with high oil prices, depleted fossil fuels, and environmental challenges, tree-borne oilseeds (TBOs) emerge as a promising solution. With the potential to provide sustainable energy and create rural jobs, TBOs like Sal, Neem, and Mahua are crucial for addressing these issues. To realize their full potential, we need to implement robust seed handling and certification processes, strengthen supply systems, and adhere to international standards. By overcoming current obstacles and drawing on successful local initiatives, TBOs can reduce India's reliance on imported oils and contribute to a more sustainable and resilient agricultural sector.

Acknowledgments

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Why technology-driven validation is becoming the new standard for ingredient integrity

In today's complex marketplace, ingredient integrity has evolved from a back-end responsibility to a key strategic differentiator. As manufacturers move toward data-driven validation, Atsushi Sugimoto, assistant manager at Mitsubishi Gas Chemical (MGC), explores how manufacturing technology is redefining ingredient safety and quality standards.

As consumers scrutinise labels and demand global transparency, manufacturers are re-evaluating what it means to source ingredients that are not only safe but also demonstrably consistent and validated.

For ingredients developed through fermentation or other biologically variable processes, traditional quality control models are no longer sufficient. Natural variability in raw materials, environmental conditions and microbial behaviour can create inconsistencies that impact both performance and safety. This is where a new generation of suppliers integrating artificial intelligence, advanced analytics and globally recognised food safety systems is shaping a different standard for the industry.

When food and beverage manufacturers partner with suppliers using these tools, they are not merely purchasing an ingredient. They are participating in a fundamentally more rigorous, data-driven and forward-looking model of ingredient assurance.

AI driven fermentation innovation

Fermentation has long been used to produce high value ingredients for functional foods, sports nutrition and wellness applications. But despite its natural advantages, fermentation is inherently complex. Microorganisms respond dynamically to different factors, and even subtle shifts in their own metabolic cycles. Historically, managing this depended heavily on manual operator intuition and experience.

Advanced machine learning systems can now analyse real-time data to visualise and predict biological variability before it impacts the final ingredient. Rather than reacting, manufacturers can intervene earlier, stabilising batches for consistency.

This results in higher ingredient reliability, where AI reduces the likelihood of unexpected fluctuations, enabling food and beverage formulators to work with ingredients that perform consistently across large production runs. As well as greater validation, because fermentation data can be captured, mapped, and archived, suppliers gain a traceable and auditable history of every batch – a key advantage for manufacturers navigating rigorous regulatory or retailer requirements.

AI is not replacing human expertise, it is upleveling it. Quality managers and scientists still determine parameters, review outcomes and manage risk assessments with AI's support, to make decisions informed by deeper insights and more data than manual processes alone could provide.

Sustainability as a measurable output

Sustainability once functioned as a corporate value statement. Today, it is increasingly evaluated through measurable operational metrics like energy intensity, waste generation, water use and carbon footprint.

AI-enabled fermentation supports these goals in ways that traditional models cannot. By optimising feedstock utilisation, improving energy efficiency and reducing off-spec batches that lead to waste, advanced fermentation systems contribute directly to both environmental and economic performance.

This shift reframes sustainability from a compliance obligation to an operational return on investment. Manufacturers benefit from lower energy consumption through improved process control, reduced raw material waste by increasing fermentation accuracy, higher yields with fewer rejected batches and more efficient scaling due to stable, predictable production.

For brands whose customers care about environmental impact, choosing suppliers that deploy AI in their production is a sustainability advantage and risk management strategy. The more stable and efficient the production process, the less vulnerable the supply

chain is to disruptions, shortages, or unexpected quality issues.

Global access and the growing importance of certifications

As supply chains become more complex and consumer bases more diverse, ingredient manufacturers must work within frameworks that ensure universal trust. Accreditations such as FSSC 22000, ISO based quality systems, and Halal certification are emerging as foundational expectations rather than optional enhancements.

FSSC 22000

FSSC 22000 provides globally harmonised food safety validation that encompasses hazard analysis, environmental controls, sanitation procedures, personnel training, and traceability. For manufacturers, sourcing from FSSC certified suppliers ensures that raw materials are produced under rigorously audited systems, offers a uniform basis for cross-border compliance and supports retailer requirements, especially for brands selling into markets with strict procurement policies.

With regulatory frameworks around the world evolving quickly, FSSC 22000 has become a baseline for entering and maintaining access to international markets.

Halal certification

Halal certification is often associated with serving Muslim consumers, but its importance has broadened significantly. It now signals integrity, cleanliness, traceability, and adherence to ethical manufacturing principles.

For global brands, Halal certification ensures supply chain compatibility across regions with diverse cultural expectations, reinforces consumer trust through transparent oversight, and serves as an additional layer of validation for ingredient purity.

In a global market seeking culturally inclusive and ethically grounded products, Halal certification is increasingly viewed as a competitive advantage.

Informed Sport and Informed Choice certifications

For sports nutrition brands, preventing unintended contamination with substances banned by the World Anti-Doping Agency (WADA) is essential. Certification by the Informed Sport quality assurance program and its sister program, Informed Choice, ensures that products and ingredients are manufactured to high standards and that every batch undergoes testing for WADA prohibited substances. Informed Sport is recognised globally by sports bodies for preventing inadvertent doping, and it tests every batch before release to market using ISO/ 17025-accredited methods. For brands creating performance products like endurance drinks, protein shots, or cognitive support meal bars, this level of independent testing provides critical assurance.

Ingredient integrity as a shared responsibility

The emerging standard for ingredient sourcing is not defined by any single technology or certification but by the integration of multiple tools and systems that together create transparency and reliability. When these are in place, ingredient sourcing becomes less about transactional purchasing and more about long-term quality partnership.

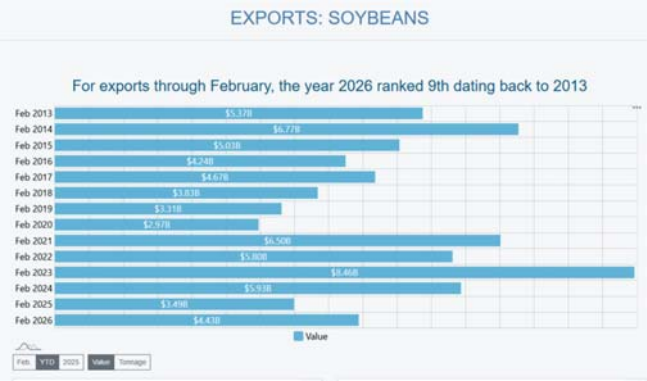
By working with suppliers who integrate AI-driven quality systems, advanced fermentation technology and globally recognised certifications, manufacturers are contributing to a new, elevated standard of safety and validation. This shift ensures the quality and reliability of ingredients, strengthens the broader supply chain, supports sustainable growth, and prepares the industry for the next generation of functional products.

In an environment defined by transparency and accountability, ingredient integrity has become one of the most powerful tools manufacturers have to build trust, protect consumers, and drive innovation.

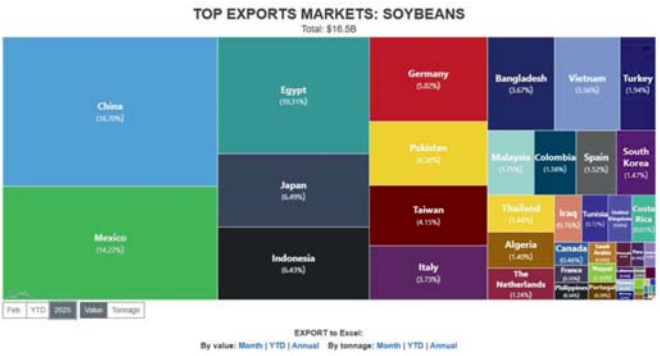
Source: FoodBev Media

U.S. Soybean Exports In 2026 Show 27% Increase After Abysmal 2025

There's a glimmer of hope in the latest U.S. Census Bureau data for badly battered American soybean farmers, who endured the worst year in nearly two decades and an unprecedented five consecutive months without any sales to China.



The 27.09% increase through the first two months of 2026 is led by a 79.66% increase in shipments to China, according to my analysis of the latest data. In fact, while exports to China increased $1.09 billion over the same two months in 2025, exports to the rest of the world actually decreased, down $141.13 million.





China is important because it has accounted for more than 50% of all U.S. soybean sales for 14 of the previous 17 years. The 2025 percentage fell to 18.70%, the second lowest percentage since 2003, just after China's ascension to the World Trade Organization and easier access to global trade.

The first two months of the year are important because they are the tail end of the U.S. soybean season, which runs from September through March, more or less. It then shifts to Brazil.

Brazil is now the world's largest producer and exporter. Over the last decade, its market share of global output has increased from just over 30% to better than 42% while the U.S. output has fallen from almost 34% to about 27%. In the season coming to an end, projections have Brazil accounting for almost 60% of global exports, with the United States accounting for 22%-23% of all exports, down from just under 40% a decade ago. Brazil exports about 70% of its soybeans to China.

It was eight years ago that U.S. soybeans became the poster child for Chinese retaliation after President Trump in his first term announced his broad-based trade war against the Asian nation. That year, 2018, as well as 2019 and 2025 are the only three years in the last 17 when China did not buy a majority of U.S. soybeans.

The market share for China topped 50% all four years when Joe Biden was president, even though he made no consequential changes to the Trump tariffs and even tightened some others. Those four years in office include the two years with the greatest value ever for imports both from China and the world. China accounted for 52.02% of the $35.45 billion total in 2022 and 54.16% of the $27.80 billion total in 2023.

Last year, with Trump back in office threatening, but never exacting, 145% tariffs, China not only completely shut off the spigot for soybean purchases for an unprecedented five months, it did so from June through October – meaning it crossed over into the U.S. soybean season. That made it particularly painful. The boycott ended with a paltry $21.83 million in exports in November. That was a 99.18% decrease from the previous November, when the total had been $2.67 billion.

So while the 27.09% increase is encouraging, it should be read as a rebound from a weak base, not as proof that the damage has passed. The deeper lesson for U.S. soybean farmers is that China still dominates the market math, Brazil has gained structural ground, and U.S. growers remain exposed to every shift in trade policy and every turn in Beijing's buying habits. Until

that relationship stabilizes, even a strong month or two will offer only limited comfort.

Source: Forbes

Updated Heating Oil Specification Includes Biodiesel Blends Up to B50

Revised standard supports expanded use of higher biodiesel blends



Clean Fuels Alliance America welcomes the approval of the latest revision to ASTM D396 that supports expanded use of higher biodiesel blends in heating applications. (Getty Images, Unsplash+)

Clean Fuels Alliance America welcomes the approval of the latest revision to ASTM D396, the standard specification for fuel oils, which now includes new grades for biodiesel blends containing 21% to 50% biodiesel by volume (B21-B50). The updated specification, ASTM D396-26a, marks a major milestone for the clean fuels industry and supports expanded use of higher biodiesel blends in heating applications.

The revision provides users and consumers of Bioheat® fuel with clear guidance on fuel properties and procedures needed to deliver the same or improved performance as fuels currently in use.

"In the Northeast and Mid-Atlantic states where Bioheat® fuel adoption continues to grow, the updated standard provides the technical foundation and industry data needed to support higher biodiesel blends in heating markets," said Scott Fenwick, Technical Director at Clean Fuels. "The specification provides greater confidence in the performance, reliability and emissions benefits of blends up to B50."

The revision passed through ASTM's rigorous consensus balloting process with no objections, underscoring broad industry support and confidence in higher biodiesel blends. The approval reflects years of collaboration among Clean Fuels, the National Oilheat Research Alliance (NORA), leading equipment manufacturers including R.W. Beckett and Carlin Combustion, and other stakeholders who contributed the research, testing and technical data needed to support the specification.

"The recent approval of the ASTM standard to include blends of B50 biodiesel in liquid heating oil is another step forward in providing the American consumers with a high-quality, domestically produced, renewable energy source," said Michael Devine, President of NORA. "This new standard represents a significant step forward, particularly at a time when increased domestic energy production is a must in the United States. On behalf of National Oilheat Research Alliance, we would like to thank all of the various stakeholders who worked tirelessly together to bring these new fuel blends to market."

Higher biodiesel blends offer benefits beyond carbon reduction, including improved air quality, lower particulate and sulfur emissions, and reduced heat exchanger maintenance. Advances in burner technologies, improved fuel quality, and innovations in cold weather additives continue to support broader adoption and reliable year-round performance. Feedstocks such as soybean oil also play an important role in delivering the quality and reliability needed for heating oil applications.

"With ASTM D396-26a now in place, the industry has a powerful new tool to accelerate adoption of higher biodiesel blends and expand the role of clean fuels in reducing emissions from home heating," said Fenwick.

Source: Clean Fuels Alliance America

Why Goodyear started using soybean oil in its tires

Thanks to World War 2 changing the way we make car tires, synthetic rubber is the primary material used in today's tires. However, that doesn't mean that tire manufacturers have stopped innovating. In fact,



Car with a Goodyear tire© Susanavalera/Getty Images

Goodyear has used a soybean oil compound in its tires since 2017. It might sound like a bizarre concept, but there's actually a very good reason the company began using soybeans, and why it still does so today.



Iberostar Eolia Djerba - Seven Bars and Restaurants - Couple or Family Getaway

Goodyear incorporates the soybean blend because it's more cost-effective than traditional petroleum-based oils used in years past. It's also more eco-friendly, and in terms of production, it mixes with rubber very easily. Because of this, the soybean oil compound makes for a more efficient process, while also using less energy as well. Soybean oil technology, which is also used to make biodiesel fuel, causes tire tread to become more flexible as the temperature changes. This means that Goodyear tires are designed to have better grip in dry, wet, and even winter, environments.

Goodyear was the first tire manufacturer to utilize a soybean formula and did so with support from the United Soybean Board. At the time, the move was promoted as the company's effort to develop high-performing tires while also experimenting with non-traditional raw materials. The fact that soybeans are a renewable resource only boosted Goodyear's positioning.

Goodyear's soybean oil expansion and future plans



Close-up of a Goodyear Eagle tire on a classic rim

In 2022, the company manufactured new commercial tires, the Metro Miler G152 and G652, for city transit systems. These tires would replace some of the existing petroleum-based tires. Goodyear maintained that the new additions would still have the same performance as before, while also moving away from the traditional tires used up to that point. That same year, the company also introduced a soybean oil compound in its Endurance WHA waste haul tire.

Goodyear later expanded even further, incorporating the soybean formula across several additional tire lines with some of the best treadwear ratings. This includes the Assurance Weather Ready tires, the Assurance Comfort Drive all-season tires, as well as two Eagle lines. The company used the same technology in its Wrangler Workhorse HT, which is mostly installed on SUVs and light pickup trucks. Goodyear's widespread use of the compound is part of a bigger strategy, as the goal is to produce a fully sustainable-material tire by 2030.

The company appears to be on track for that timeline, as, in 2023, it made a demonstration tire made with 90% sustainable materials. The new tire passed the rounds of internal and external testing, in which it exhibited lower rolling resistance than similar traditional models. This means better efficiency and fuel economy overall.

Source: msn

IMPORTANT FIGURES

Table 01: Major Oilseeds: World Supply and Distribution (Commodity View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oilseed, Copra	6.05	6.27	6.12	5.92
Oilseed, Cottonseed	40.31	39.53	41.24	42.19
Oilseed, Palm Kernel	19.78	19.59	20.36	21.15
Oilseed, Peanut	49.81	50.00	51.85	51.18
Oilseed, Rapeseed	89.86	89.97	86.28	96.04
Oilseed, Soybean	378.21	396.45	428.11	429.19
Oilseed, Sunflowerseed	52.78	55.93	53.01	55.35
Total	636.79	657.75	686.96	701.01
Imports				
Oilseed, Copra	0.08	0.08	0.09	0.11
Oilseed, Cottonseed	1.37	1.19	0.93	0.86
Oilseed, Palm Kernel	0.16	0.19	0.22	0.27
Oilseed, Peanut	4.18	4.10	3.73	4.01
Oilseed, Rapeseed	20.07	18.26	20.06	18.36
Oilseed, Soybean	168.50	178.50	179.15	188.53
Oilseed, Sunflowerseed	3.77	2.54	2.61	4.38
Total	198.12	204.85	206.78	216.52
Exports				
Oilseed, Copra	0.10	0.09	0.08	0.10
Oilseed, Cottonseed	1.11	1.21	0.92	1.32
Oilseed, Palm Kernel	0.06	0.09	0.17	0.14
Oilseed, Peanut	4.85	4.80	4.66	4.96
Oilseed, Rapeseed	19.84	18.56	19.82	19.35
Oilseed, Soybean	171.76	177.85	184.33	186.42
Oilseed, Sunflowerseed	4.02	2.72	3.37	4.29
Total	201.74	205.31	213.34	216.58
Crush				
Oilseed, Copra	5.90	6.18	6.06	5.87
Oilseed, Cottonseed	30.21	31.43	31.27	31.26
Oilseed, Palm Kernel	19.77	19.46	20.22	21.03
Oilseed, Peanut	19.08	18.44	19.35	19.34
Oilseed, Rapeseed	82.11	84.68	84.63	90.09
Oilseed, Soybean	315.77	331.25	359.16	375.84
Oilseed, Sunflowerseed	51.36	52.26	48.26	49.97
Total	524.19	543.70	568.95	593.40
Ending Stocks				
Oilseed, Copra	0.07	0.06	0.06	0.05
Oilseed, Cottonseed	1.47	1.65	1.58	1.50
Oilseed, Palm Kernel	0.29	0.32	0.32	0.41
Oilseed, Peanut	4.32	3.85	4.04	4.56
Oilseed, Rapeseed	10.91	11.87	9.93	10.91
Oilseed, Soybean	101.84	115.10	125.97	124.93
Oilseed, Sunflowerseed	4.12	3.20	2.54	3.13
Total	123.01	136.04	144.44	145.49

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 02: Major Protein Meals: World Supply and Distribution (Commodity View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Meal, Copra	1.96	2.04	2.00	1.93
Meal, Cottonseed	13.92	14.46	14.41	14.38
Meal, Fish	4.54	5.14	5.28	5.31
Meal, Palm Kernel	10.28	10.08	10.58	10.95
Meal, Peanut	7.62	7.38	7.78	7.77
Meal, Rapeseed	47.81	49.21	49.30	52.38
Meal, Soybean	248.39	259.86	281.75	293.94
Meal, Sunflowerseed	23.05	23.24	21.41	22.29
Total	357.57	371.40	392.51	408.94
Imports				
Meal, Copra	0.61	0.55	0.56	0.55
Meal, Cottonseed	0.20	0.19	0.23	0.23
Meal, Fish	3.36	3.62	3.95	3.79
Meal, Palm Kernel	7.70	7.41	7.27	7.75
Meal, Peanut	0.12	0.09	0.04	0.03
Meal, Rapeseed	9.30	9.93	10.15	11.80
Meal, Soybean	63.27	69.54	77.73	82.28
Meal, Sunflowerseed	8.55	10.16	7.75	8.65
Total	93.12	101.48	107.66	115.07
Exports				
Meal, Copra	0.56	0.54	0.53	0.51
Meal, Cottonseed	0.30	0.32	0.37	0.35
Meal, Fish	2.55	2.97	3.15	3.19
Meal, Palm Kernel	8.06	7.28	7.69	7.97
Meal, Peanut	0.18	0.12	0.10	0.14
Meal, Rapeseed	9.79	10.22	10.71	11.97
Meal, Soybean	67.07	74.22	82.89	86.98
Meal, Sunflowerseed	9.16	10.22	8.77	8.87
Total	97.66	105.88	114.21	119.97
Domestic Consumption				
Meal, Copra	2.01	2.02	2.02	1.99
Meal, Cottonseed	13.81	14.34	14.26	14.20
Meal, Fish	5.37	5.79	6.03	5.94
Meal, Palm Kernel	9.95	10.25	10.03	10.63
Meal, Peanut	7.58	7.34	7.72	7.66
Meal, Rapeseed	47.54	48.69	48.80	52.00
Meal, Soybean	246.96	255.03	272.84	288.05
Meal, Sunflowerseed	21.77	22.86	20.59	22.16
Total	354.98	366.34	382.29	402.63
Ending Stocks				
Meal, Copra	0.05	0.08	0.09	0.07
Meal, Cottonseed	0.11	0.10	0.11	0.16
Meal, Fish	0.25	0.24	0.29	0.27
Meal, Palm Kernel	0.62	0.57	0.69	0.79
Meal, Peanut	0.02	0.03	0.03	0.02
Meal, Rapeseed	1.26	1.50	1.43	1.65
Meal, Soybean	14.16	14.31	18.06	19.25
Meal, Sunflowerseed	1.81	2.13	1.93	1.83
Total	18.28	18.95	22.62	24.03

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 03: Major Vegetable Oils: World Supply and Distribution (Commodity View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oil, Coconut	3.71	3.88	3.83	3.70
Oil, Cottonseed	4.56	4.74	4.71	4.72
Oil, Olive	2.53	2.44	3.37	3.27
Oil, Palm	76.78	76.20	78.94	81.44
Oil, Palm Kernel	8.76	8.61	8.93	9.29
Oil, Peanut	6.20	6.00	6.31	6.31
Oil, Rapeseed	33.25	34.39	34.28	36.65
Oil, Soybean	60.73	64.01	70.07	73.60
Oil, Sunflowerseed	21.71	22.12	20.41	21.11
Total	218.22	222.38	230.87	240.08
Imports				
Oil, Coconut	1.93	2.18	1.86	1.92
Oil, Cottonseed	0.09	0.08	0.07	0.09
Oil, Olive	1.08	1.11	1.24	1.31
Oil, Palm	46.65	42.36	41.39	41.93
Oil, Palm Kernel	2.69	2.72	2.70	2.65
Oil, Peanut	0.39	0.34	0.47	0.43
Oil, Rapeseed	6.90	7.50	7.10	7.58
Oil, Soybean	10.98	10.53	14.18	13.82
Oil, Sunflowerseed	12.61	13.96	12.01	11.36
Total	83.30	80.77	81.01	81.10
Exports				
Oil, Coconut	2.18	2.47	2.24	2.11
Oil, Cottonseed	0.08	0.06	0.06	0.08
Oil, Olive	1.21	1.17	1.35	1.45
Oil, Palm	49.37	44.41	45.02	45.97
Oil, Palm Kernel	2.97	3.09	3.17	2.99
Oil, Peanut	0.35	0.37	0.59	0.43
Oil, Rapeseed	6.53	7.50	7.13	7.89
Oil, Soybean	11.74	11.81	15.26	15.50
Oil, Sunflowerseed	14.31	15.34	13.66	13.59
Total	88.75	86.21	88.47	90.00
Domestic Consumption				
Oil, Coconut	3.43	3.64	3.56	3.56
Oil, Cottonseed	4.57	4.72	4.73	4.74
Oil, Olive	2.58	2.48	3.16	3.06
Oil, Palm	73.88	75.18	76.25	77.25
Oil, Palm Kernel	8.48	8.23	8.46	8.80
Oil, Peanut	6.20	6.03	6.15	6.28
Oil, Rapeseed	32.71	34.35	34.40	36.00
Oil, Soybean	59.39	62.88	68.24	71.98
Oil, Sunflowerseed	19.55	21.07	19.10	19.04
Total	210.81	218.59	224.05	230.70
Ending Stocks				
Oil, Coconut	0.89	0.85	0.75	0.70
Oil, Cottonseed	0.15	0.19	0.18	0.18
Oil, Olive	0.53	0.42	0.51	0.59
Oil, Palm	16.99	15.96	15.02	15.18
Oil, Palm Kernel	0.96	0.96	0.97	1.12
Oil, Peanut	0.39	0.33	0.37	0.41
Oil, Rapeseed	3.44	3.47	3.33	3.66
Oil, Soybean	5.87	5.71	6.47	6.42
Oil, Sunflowerseed	3.22	2.89	2.55	2.39
Total	32.44	30.79	30.14	30.63

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 04: Major Oilseeds: World Supply and Distribution (Country View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Brazil	166.91	160.29	179.56	188.20
United States	125.75	122.16	128.59	126.12
China	66.87	66.92	67.81	69.37
Argentina	31.45	54.24	59.10	58.72
India	42.31	41.39	42.83	41.77
Other	203.49	212.73	209.08	216.83
Total	636.79	657.75	686.96	701.01
Imports				
China	111.71	119.13	113.51	117.45
European Union	22.34	20.70	24.27	23.29
Mexico	8.14	7.86	7.85	8.54
Argentina	9.06	7.79	6.33	7.51
Turkey	4.02	3.71	5.02	5.92
Japan	5.49	5.41	5.57	5.50
Egypt	2.00	3.33	4.56	4.93
Thailand	3.34	3.53	4.29	4.59
Pakistan	1.50	1.89	2.60	4.06
Vietnam	2.21	2.51	2.83	3.29
Other	28.31	28.99	29.95	31.44
Total	198.12	204.85	206.78	216.52
Exports				
Brazil	95.92	104.52	103.59	114.97
United States	54.77	47.57	52.56	42.48
Canada	12.22	11.73	14.99	14.30
Argentina	5.11	6.13	9.60	11.06
Paraguay	6.50	8.00	6.43	8.21
Australia	7.03	6.62	5.76	6.26
Ukraine	8.37	7.28	7.39	4.12
Other	11.81	13.47	13.04	15.19
Total	201.74	205.31	213.34	216.58
Crush				
China	134.00	137.20	141.83	146.80
United States	64.16	66.23	70.43	75.89
Brazil	57.54	59.43	63.99	68.88
Argentina	34.60	40.58	48.44	49.04
European Union	48.25	48.31	46.92	48.80
India	34.78	35.63	35.64	34.81
Russia	24.50	25.70	26.23	27.60
Ukraine	15.68	18.55	15.70	14.80
Canada	11.73	12.69	13.09	14.62
Indonesia	13.25	12.59	13.44	13.82
Mexico	8.13	7.70	7.82	8.30
Pakistan	4.01	5.10	5.16	6.62
Turkey	6.03	5.18	6.14	6.43
Malaysia	5.08	5.38	5.20	5.49
Egypt	2.35	3.39	4.67	5.01
Other	60.10	60.06	64.26	66.50
Total	524.19	543.70	568.95	593.40
Ending Stocks				
China	36.71	48.35	48.95	48.10
Brazil	37.00	29.97	38.05	38.31
Argentina	18.34	25.38	25.94	24.96
United States	8.85	10.81	10.23	10.76
European Union	3.49	3.93	4.23	4.56
Other	18.62	17.60	17.03	18.81
Total	123.01	136.04	144.44	145.49

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 05: Major Protein Meals: World Supply and Distribution (Country View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
China	95.71	98.24	101.91	105.31
United States	49.93	51.43	55.27	59.41
Brazil	43.45	44.24	47.14	50.82
Argentina	25.58	30.16	35.86	35.81
European Union	30.74	30.83	30.26	31.27
Other	112.16	116.50	122.07	126.32
Total	357.57	371.40	392.51	408.94
Imports				
European Union	21.49	22.38	25.23	25.01
China	8.39	9.39	7.93	10.23
Vietnam	5.85	7.02	6.81	6.83
Indonesia	5.67	5.24	6.44	7.00
United States	4.31	4.29	4.95	5.51
Thailand	4.01	3.60	3.51	3.94
United Kingdom	2.76	3.26	3.87	3.94
Other	40.64	46.31	48.93	52.62
Total	93.12	101.48	107.66	115.07
Exports				
Argentina	21.92	26.07	31.47	31.73
Brazil	21.33	22.72	23.39	25.51
United States	13.39	14.75	16.61	18.81
Canada	5.70	5.98	6.17	6.67
Indonesia	5.87	4.92	5.29	5.42
Ukraine	4.60	5.78	4.99	4.95
Russia	3.82	4.30	4.16	4.34
Other	21.03	21.35	22.14	22.55
Total	97.66	105.88	114.21	119.97
Domestic Consumption				
China	103.04	106.32	108.62	113.64
European Union	49.53	50.09	52.44	53.79
United States	40.78	40.90	43.65	46.07
Brazil	21.95	22.38	23.26	24.72
India	17.59	18.15	18.02	18.55
Russia	8.93	9.36	9.83	10.36
Mexico	7.82	7.82	8.17	9.23
Vietnam	7.25	8.05	8.59	9.12
Indonesia	6.62	6.85	7.59	8.42
Thailand	6.26	6.02	5.99	6.79
Other	85.20	90.41	96.12	101.95
Total	354.98	366.34	382.29	402.63
SME				
China	96.11	99.39	102.29	106.70
European Union	42.18	42.67	45.71	46.77
United States	39.34	39.46	42.09	44.37
Brazil	21.58	21.93	22.76	24.19
India	14.94	15.37	15.34	15.76
Mexico	7.54	7.59	7.95	8.97
Russia	7.26	7.62	8.01	8.43
Other	95.05	100.53	107.37	114.86
Total	324.00	334.58	351.50	370.05
Ending Stocks				
Brazil	3.83	2.99	3.49	4.08
Argentina	2.59	2.47	2.94	3.06
European Union	1.27	1.72	2.49	2.49
China	0.94	0.79	0.94	1.22
Russia	0.71	0.75	0.83	1.01
Other	8.94	10.23	11.94	12.19
Total	18.28	18.95	22.62	24.03

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 06: Major Vegetable Oils: World Supply and Distribution (Country View)

Million Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Indonesia	51.10	48.81	51.74	53.11
China	30.41	31.06	32.40	33.87
Malaysia	20.59	22.03	21.61	22.56
European Union	18.33	18.48	18.29	19.07
United States	13.18	13.59	14.49	15.30
Brazil	11.94	12.57	13.56	14.60
Argentina	7.84	9.04	10.91	11.22
Other	64.83	66.81	67.87	70.36
Total	218.22	222.38	230.87	240.08
Imports				
India	17.12	15.85	16.29	16.75
European Union	9.17	9.62	8.01	8.48
China	11.35	9.14	7.51	7.79
United States	6.27	6.87	5.93	6.15
Pakistan	3.34	3.09	3.74	3.68
Turkey	2.75	2.41	2.12	2.05
Bangladesh	2.32	2.33	2.48	2.30
Egypt	1.64	1.81	1.80	2.18
Iran	1.75	1.34	1.74	1.28
Philippines	0.96	1.23	1.59	1.48
Other	26.64	27.10	29.80	28.97
Total	83.30	80.77	81.01	81.10
Exports				
Indonesia	30.25	24.46	25.49	25.78
Malaysia	16.64	17.82	16.98	17.42
Argentina	5.33	6.80	8.89	8.77
Russia	6.07	6.50	6.31	6.51
Ukraine	5.99	7.04	5.48	5.06
Canada	3.17	3.60	3.48	3.52
European Union	3.67	3.25	2.97	3.09
Other	17.64	16.76	18.87	19.84
Total	88.75	86.21	88.47	90.00
Domestic Consumption				
China	39.46	40.44	40.43	40.63
Indonesia	23.23	24.90	26.54	27.63
India	23.86	24.75	25.39	25.88
European Union	24.49	24.39	23.77	24.27
United States	19.27	20.13	19.07	20.87
Brazil	10.15	12.31	12.67	13.31
Malaysia	5.40	5.26	5.59	5.86
Pakistan	4.29	4.35	4.75	5.05
Russia	3.70	3.80	3.95	4.09
Thailand	2.98	2.97	2.99	3.34
Bangladesh	3.12	3.18	3.43	3.55
Mexico	3.17	3.13	3.18	3.24
Canada	1.71	2.18	2.29	2.91
Nigeria	2.66	2.71	2.88	2.89
Egypt	2.05	2.23	2.42	2.75
Other	41.28	41.86	44.70	44.43
Total	210.81	218.59	224.05	230.70
Ending Stocks				
India	4.37	4.63	4.69	4.69
Indonesia	5.64	5.24	5.07	4.89
Malaysia	2.87	2.56	2.74	3.05
European Union	2.10	2.56	2.12	2.31
China	3.73	3.32	2.44	2.20
Other	13.73	12.48	13.10	13.51
Total	32.44	30.79	30.14	30.63

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 07: Middle East Oilseeds and Products Supply and Distribution

Thousand Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oilseed, Cottonseed	1,857	1,236	1,501	1,208
Oilseed, Rapeseed	470	470	475	475
Oilseed, Soybean	317	309	324	324
Oilseed, Sunflowerseed	1,946	1,595	1,399	1,299
Other	186	200	205	200
Total	4,776	3,810	3,904	3,506
Domestic Consumption				
Meal, Cottonseed	998	682	803	665
Meal, Soybean	9,746	11,748	12,622	12,960
Meal, Sunflowerseed	2,252	2,435	2,190	2,476
Other	1,250	1,075	1,137	1,238
Total	14,246	15,940	16,752	17,339
SME				
Meal, Cottonseed	809	553	651	539
Meal, Soybean	9,744	11,748	12,622	12,960
Meal, Sunflowerseed	1,502	1,624	1,461	1,651
Other	924	841	862	943
Total	12,978	14,765	15,595	16,093
Imports				
Meal, Cottonseed	12	32	11	19
Meal, Soybean	5,372	8,229	8,194	9,045
Meal, Sunflowerseed	1,059	1,519	1,198	1,202
Other	710	629	670	846
Total	7,153	10,409	10,073	11,112
Imports				
Oil, Palm	3,514	3,559	3,656	3,525
Oil, Rapeseed	148	111	135	109
Oil, Soybean	523	152	238	343
Oil, Sunflowerseed	3,617	3,405	3,617	2,938
Other	255	220	216	225
Total	8,057	7,447	7,862	7,140
Industrial Dom. Cons.				
Oil, Palm	245	240	255	255
Oil, Rapeseed	25	25	25	25
Oil, Soybean	55	50	50	50
Oil, Sunflowerseed	25	25	25	25
Other	37	40	35	42
Total	387	380	390	397
Food Use Dom. Cons.				
Oil, Palm	2,667	2,726	2,770	2,755
Oil, Rapeseed	379	320	360	355
Oil, Soybean	1,186	909	747	964
Oil, Sunflowerseed	3,073	3,505	3,285	3,175
Other	758	637	916	682
Total	8,063	8,097	8,078	7,931
Domestic Consumption				
Oil, Palm	2,912	2,966	3,025	3,010
Oil, Rapeseed	404	345	385	380
Oil, Soybean	1,246	964	827	1,044
Oil, Sunflowerseed	3,113	3,545	3,325	3,215
Other	795	677	951	724
Total	8,470	8,497	8,513	8,373

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 08: European Union Oilseeds and Products Supply and Distribution

Thousand Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oilseed, Rapeseed	19,613	20,431	17,073	20,657
Oilseed, Soybean	2,610	2,811	2,911	2,851
Oilseed, Sunflowerseed	9,386	10,051	8,645	8,629
Other	526	367	419	423
Total	32,135	33,660	29,048	32,560
Domestic Consumption				
Meal, Rapeseed	13,800	13,900	13,100	14,500
Meal, Soybean	26,642	27,042	31,242	31,542
Meal, Sunflowerseed	6,860	7,110	6,260	5,960
Other	2,232	2,038	1,841	1,789
Total	49,534	50,090	52,443	53,791
SME				
Meal, Rapeseed	9,819	9,890	9,321	10,317
Meal, Soybean	26,600	27,000	31,200	31,500
Meal, Sunflowerseed	4,536	4,702	4,135	3,935
Other	1,230	1,082	1,050	1,021
Total	42,184	42,675	45,706	46,773
Imports				
Meal, Rapeseed	846	839	420	862
Meal, Soybean	15,997	16,564	20,609	20,300
Meal, Sunflowerseed	2,753	3,238	2,567	2,300
Other	1,892	1,736	1,633	1,548
Total	21,488	22,377	25,229	25,010
Industrial Dom. Cons.				
Oil, Palm	2,200	1,850	1,300	1,300
Oil, Rapeseed	6,975	7,050	6,750	7,250
Oil, Soybean	1,100	1,150	1,400	1,250
Oil, Sunflowerseed	550	550	475	475
Other	555	555	535	535
Total	11,380	11,155	10,460	10,810
Food Use Dom. Cons.				
Oil, Palm	2,150	1,880	1,800	1,700
Oil, Rapeseed	2,900	2,850	2,900	3,250
Oil, Soybean	1,250	1,425	1,550	1,675
Oil, Sunflowerseed	4,650	4,950	4,725	4,450
Other	1,887	1,855	2,114	2,165
Total	12,837	12,960	13,089	13,240
Domestic Consumption				
Oil, Palm	4,500	3,890	3,200	3,100
Oil, Rapeseed	9,925	9,950	9,700	10,550
Oil, Soybean	2,405	2,630	3,005	2,980
Oil, Sunflowerseed	5,213	5,513	5,213	4,938
Other	2,447	2,410	2,649	2,700
Total	24,490	24,393	23,767	24,268
Imports				
Oil, Palm	4,576	4,013	3,140	3,200
Oil, Rapeseed	391	463	295	618
Oil, Soybean	641	592	757	825
Oil, Sunflowerseed	2,103	3,022	2,411	2,300
Other	1,461	1,534	1,407	1,535
Total	9,172	9,624	8,010	8,478

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 09: China Oilseeds and Products Supply and Distribution

Thousand Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oilseed, Peanut	18,330	19,231	19,000	18,400
Oilseed, Rapeseed	16,317	15,800	15,800	16,000
Oilseed, Soybean	20,284	20,840	20,650	20,900
Oilseed, Sunflowerseed	1,741	1,983	1,750	2,200
Other	10,196	9,069	10,611	11,871
Total	66,868	66,923	67,811	69,371
Imports				
Oilseed, Peanut	940	774	448	650
Oilseed, Rapeseed	5,335	5,486	4,600	3,500
Oilseed, Soybean	104,500	112,000	108,000	113,000
Oilseed, Sunflowerseed	266	183	132	100
Other	665	690	332	200
Total	111,706	119,133	113,512	117,450
Domestic Consumption				
Meal, Peanut	4,005	3,973	3,885	3,883
Meal, Rapeseed	13,512	14,519	14,639	14,048
Meal, Soybean	75,050	77,150	80,850	84,550
Other	10,472	10,678	9,249	11,162
Total	103,039	106,320	108,623	113,643
SME				
Meal, Peanut	4,502	4,466	4,367	4,364
Meal, Rapeseed	9,276	9,992	10,074	9,654
Meal, Soybean	73,900	76,000	79,700	83,400
Other	8,435	8,936	8,147	9,277
Total	96,112	99,394	102,288	106,696
Food Use Dom. Cons.				
Oil, Palm	3,100	2,800	1,800	2,325
Oil, Peanut	3,418	3,373	3,440	3,434
Oil, Rapeseed	8,800	9,700	10,350	9,700
Oil, Soybean	17,900	18,900	20,500	20,800
Oil, Sunflowerseed	1,803	1,419	717	825
Other	1,387	1,369	1,367	1,399
Total	36,408	37,561	38,174	38,483
Domestic Consumption				
Oil, Palm	5,400	5,000	3,300	3,725
Oil, Peanut	3,418	3,373	3,440	3,434
Oil, Rapeseed	8,800	9,700	10,350	9,700
Oil, Soybean	17,900	18,900	20,500	20,800
Oil, Sunflowerseed	1,803	1,419	717	825
Other	2,134	2,051	2,121	2,149
Total	39,455	40,443	40,428	40,633
Imports				
Oil, Palm	6,190	4,377	3,203	3,700
Oil, Peanut	292	247	347	340
Oil, Rapeseed	1,978	2,039	2,171	2,000
Oil, Soybean	365	381	296	150
Oil, Sunflowerseed	1,555	1,207	532	600
Other	967	884	956	995
Total	11,347	9,135	7,505	7,785

Source : Foreign Agricultural Service / USDA Global Market Analysis

Table 10: India Oilseeds and Products Supply and Distribution

Thousand Metric Tons

	2022/23	2023/24	2024/25	2025/26
Production				
Oilseed, Cottonseed	11,166	10,783	10,189	10,104
Oilseed, Peanut	6,300	6,000	7,100	7,500
Oilseed, Rapeseed	11,200	11,600	11,520	12,000
Oilseed, Soybean	12,411	11,875	12,882	11,027
Oilseed, Sunflowerseed	215	112	113	113
Other	1,022	1,021	1,021	1,021
Total	42,314	41,391	42,825	41,765
Domestic Consumption				
Meal, Cottonseed	4,443	4,409	4,329	4,257
Meal, Rapeseed	4,350	4,600	4,360	4,850
Meal, Soybean	6,625	7,075	7,185	7,130
Other	2,176	2,069	2,146	2,316
Total	17,594	18,153	18,020	18,553
SME				
Meal, Cottonseed	3,600	3,573	3,508	3,449
Meal, Rapeseed	3,095	3,273	3,102	3,451
Meal, Soybean	6,225	6,625	6,710	6,700
Other	2,021	1,903	2,015	2,158
Total	14,941	15,373	15,335	15,758
Food Use Dom. Cons.				
Oil, Cottonseed	1,315	1,290	1,285	1,265
Oil, Palm	8,300	8,340	8,150	7,750
Oil, Peanut	1,050	995	1,000	1,170
Oil, Rapeseed	3,600	3,900	3,925	4,000
Oil, Soybean	5,400	5,175	6,645	7,200
Oil, Sunflowerseed	2,750	3,525	2,900	3,070
Other	400	410	395	395
Total	22,815	23,635	24,300	24,850
Domestic Consumption				
Oil, Cottonseed	1,361	1,345	1,330	1,305
Oil, Palm	8,900	8,990	8,800	8,350
Oil, Peanut	1,060	1,005	1,010	1,180
Oil, Rapeseed	3,680	3,980	4,005	4,080
Oil, Soybean	5,400	5,175	6,645	7,200
Oil, Sunflowerseed	2,750	3,525	2,900	3,070
Other	710	730	700	695
Total	23,861	24,750	25,390	25,880
Imports				
Oil, Cottonseed	1	0	1	5
Oil, Palm	10,045	8,886	7,786	8,100
Oil, Peanut	0	0	0	1
Oil, Rapeseed	6	6	26	40
Oil, Soybean	3,968	3,308	5,471	5,500
Oil, Sunflowerseed	2,988	3,516	2,905	3,000
Other	111	131	98	101
Total	17,119	15,847	16,287	16,747

Source : Foreign Agricultural Service / USDA Global Market Analysis

PHYSICOCHEMICAL AND SENSORIAL PROPERTIES OF CHOCOLATE SPREAD SUBSTITUTED WITH OLEOGEL BASED ON PALM OIL AND COCONUT OIL

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Abstract

Fat plays an important role in the texture and structure of chocolate spread, but excessive fat use negatively affects health. In general, oleogel can be used as an alternative to conventional fats. Therefore, this study aimed to determine the effect of substituting beeswax-structured oleogel prepared from 1:1 palm: coconut oil on the characteristics of chocolate spread. The fat in chocolate spread was substituted with palm-coconut oleogel. The substitution levels included A-0%, B-25%, C-50%, D-75%, and E-100%. The results showed that substituting oleogel increased the color chromaticity for L*, a*, and b*. The texture increased for hardness, adhesiveness, and cohesiveness. Sensory characteristics also increased, as evidenced by taste, texture, spreadability, and overall acceptance. Chocolate spread, which was substituted with palm-coconut oleogel at 25%, showed suitable characteristics and was acceptable to the panelists. The hardness, adhesiveness, and cohesiveness of chocolate spread were 6.89 ± 0.46 g, -8.07 ± 1.00 g.s, and 0.65 ± 0.03, respectively, while the color chromaticity of L*, a*, and b* was 29.17 ± 0.13, 8.50 ± 0.11, and 9.09 ± 0.14, respectively. The crystal microstructure consisted of small spherulites without needle-like crystals, dominated by β′-crystal polymorph. These results showed that substitution of palm-coconut oleogel for up to 25% improved physicochemical and sensorial properties of chocolate spread. However, the high levels of oleogel had limitations, including compromised spreadability and texture.

Keywords: Chocolate spread, Fat, Oleogel, Palm oil, Coconut oil

Introduction

Chocolate spread is a chocolate-based product often used primarily as a topping or filling for bread and cakes. It typically contains palm oil and cocoa butter as the primary fat component, which serves to create a spread-able texture. However, palm oil and cocoa butter have disadvantages due to the high saturated and long-chain fat content, which can increase the risk of obesity and other degenerative diseases[1,2] underscoring the need for a healthier alternative, in the form of coconut oil. To maintain compatibility, a mixture of coconut oil and palm oil may be used. Other healthier ingredients, such as oleogel, are also needed to replace conventional fats for improved product characteristics. Oleogel is a gel derived from liquid oil that transforms into a 'gel-like' structure with semi-solid to solid properties at room temperature. This structure is due to the addition of an oleogelator, which forms a network capable of restricting the movement of oil molecules[3,4]. Oleogel, a lipophilic fat mixed with an oleogelator, forms and structures the network in the oil, which can bind or trap fat, making the product structure more plastic and stable. Moreover, oleogel has the ability to mimic the function of fat and produce bioactive compounds, supporting the development of innovative, healthier food[5–7].

The application of oleogel to replace fat in chocolate spreads requires selecting suitable ingredients that can improve the physicochemical and sensorial characteristics. Therefore, it is necessary to replace conventional fat in chocolate spread with an oleogel system that is more stable and has a suitable texture, while maintaining the low price and abundant availability. One of the applicable systems is a blend of palm-coconut oil

with beeswax as a natural oleogelator. Coconut oil contains medium-chain saturated fatty acids, specifically laurate (C12:0), which is good for health[8–10]. Meanwhile, palm oil contains a balance of saturated and unsaturated fatty acids, has good oxidation stability, and is highly compatible for use in fat-based products, including margarine and choco-late[11–13]. Beeswax oleogelator is a natural, non-polar polymer that can trap fat, indigestible, and has characteristics suitable as a substitute for oil in chocolate products[14–16].

Replacing conventional fats such as palm oil with oleogel has become a promising strategy to produce healthier chocolate spreads. Oleogels are also able to form a three-dimensional network that retains liquid oil. The use of oleogels reduces saturated fat, improves lipid profiles, increases oil-binding capacity, and enhances sensory characteristics acceptable to consumers[17,18]. However, oleogels can cause changes in texture, making them harder, affecting rheological properties, melting point, and product homogeneity. Therefore, formulation optimization is needed to achieve a balance between physical stability and sensory acceptance[19]. Limitations that are still often found are the lack of stability studies, shelf life, crystallization behavior, a limited number of sensory panelists, long-term health impacts, and the feasibility of industrial-scale production to ensure the implementation of oleogels as a sustainable fat replacement in chocolate spread formulations[19,20].

Oleogel has previously been applied to chocolate spread to improve the characteristics, including systems based on sunflower oil[21], a mixture of olive oil and sunflower oil[22], corn oil[23], and a complex blend of rice bran, camellia seed, oleifera seed, perilla seed, and fish oil[24]. Although oleogel, derived from a palm-coconut blend, as a tropical oil/fat, offers advantages in oxidation stability, studies on the substitution of palm oil in chocolate spreads remain limited. Both oil have different fatty acids and crystallization behaviors, which can affect the physical and sensory properties of the product. However, palm oil and coconut oil are limited by the low essential fatty acid content, underscoring the need to explore alternative oleogel based on different oil sources to overcome this limitation. Therefore, this study aimed to determine the effect of substituting palm-coconut oleogel on the characteristics of chocolate spreads, particularly in terms of color, texture, microstructure, polymorphism, functional groups, and sensory properties. Palm fat was replaced with a palm-coconut oleogel because the resulting chocolate spread was too soft, necessitating improvements in its physicochemical and sensory properties.

Materials and Methods

Materials

The materials used to produce oleogel were coconut oil, palm oil, and beeswax. The ingredients used to make the chocolate spread included cocoa powder from PT. Barry Callebaut, sugar, lecithin, palm oil, full-cream milk powder, and vanilla paste from the local market, Bandung, Indonesia. Materials for analysis were obtained from Merck KGaA (Darmstadt, Germany), analytical grade specifications.

Oleogel production

The oleogel was prepared according to a previous study by Fayaz et al[25]. Coconut oil and palm oil in a ratio of 1:1 (w/w) were mixed in a beaker glass using a magnetic stirrer at 300 rpm at room temperature for 5 min. About 300 g of the oil mixture was then heated on a hot plate stirrer at 300 rpm, 80 °C for 15 min. Subsequently, the 30 g of beeswax (10% of the oil mixtures, based on preliminary studies and references[26,27] was melted on a hot plate stirrer at 300 rpm, 90 °C until it became liquid. The melted beeswax was poured into the oil mixture at 300 rpm, 80 °C for 15 min, and placed in a dark jar. The oleogel was cooled and stored at room temperature (25 ± 2 °C) and held for 24 h before application.

Chocolate spread production

Chocolate spread was produced as described by

Bascuas et al[22], with minor modifications. The control sample of chocolate spread was prepared by mixing cocoa powder (10 g), granulated sugar (40 g), lecithin (1 g), palm oil (32 g), full cream milk powder (16 g), and vanilla paste (1 g). The cocoa powder, sugar, palm oil, and milk powder were placed in a conch (Premiere Chocolate Refiner-8LBS, Melanger, USA). Oleogel was applied to substitute or replace palm oil at concentrations of 0, 25, 50, 75, and 100%, coded as A-0%, B-25%, C-50%, D-75%, and E-100%, respectively, and the amount of fat in the chocolate spread remained 32%. Conching was carried out at 35–40 °C and 140 rpm until the ingredients were evenly mixed. This procedure was performed under closed conditions for 4 h to obtain the chocolate spread. The samples were cooled and stored at room temperature for 24 h before analysis, and the analyses were conducted at room temperature (25 ± 2 °C).

Color chromaticity analysis

The chromaticity analysis of chocolate spread was performed using a chromameter (CM-5, Konica Minolta) calibrated against a white plate, and color analysis included L*, a*, b*, ΔE, and Hue. The analysis was performed at room temperature in triplicate by attaching a sensor to the sample surface and then reading the results[28].

Texture analysis

The texture of the chocolate spread was analyzed using TA.XTplus Texture Analyzer (Stable Micro Systems, Surrey, UK). The chocolate spread sample in the container with dimensions (height 5 cm, diameter 8 cm) was conditioned by equilibration at 25 ± 2 °C for 2 h, and was pressed using a cylindrical probe with a 6 mm diameter twice. The probe speed was set at 1, 5, and 5 mm/s (pretest, test, and posttest) with a distance of 10 mm and a trigger force of 5 g. The parameters observed include hardness, adhesiveness, and cohesiveness. The analysis was conducted at room temperature in triplicate, and the results were obtained from the TXT 32 texture analyzer software[29].

Microstructure analysis

Microstructures were analyzed using a BX41 Olympus, Hachioji, Japan, connected to a digital video camera (Optilab). The samples were melted at 80 °C for 10 min, then dropped onto a glass slide and covered with another glass slide, followed by subsequent cooling at room temperature before imaging without staining. The crystal microstructure was observed with the imaging mode of optical at room temperature, at three different points with magnifications of 40x, 100x, and 400 ×[30].

Sensory analysis

The sensory analysis of the chocolate spreads was performed using a hedonic testing approach to measure pan-elists' degree of liking for each sample. The participants comprised 15 semi-trained panelists who had passed courses in chocolate processing technology and sensory evaluation. The sensory analysis aimed to provide preliminary information for further research leading to product commercialization. The samples were served with specific codes and presented in a randomized order. Six sensory attributes were evaluated, including aroma, color, flavor, texture, spreadability, and overall acceptability. A five-point rating scale was applied, and each sample was identified using a unique code[31].

Functional groups analysis

Functional group testing was performed using a "Nicolet iS10 FTIR spectrometer" with a spectrum of 400 to 4000 cm − 1, integrated with ATR. FTIR required a resolution of 4 cm^{-1}, 32 scans averaged, and a background collection using an empty, clean sample holder. A 2 mg sample was placed in a sample holder, then pressurized for 1–2 min, and the functional group spectrum was displayed[32].

Polymorphism analysis

Polymorphism was analyzed using fine-focus copper X-ray diffraction (XRD) (x-ray 40 kV, 30 mA) with SC70 detector (SmartLab, Warriewood,

Australia) in wide-angle mode. The sample was smeared on a glass slide and then incubated at room temperature for 10 min. The scan conditions include speed (2 deg/min), step size (0.01 deg), temperature control (at room temperature), and sample thickness (0.3 mm). The diffraction pattern was determined at 2-theta of 3–30 deg, and then the short spacing of the diffractogram peak was assessed by the formula $\lambda = 2\ d\ \sin\theta$[33].

Statistical analysis

The data obtained were analyzed using One-Way ANOVA at a 95% confidence level ($\alpha = 0.05$) to determine the effect of the treatment. The number of independent batches was doubled per treatment, and these were treated as replicates in ANOVA. When the ANOVA results showed a significant difference ($P < 0.05$), the analysis proceeded with the Duncan test. Data processing was performed using IBM SPSS Statistics version 21.0.

Results and Discussion

Texture

Texture characteristics play an important role in the quality of the chocolate spread, which was primarily determined by the fat components used. The texture profile of the chocolate spread, substituted with palm-coconut oleogel, is shown in Table 1. The hardness of A-0% at 4.13 ± 0.63 g and B-25% at 6.89 ± 0.46 g were the smallest and differed significantly ($p < 0.05$) from treatments C-50% (21.03 ± 1.50 g), D-75% (21.82 ± 1.91 g), and E-100% (88.87 ± 9.16 g). This was due to an insufficient oleogel concentration to achieve a dense, harder texture, or probably because the substantial crystalline network formed was not sufficient to increase hardness. Meanwhile, treatments C-50% and D-75% had the appropriate oleogel concentration, making the crystal structure denser and more homogeneous. Treatment E-100% had the highest hardness and was significantly different from others because using 100% oleogel triggers aggregation, which causes the crystals to form larger and denser. Overall, the results suggest that palm-coconut oleogel substitution affected the hardness of the chocolate spread.

Table 1 Effect of lipid phase substitution with palm-coconut oleogel on the texture of chocolate spread.

Treatments	Hardness (g)	Adhesiveness (g.s)	Cohesiveness
A-0%	4.13 ± 0.63^{a}	-3.23 ± 1.62^{c}	0.65 ± 0.03^{a}
B-25%	6.89 ± 0.46^{a}	-8.07 ± 1.00^{c}	0.65 ± 0.03^{a}
C-50%	21.03 ± 1.50^{b}	-25.12 ± 2.46^{b}	0.57 ± 0.02^{a}
D-75%	21.82 ± 1.91^{b}	-28.59 ± 3.50^{b}	0.65 ± 0.02^{a}
E-100%	88.87 ± 9.16^{c}	-94.64 ± 18.75^{a}	0.85 ± 0.17^{b}

Different letters in the same column mean significantly different at the 5% significance level, according to Duncan's multiple range test.

The higher the oleogel concentration, the greater the hardness value of the chocolate spread. This was due to the beeswax in the oleogel having a system that reduced free oil and enhanced network connectivity[34,35]. Hydrogen bonding may also contribute, as such interactions can form increasingly strong three-dimensional gel networks[36]. The bonds may occur between oleogelator molecules that trap liquid oil, creating a network of beeswax crystals into a gel. In this context, hardness represents a textural attribute related to firmness and resistance to deformation and is influenced by both the type and quantity of fat as well as particle size[37,38].

Treatments A-0% (−3.23 ± 1.62 g.s) and B-25% (−8.07 ± 1.00 g.s) had the smallest adhesiveness value and differed significantly ($p < 0.05$) from C-50% (−25.12 ± 2.46 g.s), D-75% (−28.59 ± 3.50 g.s), and E-100% (−94.64 ± 18.75) with the highest value (Table 1). The high adhesiveness of treatment E can be attributed to oleogel aggregation, leading to the collection of the free oil phase in the crystal gaps, which resulted in the product stickiness. In addition, the oleogelator of beeswax has high adhesive and binding power[25,39]. These results showed that palm-coconut oleogel affected the adhesive power of the chocolate spread because the network carried oil trapped in the gel structure, resulting in a greater amount on the surface of the crystal aggregate. The condition caused the

product texture to become stickier[17]. Chocolate spread with low adhesiveness and moderate hardness is generally considered desirable because it is not excessively sticky[40]. The sticky surface of a product can be affected by the characteristics of the constituent ingredients[41]. Meanwhile, oleogel containing oil and beeswax are hydrophobic compound that may affect stickiness[42].

Cohesiveness at E-100% (0.85 ± 0.17) was the highest, and significantly different ($p < 0.05$) from all treatments. This was due to the increasing amount of oleogel, forming a denser, stronger, and more stable crystal structure[17]. Meanwhile, A-0% (0.65 ± 0.03), B-25% (0.65 ± 0.03), C-50% (0.57 ± 0.02), and D-75% (0.65 ± 0.02) did not differ significantly from each other because these treatments still contained liquid palm oil, resulting in a more flexible or plastic structure. Palm-coconut oleogel did not significantly affect the cohesiveness of the chocolate spread, except for the E-100%. Adding oleogel reduced the free oil phase in the product because the oil was trapped within the gel network formed. The network filled the gaps between particles, resulting in closer distances and increased molecular interactions. This triggers the formation of more stable and evenly distributed crystals, resulting in a more compact structure[6,43]. Optimal cohesiveness should neither be too low nor too high, as extreme values may trigger oil separation, easy crumbling, and difficulty spreading. Lower cohesiveness is generally associated with a smoother texture. A product cohesiveness shows the strong internal bonds between the ingredients that form the product structure and resist deformation before breaking[44].

Color chromaticity

Color chromaticity was determined by measuring the L*, a*, and b* values, as well as the total color change. The L* value shows the brightness level, the a* value represents the chromatic color mixture of red (+) to green (-), and the b* value corresponds to the chromatic color mixture of blue (+) to yellow (-). The average results of the color test in Table 2 showed that the L* value increased significantly ($p < 0.05$) with higher oleogel concentration from 28.29 ± 0.15 at A-0% to 30.78 ± 0.60 at E-100%. This increase may be attributed to the presence of carot-enoids in palm oil, which impart a yellowish hue. In contrast, coconut oil lacks natural pigments; hence, oleogel containing coconut oil appears lighter, producing a brighter final appearance in the chocolate spread.

The a* value of the chocolate spread ranged from 8.01 ± 0,26 to 8.54 ± 0,06. Based on the color scale, this value showed that the chocolate spread with a palm-coconut oleogel substitution had a reddish-brown color, presumably produced from natural pigments in cocoa powder, namely polyphenols and melanoidins[45].

Table 2 Effect of lipid phase substitution with palm-coconut oleogel on the color chromaticity of chocolate spread.

Treatments	L*	a*	b*	ΔE	Hue (°)
A-0%	28.29±0.15^{a}	8.32±0.07^{bc}	8.79±0.10^{ab}	0.00±0.00^{a}	46.55±0.14^{a}
B-25%	29.17±0.13^{b}	8.50±0.11^{c}	9.09±0.14^{b}	0.95±0.13^{b}	46.91±0.14^{a}
C-50%	29.72±0.45^{b}	8.15±0.15^{ab}	8.66±0.15^{ab}	1.45±0.63^{b}	46.76±0.38^{a}
D-75%	29.35±0.33^{b}	8.01±0.26^{a}	8.41±0.52^{a}	1.21±0.33^{b}	46.37±0.90^{a}
E-100%	30.78±0.60^{c}	8.54±0.06^{c}	9.84±0.19^{c}	2.72±0.73^{c}	49.05±0.42^{b}

Different letters in the same column mean significantly different at the 5% significance level, according to Duncan's multiple range test.

The b* value of the chocolate spread ranged from 8.41 ± 0.52 to 9.84 ± 0.19. Based on the color scale, this value showed that the chocolate spread with palm-coconut oleogel as a substitute had a yellowish color. This is presumably because palm oil contains β-carotene, which provides the yellow color. In addition, beeswax used as an oleogelator has a pale yellow or cream color, which also affected the b* value of the chocolate spread toward a positive value. The ΔE value of the chocolate spread with palm-coconut oleogel as a substitute increased significantly ($p < 0.05$), ranging from 0.95 ± 0.13 at B-25% to 2.72 ± 0.73 at E-100%. This showed that the chocolate spread in each treatment differed significantly from the control. The ΔE value indicates the extent to which color differences can be detected by the human eye. The higher the ΔE value, the more pronounced the color difference is visually. Therefore, ΔE is often used as an objective indicator for evaluating color changes in food products, as it can represent human visual perception of color differences[46,47]. The color change can be attributed to the higher level of oleogel, making the chocolate spread brighter. The Hue of the chocolate spread substituted by palm-coconut oleogel increased significantly ($p < 0.05$), ranging from 46.37 ± 0.90° to 49.05 ± 0.42°, categorized as red.

Microstructure

Microstructure determines the characteristics of chocolate, specifically texture, and ultimately affects product quality. In chocolate spreads, the incorporation of oleogel may affect particle distribution within the chocolate network, including crystal shape, type, and size[48]. The microstructure of chocolate spreads substituted with palm-coconut oleogel is shown in Fig. 1. Observation using polarized light microscopy showed that the control and the chocolate spread substituted with palm-coconut oleogel had bright areas, indicating the polarization of the crystals (Fig. 1, red highlight). The black spots in the analysis results were amorphous cocoa particles or non-polarized parts, such as palm oil[49,50] As the level of oleogel substitution increased, the crystalline phase became more pronounced, with crystals appearing more numerous, smaller, and densely packed. This may be due to beeswax being a polymer of long-chain alcohols and saturated fatty acids, which potentially affect the rate of formation and the number of crystals. However, more numerous, smaller, and denser crystals can further form aggregated domains, leading to larger crystal sizes known as aggregation-based crystal growth or oriented attachment[51].

In the D-75% and E-100% treatments, there were crystals of larger sizes. This probably resulted from the rapid formation of beeswax crystals in

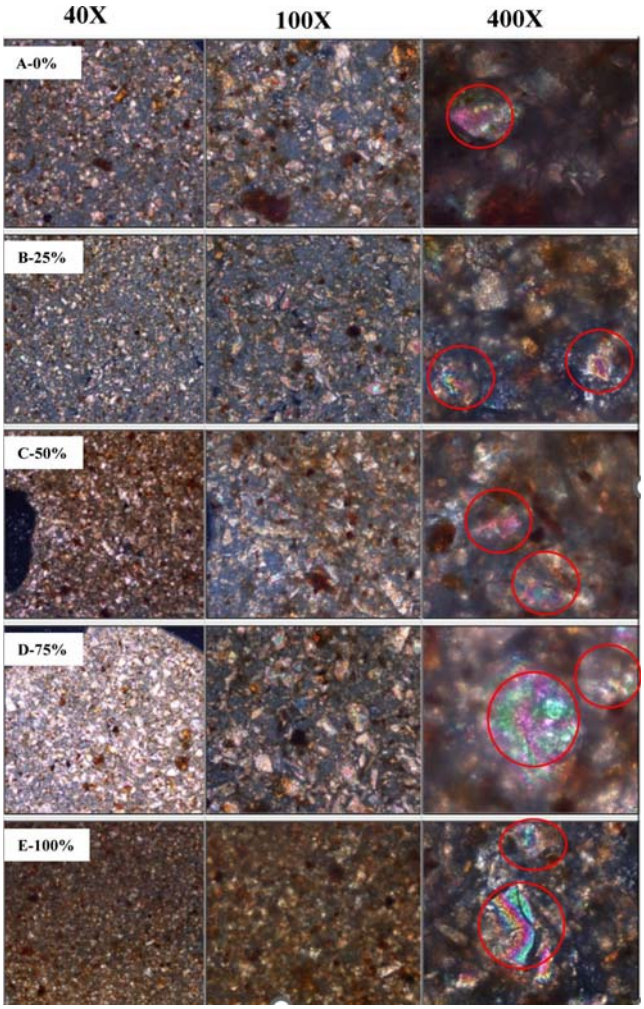


Fig. 1 Effect of lipid phase substitution with palm-coconut oleogel on the microstructure of chocolate spread (A-0%, B-25%, C-50%, D-75%, and E-100%), at 40X, 100X, and 400X magnification.

large quantities, causing aggregation, which made the texture of the chocolate spread denser and rougher. The observation is consistent with the texture profile in Table 1. The crystals showed a spherulitic morphology, and needle-like crystals were not observed. The dense structure and stable crystals can lead to limited fat flow gaps, thereby minimizing the formation of fat bloom[52]. These results are consistent with Afoakwa et al[50], showing that a high fat content in chocolate matrices can reduce interactions among material particles, increase intercrystalline spacing, and ultimately produce a less cohesive crystal network.

Functional groups

The FTIR spectra of chocolate spreads substituted with palm-coconut oleogel are shown in Fig. 2. All formulations showed similar triglyceride spectra with minor differences in the O-H region at higher oleogel levels. The spectrum of chocolate spread from all treatments showed strong peaks at wave numbers 2921.77 cm^{-1} and 2852.19 cm^{-1}, indicating the aliphatic alkane hydrocarbon functional group (C-H stretch) of methyl and methylene[53]. This functional group is often found in fatty acids and triglycerides from palm and coconut oil. Furthermore, a strong peak formed at wave number 1743.72 cm^{-1} showed

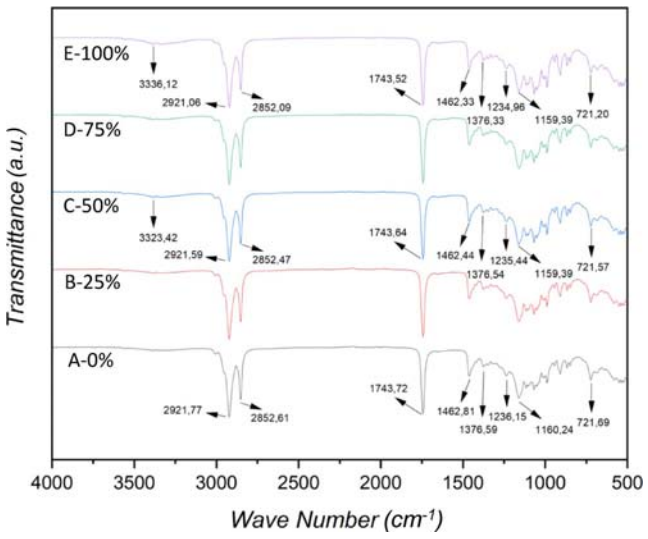


Fig. 2 Effect of lipid phase substitution with palm-coconut oleogel on the FTIR spectra of chocolate spread (**A**-0%, **B**-25%, **C**-50%, **D**-75%, and **E**-100%).

the presence of a carbonyl functional group (C = O stretch) in fatty esters, which dominated in vegetable oil and beeswax, and was found in lauric acid in coconut oil[21]. The presence of peaks at wave numbers 1462.81 cm^{-1} and 1376.60 cm^{-1} corresponded to the presence of a C-H bending functional group[53]. The wave number of 1376.59 cm^{-1} also showed the presence of methyl -CH3 groups from various fatty acids. Peaks also formed at wave numbers 1236.15 cm^{-1} – 1067.33 cm^{-1} showed C-O stretching vibrations, characteristic of ester and alcohol groups, as well as crystalline structures. This was reinforced by absorption at wave numbers around 700 cm^{-1}, corresponding to the rocking vibration of the CH_2 group, typically found in long-chain saturated fatty acids in palm oil and coconut oil.

Another difference was the presence of a weak but discernible peak at wave number 3323.42 cm^{-1}, in the chocolate spread of C-50%, D-75%, and E-100%, showing hydroxyl functional groups (O-H stretch) from polar compounds such as acid alcohols or minor components of oleogel or beeswax. The O–H band intensity tended to increase with higher beeswax content as the oleogelator[54]. The increasing oleogel also showed a slight shift in the peak due to changes in the chemical environment. However, these variations were minimal, and the overall triglyceride spectral pattern remained unchanged, showing that no substantial chemical degradation occurred and the structural integrity of the chocolate spread was preserved.

The presence of O-H, CH_2, and C = O ester groups shows that the product contains hydrogen and fat bonds, capable of increasing hardness, intermolecular bonds, and stickiness[55,56]. The C-O group also showed a more compact bond between lipid molecules, thereby strengthening cohesiveness. The presence of polar groups increased adhesion due to the ability of molecules to interact with surfaces. The hydroxyl group in oleogel forms a structural network that makes it more stable in the gel state[57]. Therefore, oleogel levels above 50%, as shown by stronger O–H

absorption bands, suggest a higher concentration of hydroxyl-containing components, which may be associated with a more stable gel network.

Sensorial properties

Sensory testing was carried out using the hedonic method to determine the level of acceptability for chocolate spread substituted with palm-coconut oleogel. The sensorial properties of the formulations assessed relative to the negative control are shown in Table 3. The different concentrations of oleogel as a substitute did not significantly affect panelists' acceptability for the color of the chocolate spread, ranging from 3.93 ± 0.70 to 4.40 ± 0.50 ($p > 0.05$). This was because the palm-coconut oleogel did not produce significant color changes. Sensory evaluation of color has inherent limitations compared with instrumental chromaticity analysis using a chromameter, which detected significant color differences (Table 2). This shows that the visual sensitivity of panelists was insufficient to distinguish subtle color variations, resulting in uniformly acceptable ratings across treatments.

Differences in oleogel substitution concentrations did not significantly affect panelists' acceptance for the aroma of chocolate spread, ranging from 3.87 ± 0.92 to 4.40 ± 0.74 ($p > 0.05$). This may be explained by the relatively neutral aroma profiles of oleogel and palm oil, which do not contain compounds that strongly enhance aroma. The aroma of chocolate products is influenced by additional ingredients, such as milk and vanilla paste[58]. The acceptability for the taste of the chocolate spread increased significantly ($p < 0.05$) with the addition of oleogel as a substitute, ranging from 3.60 ± 0.51 to 4.20 ± 0.68. This improvement may be attributed to the oleogel ability to bind ingredients effectively, thereby contributing to preventing the loss of flavor compounds during pro-cessing[59,60]. The control chocolate spread (A-0%) had a slightly oily taste, which panelists less favored. Increasing the amount of oleogel reduced the oily taste of the chocolate spread, which was also related to the texture acceptance. The presence of bioactive phenolic compounds in the oil extracted from the source also significantly affected the balance of sweetness and bitterness in the chocolate spread[21].

Texture acceptability of chocolate spread increased significantly ($p < 0.05$) with the amount of oleogel used as a substitute, ranging from 3.07 ± 0.59 to 4.33 ± 0.62. However, spreads with very high oleogel levels tended to exhibit a rougher and denser texture, which could reduce acceptability. The texture of the chocolate spread is generally expected to be soft, melting, and not sticky in the mouth[61]. The use of oil in this chocolate provided a soft texture.

The acceptability for the spreadability of chocolate spread ranged from 3.07 ± 0.59 to 4.40 ± 0.51. As the oleogel concentration increased, preadability generally decreased because the oleogel network bound liquid components more tightly, producing a denser structure. Spreadability is a textural attribute reflecting ease of application to food surfaces, and products that spread easily typically receive higher ratings[62]. Lower viscosity is generally associated with higher spreadability[63]. Spreadability is also related to the hardness of chocolate spread, which typically ranges from 23.91 to 69.51 g[64]. This corresponds to the hardness of chocolate spread substituted with palm-coconut oleogel, which ranged from 6.89 to 88.87 g (Table 1).

The overall acceptability of chocolate spread increased significantly ($p < 0.05$), ranging from 3.40 ± 0.74 (A-0%) to 4.40 ± 0.63 (B-25%), showing a normal to good value and acceptable to the panelists. Based on the characteristics, treatment B-25% has the best chocolate in terms of sensory properties and is supported by suitable other physicochemical properties, including texture, color, functional groups, and microstructure. Meanwhile, the control (A-0%) and the chocolate spread treatment E-100% had low overall acceptability. The best treatment (B-25%) was tested for polymorphism to determine the crystal type, compared to the control (A-0%).

Table 3 Effect of lipid phase substitution with palm-coconut oleogel on the sensorial properties of chocolate spread

Treatments	Color	Aroma	Taste	Texture	Spreadability	Overall acceptance
A-0%	3.93±0.70^{a}	3.87±0.92^{a}	3.60±0.51^{a}	3.07±0.59^{a}	4.13±0.74^{bc}	3.40±0.74^{a}
B-25%	4.13±0.64^{a}	3.93±0.59^{a}	3.93±0.70^{ab}	4.33±0.62^{c}	4.40±0.51^{c}	4.40±0.63^{b}
C-50%	4.40±0.50^{a}	4.20±0.68^{a}	4.00±0.85^{ab}	4.07±0.70^{bc}	3.73±0.70^{b}	4.27±0.60^{b}
D-75%	4.13±0.74^{a}	4.40±0.51^{a}	4.20±0.68^{b}	3.93±0.70^{bc}	4.33±0.82^{c}	4.00±0.76^{b}
E-100%	4.20±0.68^{a}	4.40±0.74^{a}	3.93±0.80^{ab}	3.73±1.03^{b}	3.07±0.59^{a}	3.47±0.64^{a}

Different letters in the same column mean significantly different at the 5% significance level, according to Duncan's multiple ran test.

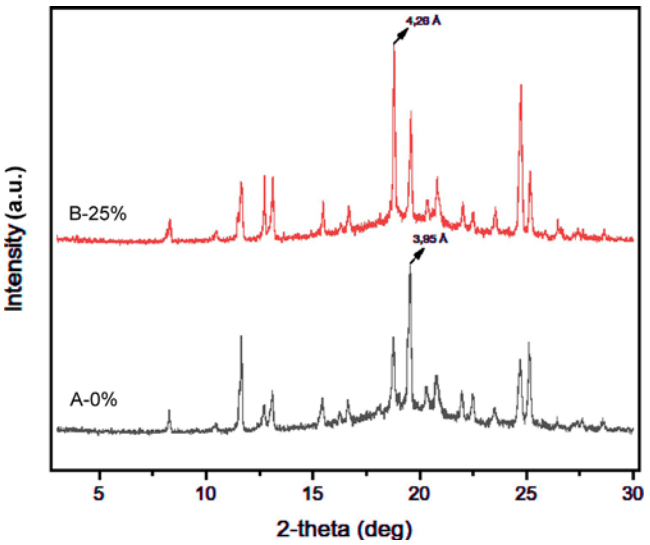


Fig. 3 The diffractogram of the chocolate spread, which was substituted with a 25% palm-coconut oleogel (B-25), was compared with the chocolate spread control (A-0%).

Polymorphism

Fat polymorphism has a significant effect on the structural properties and the distribution on a surface. According to Török (2014), six different polymorphs can be distinguished into form I, which has a d-spacing of 4.18 Å, form II (α) and form III (β′2) with a d-spacing of 4.24 Å, form IV (β′1) with a d-spacing of 4.38 Å, form V (β2) with a d-spacing of 4.56 Å, and form VI (β1) with a d-spacing of 4.59 Å. The β′ form is an ideal crystal for creating products with a soft mouthfeel and texture[65]. The diffractogram of the chocolate spread, substituted with palm-coconut oleogel 25% (A-25), was compared to the control (A-0%), as shown in Fig. 3.

The X-ray diffraction pattern shows that the control (A-0%) formed peaks at d-spacings of 4.26 Å, 3.95 Å, and 3.54 Å, identified as form III (β′) crystals. In the B-25% chocolate spread treatment, peaks were formed at d-spacings 4.26 Å, 3.95 Å, and 3.60 Å, identified as form III (β′) crystals. The peaks formed show that the control and the B-25% chocolate spread treatment have a crystalline phase. The absence of β-form crystals shows the absence of needle-like crystals (Fig. 1).

The intensity of the diffraction peak at a d-spacing of 4.26 Å in the chocolate spread with 25% oleogel increased compared to the control due to the addition of oleogel. This shows that increasing beeswax content promotes crystallization, resulting in a chocolate spread with an appropriate degree of crystallinity and crystal orientation. Based on the microstructure results, long chains and saturated fatty acids (the presence of CH_2, C = O esters, and C–O), specifically in beeswax, can trigger faster crystal formation, which may contribute to increased hardness, intermolecular bonds, and stickiness[55,56]. Beeswax also binds components more strongly, thereby increasing cohesion and forming a stronger and more stable crystalline network[16].

Conclusion

In conclusion, palm–coconut oleogel showed strong potential as a partial replacement for conventional fat in chocolate spread formulations. The incorporation of oleogel not only improved

important physicochemical characteristics, including color, texture, crystal structure, and polymorphic stability, but also enhanced consumer acceptance, particularly in taste, texture, and spreadability. The formation of predominantly β′-crystals indicates a desirable crystal network that provides a smooth, stable product structure. Among the formulations tested, the use of 25% palm–coconut oleogel appeared to offer the best balance between functionality and sensory quality, producing a chocolate spread with acceptable color, soft texture, and high panelist acceptability. Therefore, palm–coconut oleogel can be considered a promising alternative fat ingredient for developing chocolate spread products with improved quality while reducing dependence on conventional fats. However, higher substitution levels showed limitations, particularly reduced spreadability and less favorable textural attributes.

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Simple mineral treatment rescues flaxseed oil, slashing bitterness and keeping omega-3-rich flavour intact

How can the mild flavour of flaxseed oil be preserved for longer? A research team led by Roman Lang from the Leibniz Institute for Food Systems Biology at the Technical University of Munich has investigated this question. As the team demonstrates in its study, natural precursors of bitter-tasting compounds can be gently removed from the oil using bleaching earth (magnesium-aluminum silicate).

This results in significantly fewer bitter-tasting compounds formed during storage, and the flaxseed oil remains flavour-stable for longer. The particular advantage: The high content of health-beneficial fatty acids as well as the oil's typical character are preserved despite the purification process. These findings are published in the journal *Applied Food Research*.

The German Federal Center for Nutrition recommends reducing saturated fatty acids in the diet in favor of polyunsaturated fatty acids, as this can help lower LDL cholesterol levels and reduce the risk of coronary heart disease. Flaxseed oil can contribute to this, as it is particularly rich in the polyunsaturated omega-3 fatty acid alpha-linolenic acid.

However, flaxseed oil has a drawback: while it has a pleasantly mild taste when fresh, it quickly develops bitter notes during storage and eventually becomes inedible. Previous research by the Leibniz Institute and the Technical University of Munich had already shown that so-called cyclolinopeptides are responsible for this change in taste. These peptides, which are naturally present in the oil, oxidize during storage into substances with a strong bitter taste.

"We therefore investigated whether the flavor stability of flaxseed oil can be improved by specifically removing these cyclolinopeptides," explains principal investigator Roman Lang. To test this hypothesis, the research team examined eight mineral-based cleaning agents approved for the refining of edible oils, including bleaching earth.

Successful application on a laboratory scale

On a laboratory scale, the research team at the Leibniz Institute has now succeeded in selectively reducing the natural bitter compound precursors using magnesium-aluminum silicate. When the researchers mixed 200 grams of oil with 10 grams of the natural mineral, stirred it for 20 minutes at 30°C, and separated the mineral again by centrifugation, the cyclolinopeptide content in the oil decreased by more than 80%. The color, odor, and fatty acid profile of the oil remained largely unchanged.

Sensory tests subsequently confirmed the success of the new research approach: While the untreated flaxseed oil exhibited a noticeable bitterness right from the start, the treated oil tasted hardly bitter at all. The taste advantage of the treated oil persisted even over a longer period.

As the research team further reports, although the bitterness increased in both samples after nine weeks of storage in the dark, the treated oil reached only the bitterness level of fresh, untreated oil. Even at room temperature, under UV light and air exposure, the oil purified with bleaching earth remained milder for longer and exhibited significantly lower concentrations of bitter-tasting oxidation products.

Potential for more sustainable food production

Given the rising demand for omega-3-rich foods, the new research approach offers a solid foundation for extending the sensory shelf life of flaxseed oil and increasing consumer acceptance—without chemical additives or complex refining.

The researchers view the reduction of cyclolinopeptides as a sustainable approach to waste prevention due to the extended shelf life.

In further studies, they aim to investigate the optimal combination of materials used, as well as the influence of treatment duration and temperature on cyclolinopeptide residues and the stability of polyunsaturated fatty acids, in order to further refine the purification process.

Source: Phys.org

Could Cultured Chocolate Unlock the Next Food Revolution?



UC Davis researchers are working with Sacramento company California Cultured to develop alternatives to cocoa harvested from cacao trees, which are threatened by climate change. Ripe cacoa pods on a tree located at the UC Davis Botanical Conservatory greenhouse.

Researchers at the University of California, Davis, are working with California Cultured, a Sacramento based food-tech company, to keep chocolate affordable and sustainable by growing everyone's favorite treat directly from plant cells.

According to a 2024 report from the National Confectioners Association, 65% of U.S. consumers consume chocolate as an affordable treat, driving $21.4 billion in confectionery sales. By 2029, U.S. chocolate sales are projected to reach $37.6 billion.

However, cacao, the plant that gives us cocoa, is rapidly declining. Climate change-related excessive heat, erratic rainfall, prolonged droughts and flooding have already caused significant cocoa crop failures in Ivory Coast, the world's leading producer of cocoa beans. Farmers are seeing lower yields, dying trees and in some cases total harvest loss. A 2025 study projects that up to 50% of the current cocoa growing areas in Ivory Coast could become unsuitable by 2060 due to shifting temperature and rainfall patterns.

While the data may taste bitter to chocolate lovers, scientists may have just found a sweet spot to tackle the challenge: Enter cultured chocolate.

Steve Lang, vice president of science and technology at California Cultured, believes that chocolate grown in bioreactors could one day challenge the real thing without the deforestation, child labor and climate vulnerability that plague cacao farming.

With grants from the National Science Foundation and BioMADE, California Cultured and UC Davis scientists Karen McDonald, Somen Nandi, David Block, Harishankar Manikantan, Boon-Ling Yeo and Juliana de Moura-Bell are aiming to reduce cost drivers for cultured chocolate. Specifically, UC Davis labs will work with California Cultured to optimize prototype bioreactor geometries and operations to reduce costs.

Rise of cellular foods

As the debate around cultivated meat and plant-based proteins continues to swirl, a different technology is emerging: plant cell suspension culture.

Plant cell cultures can produce edible cells — think chocolate, coffee, berries, even walnut embryos — without the land, water or climate risks of traditional agriculture. They can also generate pigments, flavors, sweeteners and proteins that are chemically identical to their plant-grown counterparts.

Last year, at a talk hosted by iCAMP (Integrative Center for Alternative Meat and Protein), McDonald, distinguished professor emerita in the Department of Chemical Engineering, argued that this decades-old biotechnology could become one of the most versatile production platforms of cellular agriculture.

What are plant cell cultures?

While whole plant protein extraction, animal cell culture and fungal/yeast fermentation are often the main production routes for alternative protein and cultivated meat, plant cell bioreactor cultures are playing an increasingly significant role in the sustainable production of foods and key food ingredients.

The approach relies on dedifferentiated plant cells (as well as more organized tissues such as plant embryos and even whole small aquatic plants such as duckweed) that can be grown in liquid media, using simple ingredients like sucrose, salts, vitamins and plant hormones. Unlike whole plants, these cells don't need sunlight. They grow in the dark, metabolizing sugar, and can be propagated indefinitely.

"They're maintained using plant growth-regulating hormones," McDonald explained. Because the cells grow in sterile, controlled environments, they're insulated from drought, pests, heavy metals and other agricultural hazards and provide a food-safe product. They also avoid the inefficiencies of field-grown crops, such as discarding the stems, leaves, or roots.

Scientific challenges

Despite the advancements in technology, the field faces several significant challenges. Traditional bioreactors are prohibitively expensive to purchase and operate for food products. California Cultured has developed low-cost alternative bioreactors suited specifically to plant cell cultivation. UC Davis plant cell culture expertise will contribute to validating prototype designs, improving cleaning and sterilization techniques and assessing advances in commercial viability.

Recent work by California Cultured demonstrated proof of concept for growing *Theobromo cacao* cell culture in novel large-scale (1600 L) bioreactors. Researchers are also working to develop food-safe growth media, improve strain productivity and understand the sensory and nutritional properties of cultured plant cells. Lang anticipates commercial cocoa powder production to start in early 2027 to fulfill their first purchase order from a chocolate company.

Source: UC Davis Research

Enzymes pack a punch as clean label superstar:

Consumers are looking for ways to lead healthier lifestyles, and they're finding several ways to do it. This includes eating foods with fewer calories, more protein and fiber as well as natural foods that have clean labels, something Generation Z and millennials are especially interested in.

Circana's Global Health and Wellness Market report published in October said clean label foods are among the wellness foods that will dominate innovation pipelines in the future. That, along with laws banning certain ingredients, means that food manufacturers have plenty of incentive to clean up their labels.

"Clean label is still a major priority in bakery, and enzymes have become one of the most powerful tools for shortening ingredient lists without compromising performance," said Constance Macri, R&D manager, bakery improvers and innovation, Puratos. "Bakers often lean on enzymes when they want to move away from ingredients that sound overly synthetic to consumers — things like emulsifiers (DATEM, SSL)

or chemical dough conditioners such as azodicarbonamide or potassium iodate."

Enzymes allow bakers to eliminate ingredients that consumers find objectionable while providing a wide range of functionality.

"In markets around the world, 'cleaner label' has moved from a trend to an expectation," explained Mauricio Arrieta, strategic marketing director bakery, North America, Kerry. "Enzymes are substrate specific and therefore are extremely valuable in the baking industry, used as highly functional ingredients that can reduce the need for conventional additives and improve the dough system for desired characteristics."

Nicole Rees, product director, AB Mauri North America, explained that as laws and tastes change, producers must be aware of them and adjust accordingly.

"The clean label trend never goes away, but it certainly has a different focus year to year," she said. "With individual states legislating against specific ingredients like DATEM and bromate, there's been a need to help bakers move away from these ingredients as quickly as possible."

Enzymes are valuable for baked foods because consumers consider them natural, enabling bakers to reduce synthetic additives, and perform a wide variety of functions such as improved dough handling, extended shelf life and more.

"Common functions enzymes perform are improving dough strength and elasticity, mix reduction, flavor enhancement, improving handling and tolerance in processing, increasing volume and crumb structure softness and anti-staling, and natural emulsification effects for crumb softness," said Bradley Cain, president, Cain Food Industries.

Enzymes make the components of wheat flour more functional in the bread system.

"Enzymes cut down starch into simple sugars like glucose to provide food for yeast," said Sherrill Cropper, new product development lab manager, Lesaffre. "Also, starch degrading enzymes can cut down starch into longer chain disaccharides or polysaccharides, which helps to extend the shelf life and prevent starch retrogradation, aka starch staling."

Because enzymes act in a targeted and highly specific way, they give bakers precise control over performance without overcomplicating formulations, said Gwynnie Hagen, global category marketing manager bakery food enzymes, IFF.

"Enzymes support a wide range of functions across bakery categories, from bread and buns to sweet goods, cakes and flatbreads," she noted.

Enzymes act on starches, proteins, lipids and fibers during mixing, fermentation and baking, said Joy Zhong, R&D director, Kemin Food Technologies, North America.

"Often, a blend of various enzymes is used to achieve very specific needs by application," she said. "These are micro-dosed in various ways to support the textural stability and quality of finished goods and are also used during processing to help improve machinability, processing time, yield and waste reduction."

Sustainability is another asset of enzymes.

"What I like about enzymes is that they are environmentally friendly, more sustainable to produce as well as to dispose," Rees said.

Additionally, enzymes drive waste reduction by lowering production losses, preventing early staling, minimizing product returns and ensuring better slicing and packaging performance, Arrieta pointed out.

"They also allow for nutritional optimization by mimicking the processing or sensory effects of fat and sugar, effectively reducing their requirement in dough," he said. "Finally, enzymes are critical in

frozen dough applications, where they prevent quality loss caused by water migration, ice crystal formation and compensating for the reduced yeast activity."

Enzymes can replace chemical oxidizing agents such as ADA, ascorbic acid and bromate, said Sivakumar Pattathil, director, baking applications and R&D, Lallemand Baking Solutions (North America).

"Glucose oxidase and lipase used together can partially or fully substitute for gluten by improving dough structure and gas retention," he said. "Meanwhile, starch-degrading enzymes such as amylase and amyloglucosidase can generate fermentable sugars within the dough, allowing partial or complete replacement of added sugar when applied in effective combinations."

"Oxidizing enzymes — such as glucose oxidases, hexose oxidases and sulfhydryl oxidases — promote the formation of disulfide linkages between gluten molecules," Pattathil said. "This results in a more cohesive and elastic gluten matrix capable of retaining fermentation gases efficiently, ultimately supporting improved loaf volume."

One key mechanism of enzymes is strengthening the gluten network.

Source: Backing Business

DILL (*ANETHUM GRAVEOLENS LINN.*) ESSENTIAL OIL

Introduction :

Dill (Anethum graveolens Linn.) is a seed spice crop and an important aromatic herb which is used for flavouring tea, pickles, and confectionery. Dill leaves are rich in minerals, proteins and fibre. The seeds are mainly used for spice, culinary and medicinal uses. It is also used as a vegetable and an aromatic, and as an inhibitor of sprouting in stored potatoes. The aroma volatiles of seed and herb of dill have been identified along with several therapeutic properties, and the antimicrobial activity of carvone isolated from the dill seed oil has been reported. Dill contains carotenoids, vitamin C and polyphenols, the contents of which vary during different stages of its growth.

Dill is probably native to South West Asia or South East Europe, and has been cultivated since ancient times. Europe, Africa and Asia are considered as the centre of origin for dill crop. It is cultivated worldwide in countries like India, Germany, Hungary, the Netherlands, Pakistan and the USA. Principal dill production areas are India and Pakistan; but Egypt, Mexico, the Netherlands, the USA, Hungary, Germany and Holland also have commercially productive a

of sowa (A. sowa) in the states of Rajasthan, Gujarat, Maharashtra, Andhra Pradesh and Madhya Pradesh for its seeds.

The earliest reference to the use of dill seed in medicine goes back to 'Charak Samhita' (700 BC). It is an ancient Egyptian remedy described in the Ebers papyrus (1500 BC), where it is an ingredient in a pain-killing mixture. The Romans chewed dill seeds to promote digestion, and they hung dill garlands in their dining halls, believing the herb would prevent stomach upset. It was also spread on the floors of banquet halls so that its fragrance would counteract the heavy food smells. In the seventeenth century, Nicolas Culpeper listed dill as a 'tonic that strengthens the brain'. The Puritans were known to place dill seeds in their Bibles to discreetly chew so that their stomach would not rumble during the long church services.

Botanical Name:

Anethum graveolens Linn.(European or common dill) or Anethum sowa (Indian dill).



Habitat and Cultivation :

There are two closely related cultivated species of dill, i.e. European dill (A. graveolens) and Indian dill (A. sowa). European dill is widely distributed in the world. Indian dill, which grows in India, has a lower carvone content and a slightly different flavour. The seeds are longer and narrower, with paler ridges. In India, dill is considered a minor seed spice crop and its cultivation is limited to a few parts of the country. Farmers cultivate the local varieties using their own seed. Mehasana local and Ruby local are those used by farmers in Gujarat and Pratapgarh local by farmers in Rajasthan.

The National Research Centre on Seed Spices in India has developed and recommended two improved varieties of dill: Ajmer dill 1 (NRCSS-AD-1) and Ajmer dill 2 (NRCSS-AD-2) for general cultivation. Ajmer dill 1 is a European-type dill variety which is suitable for cultivation under irrigated conditions. The leaves are dark green in colour with good content of herbal constituents. The seeds are dillapiole-free and contain about 3.5 % essential oil. The average plant height of Ajmer dill 1 is 134 cm. It takes about 142 days to reach maturity and yields 14.7 q/ha of seed under irrigated conditions. Ajmer dill 2 is an Indian-type dill variety, with bold, compact and dark brown seeds. It is suitable for cultivation under irrigated and rain-fed conditions. The average plant height is 90 cm and it takes about 135 days to reach maturity. The average seed yield is 14.6 q/ha under irrigated conditions and 5.8 q/ha under rain-fed conditions. The seed of this variety contains about 3.2 % essential oil.

Harvesting :

Dill essential oil is harvested by timing the collection of either the fresh leaves/stems (dill weed oil) or the mature seeds (dill seed oil) and extracting the oil usingsteam distillation.

1. Choosing What to Harvest

- **Dill Weed Oil (from leaves and stems):** Harvested during the pre-blossoming to early-blooming phase when the plant is lush and green, maximizing compounds like phellandrene and a fresh, herbaceous aroma.
- **Dill Seed Oil (from seeds):** Harvested right after the plant has bloomed when the seeds are formed and changing color, which maximizes the high carvone content.

2. Timing the Harvest

- **Time of Day:** For seed harvest, collect the plants in the early morning while dew is still on them; this prevents the dry seeds from shattering and dropping off the umbels.
- **Maturity:** Wait until the main terminal umbels reach proper maturity, keeping in mind that different umbrella clusters (umbels) on the plant mature at slightly different rates.

Extraction Method :

A dill extraction plant is a specialized facility designed to extract essential oil from the seeds and/or aerial parts (leaves and stems) of the dill plant (Anethum graveolens). Dill oil is known for its fresh, herbaceous, slightly sweet aroma and is widely used in flavoring foods, as well as in pharmaceuticals, perfumery, and aromatherapy for its digestive and calming properties.

The most common method of extraction in such a plant is steam distillation. In this process, cleaned and dried dill seeds or herb parts are placed in a distillation chamber. Steam is passed through the plant material, vaporizing the essential oil. The oil-laden steam is then cooled in a condenser, and the essential oil is separated from the water in a collection vessel. The final oil is filtered and stored in airtight, light-resistant containers to preserve its therapeutic and aromatic qualities.

Modern dill extraction plants are equipped with stainless steel distillation units, boilers, condensers, separators, and precise temperature and pressure control systems. These facilities follow GMP (Good Manufacturing Practices) and often meet food or pharmaceutical-grade standards. The two main types of dill oil are dill seed oil, which contains high levels of carvone, and dill weed oil, which is richer in compounds like limonene and phellandrene. The plant's design ensures efficient oil recovery, hygiene, and safety during production.

Chemical Composition of Dill Essential Oil :

The chemical composition of dill essential oil (Anethum graveolens L.) varies significantly depending on the part of the plant used (seeds/fruit vs. leaves/herb) and its geographic origin.

1. Dill Seed / Fruit Oil (Seed Oil)

Dill seed oil is typically high in oxygenated monoterpenes and monoterpene hydrocarbons, with carvone and limonene making up 70% to 95% of the total composition:

- **Carvone:** 30% to 60% (often higher in European cultivars, reaching up to 81–89%)
- **Limonene:** 15% to 45%
- **Dihydrocarvone / Trans-dihydrocarvone:** 4% to 13%
- **Myristicin:** 0% to 24% (varying by region)
- **Dillapiole:** Present in notable amounts (up to 15–26%) in certain Indian or local chemotypes, though typically absent in European types.

2. Dill Herb / Weed Oil (Leaf and Stem Oil)

Essential oil extracted from the fresh aerial green parts contains higher proportions of monoterpene hydrocarbons and ether compounds:

- **Phellandrene:** 20% to 56%
- **Dill Ether:** 3% to 21%
- **Limonene:** 10% to 19%
- **Carvone:** 8% to 19% (lower than in seeds)
- **Carvacrol / p-Cymene:** Variable amounts (3% to 22%)

Benefits and Uses of Dill Seed Oil :

Dill seed oil is a warm, spicy, and caraway-like essential oil extracted from the seeds of the dill plant (Anethum graveolens) via steam distillation.

Key Benefits

- **Digestive Relief:** High carvone content helps relax smooth muscles in the gut, easing bloating, gas, indigestion, and intestinal spasms.
- **Calming and Sedative Effects:** Aromatherapy usage promotes nervous system relaxation, reduces mental tension, and aids with mild insomnia or stress.
- **Antimicrobial and Antiseptic:** Contains compounds that fight bacteria and support minor skin healing when properly diluted.
- **Galactagogue Support:** Traditionally used to help stimulate milk production in nursing mothers (though essential oil ingestion should be approached with caution).
- **Respiratory Care:** Possesses mild mucolytic and anticatarrhal properties that help clear the respiratory tract during colds or bronchitis.

Common Uses:

- **Aromatherapy and Diffusers:** Add a few drops to a vaporiser, diffuser, or steam bath to calm nerves and clear the air.
- **Massage and Topical Blends:** Dilute with a carrier oil (such as sesame or jojoba oil) and massage onto the abdomen for digestive comfort or onto joints to ease stiffness.
- **Skin care and Cosmetics:** Incorporated into soaps, lotions, and shaving creams for its refreshing scent and antioxidant properties.
- **Flavoring and Culinary:** Used in small, food-grade amounts to enhance marinades, soups, pickling brines, and savory dishes.
- **Precaution:** Essential oils are potent. Always dilute dill seed oil with a carrier oil before skin application, and consult a doctor before use if you are pregnant, breastfeeding, or managing a medical condition.

Compiled by:
Dr. S. Adhikari

LAUGH AND LOUD



Q. Why do elements make terrible friends?

A. They're always reacting.

****

Q. Why is combining a proton and an electron to make a neutron so popular?

A. It's free of charge.

****

Q. What can run but cannot walk?—

A . Water

****

Q . Why did the physicist break up with the biologist?

A. There was no chemistry.

****

Q. Why do plants hate algebra?

A. It gives them square roots

****

Q. What did one DNA say to the other DNA?

A. Do these genes make me look fat?

****

Q. Why did sodium break up with chlorine?

A. Because it felt salty.

****

Q. What's a geologist's favourite type of music?

A. Rock.

****

Q. What kind of tree can fit into your hand?

A. palm tree.

****

Q. How does a scientist freshen her breath?

A. With experi-mints

****

Q. What do you call it when your science teacher lowers your grade?

A. Bio-degraded.

****

Q. What did the science book say to the math book?

A. You've got problems.

****

Q. Why did the robot go on vacation?

A. Because it needed to recharge its batteries

****

MEMBERS' PAGE

HOW TO IMPROVE BONE HEALTH

by R.C. ARORA (Ex. Manager Q.C. - S.F.F.I., New Delhi)

3 Vitamins and Minerals that are a must- have :

The foundation of a healthy and active life is strong bones. Despite its importance, many tend to overlook bone health. Nutrients are essential for maintaining bone density and strength.

Incorporating three key vitamins and minerals - calcium, vitamin D, and magnesium - into the diet can significantly improve bone health and reduce the risk of fractures. Let's take a look.

Calcium : Calcium is the building block of bones. About 99% of the body's calcium is stored in bones and teeth. It is responsible for strengthening bones by supporting their structure and density. A deficiency may result in the body pulling calcium from bones, and would increase fracture risk.

Vitamin D : is another essential nutrient required for bone health. This vitamin helps calcium absorption in the intestines, ensuring the mineral reaches your bones. Without it , even a calcium-rich diet may fall short. Low vitamin D levels are linked to weakened bones, which increases fall risk, particularly in the elderly.



Magnesium : The role of magnesium in bone health is often overlooked despite its significance. Magnesium plays a critical role in converting vitamin D into its active form and supporting bone mineralisation. About 60% of the body's magnesium is stored in bones, and deficiency is linked to reduced bone density.

How to boost bone health

1. Consume adequate calcium daily from dairy, leafy greens, or fortified foods.
2. Get vitamin D daily via sunlight, fatty fish, or supplements.
3. Include magnesium - rich foods from nuts, seeds, and whole grains.
4. Do weight-bearing exercises like walking or jogging for atleast 30 minutes.
5. Perform strength training exercises 2-3 minutes weekly.
6. Practice balance exercises like yoga to reduce the risk of falls.
7. Limit sodium, caffeine, and soda to minimize calcium loss.
8. Quit smoking to prevent bone weakening.

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