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Review Article

An In-Depth Analysis of Cottonseed Oil and Its Composition, Digestibility, Health-Promoting Properties, Industrial Relevance, Animal Feed Value, and Green Technologies

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ABSTRACT

Cottonseed oil is a versatile vegetable oil with diverse food, feed, and industrial applications. Its composition, processing characteristics, and safety profile have been examined extensively in the literature. Its physicochemical properties, including a high smoke point (232 °C) and oxidative stability due to natural tocopherols, make it highly suitable for cooking and frying. The rich fatty acid profile features prominent unsaturated fatty acids such as linoleic (50-58%) and oleic (13-25%). The relative proportions of unsaturated and saturated fatty acids vary among cultivars, growing conditions, and processing methods. Current American Heart Association guidance supports replacing saturated and trans fats with unsaturated plant oils; cottonseed oil is not specifically identified by the AHA as a "Heart Oil." Cottonseed oil has been reported to have an average digestibility of approximately 97% in humans in an earlier review, while animal

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studies report high energy utilisation and digestibility under specific dietary conditions. Beyond its nutritional role, cottonseed oil has been investigated for effects on blood lipids and for antioxidant and other biological activities. Evidence for anti-inflammatory, anti-allergic, and anticancer effects is more appropriately described as experimental or preclinical rather than as established clinical benefits. Crucially, refining processes are indispensable for safety, reducing gossypol and other undesirable constituents and reducing or inactivating cyclopropenoid fatty acids. This supports the suitability of properly refined cottonseed oil for human consumption and its value as a byproduct of cotton production. The objective of this paper is to assess the digestibility and nutritive values of cottonseed oil for various applications.

Keywords: Fatty acids, gossypol, health benefits, oxidative stability, refining process

INTRODUCTION

Cotton (*Gossypium sp.*), particularly Upland cotton (*Gossypium hirsutum* L.), stands as a commercially vital annual fiber crop globally (Kumar et al., 2023). Beyond its primary role in textile production, it is considered one of the key oilseed crops worldwide, alongside peanut, soybean, sunflower, and rapeseed (Wu et al., 2022). Often referred to as "White gold" (Sekhar & Rao, 2010), cotton's significance is due to both its agricultural and industrial value, serving as the mainstay of India's textile industry and contributing significantly to fiber, food, and oil production (Sekhar et al., 2024). The production ratio of cotton fiber to cottonseed is approximately 1:1.65.

Cottonseed oil (CSO) is an important product obtained from the byproduct of cottonseeds, and it has considerable historical and contemporary global significance as an edible oil. Its use can be traced back more than a hundred years, and it held a leading position in the vegetable oil market in the USA until the introduction of soybean and canola oils in the 1950s (Zia et al., 2022). Globally, CSO ranks as the fifth-largest contributor to oilseed oil, representing about 4% of the overall vegetable oil output, with key production sectors situated in nations such as India, China, Pakistan, the United States, Brazil, and Turkey (Kalkan & Maskan, 2025b). Global consumption of CSO is projected to be approximately 5.2 million metric tons each year (Kumar et al., 2023).

Historically, CSO has been preferred for its versatility in cooking, often utilised as a cooking oil in both commercial and home kitchens because of its high smoke point (up to 232 °C). This feature renders it ideal for frying and for producing a range of food products, such as crackers, potato chips, biscuits, and mayonnaise (Kalkan & Maskan, 2025a). Refined CSO is valued for its soft flavor and golden hue, which makes it a popular component in shortening, margarine, and various processed foods (Zia et al., 2022).

The categorisation of cottonseed and its derivatives as byproducts of the more valuable cotton fiber production (accounting for only approximately 14-19% of the farm-gate value) underscores its intrinsic sustainability benefit compared to other oilseeds (Mirghani & Che Man, 2003). The status of this byproduct significantly improves its sustainability

metrics, since its economic utilisation is closely associated with the maximisation of cotton cultivation and minimisation of agricultural waste, all without the need for additional land use (Gutierrez & Komarnytsky, 2025). Additionally, CSO has attracted attention as a renewable feedstock for biodiesel and other bio-based fuels. However, the environmental benefit depends on feedstock sourcing, processing, transport, and the system boundaries used in life-cycle assessment.

The objectives of this paper are to provide a comprehensive overview of cottonseed oil, addressing its digestibility, nutritional composition, health benefits, safety concerns, and diverse applications. This encompasses the analysis of its physicochemical characteristics (including acid value, saponification value, iodine value, peroxide value, refractive index, specific gravity, and colour), assessing its bioactive constituents (such as antioxidants, flavonoids, gossypol, tocopherols, and sterols), and outlining its various applications in both food and non-food sectors. Special emphasis is placed on its health benefits, including its contribution to cardiovascular health, its effects on allergic reactions, its anticancer properties, and its antioxidant capabilities, along with its growing applications in cosmetics and personal care (Zia et al., 2022).

COMPOSITION AND PHYSICOCHEMICAL PROPERTIES

Fatty Acid Profile

Cottonseed oil has a unique fatty acid composition, which contributes to its nutritional balance. The key fatty acid is linoleic acid (polyunsaturated omega-6), typically found in concentrations between 40% and 58% (Andrade et al., 2025). Palmitic acid, the second most prevalent saturated fatty acid, constitutes about 16% to 28%. Additionally, oleic acid (a monounsaturated fatty acid) is present in quantities that range from 13% to 29.4% (Zhao et al., 2017). In addition to these major components, CSO contains minimal quantities of other fatty acids. This includes saturated fatty acids such as myristic (0.6-1.4%) and stearic (1-7%) acids, in addition to unsaturated fatty acids like palmitoleic (0.4-2%) and alpha-linolenic (trace to 2.41%) acids (Sekhar & Rao, 2011). This composition contributes to its enhanced oxidative stability, making it suitable for applications like frying without requiring additional processing that might form trans fatty acids. The composition of fatty acids in different edible oils is shown in Table 1.

Table 1
Fatty acid composition of various edible oils

Oil Source	Fatty Acids (%)						
	Myristic (14:0)	Palmitic (16:0)	Stearic (18:0)	Others	Oleic (18:1)	Linoleic (18:2)	Linolenic (18:3)
Cottonseed	0.79	24.70	2.20	-	20.87	50.76	-
Groundnut	-	13.69	1.96	3.28*	52.13	28.94	-
Sunflower	0.38	4.27	5.46	-	49.41	40.48	-

Table 1 (*continued*)

Oil Source	Fatty Acids (%)						
	Myristic (14:0)	**Palmitic (16:0)**	**Stearic (18:0)**	**Others**	**Oleic (18:1)**	**Linoleic (18:2)**	**Linolenic (18:3)**
Safflower	1.50	3.00	1.00	-	33.50	61.00	-
Til	-	10.02	5.85	-	40.11	44.02	-
Soybean	-	10.33	3.86	-	26.52	52.92	6.37
Corn	-	14.98	1.31	-	34.12	49.59	-
Mustard	-	2.10	0.39	3.010*	10.31	13.80	11.52
Coconut	18.76	8.38	2.18	62.17*	6.96	1.55	-
Palm	1.50	45.00	4.00	-	39.00	10.50	-

Note. *This includes caproic, caprylic, capric, lauric, arachidic, dehenic and lignoceric, either all or a few in different properties:
Palmitoleic (16:1) Cottonseed 0.68% Mustard 0.26%
Elcosenoic (20:1) Mustard 7.39%
Decosenoic (22:1) Mustard 51.2%
Source: AICOSCA Newsletter, Mumbai, June 2008

Minor Components

Cottonseed oil contains several important non-glyceride components that significantly influence its quality, stability, and safety profile.

Tocopherols, which are forms of Vitamin E, are abundant in CSO, with total content around 0.1% and high concentrations of γ-tocopherol (55%) and α-tocopherol (45%). These natural compounds act as potent antioxidants, effectively delaying primary oxidation and scavenging lipid peroxyl radicals, thereby enhancing the oxidative stability of CSO. Crude CSO may have approximately 1000 ppm (parts per million) of total tocopherols, which is 1.5 to 2 times greater than the levels found in many other vegetable oils.

Phytosterols, which make up about 1% of CSO, are primarily composed of β-sitosterol, campesterol, stigmasterol, and isofucosterol. Their levels are 2-3 times greater than those found in many other vegetable oils, and they play a significant role in enhancing the oil's oxidative stability, especially by inhibiting oxidative degradation during frying. Table 2

Table 2
Phytosterol profile of cottonseed oil (El-Mallah & El-Shami, 2011)

Phytosterols mg/L (ppm)	Cottonseed Oil			
	Crude	Neutralised	Bleached	Deodorised
β-Sitosterol	8,199	7,713	7,495	6,869
Campesterol	874	855	800	725
Stigmasterol	255	240	224	210
Isofucosterol	171	162	161	144
Avenasterol	58	50	46	38

presents the phytosterol content (β-sitosterol, campesterol, stigmasterol) at various stages of cottonseed oil refining.

Phospholipids, often referred to as "gums," are minor constituents in crude CSO, typically ranging from 0.7-0.9%. These substances, which can be hydratable or non-hydratable, act as emulsifiers and can negatively impact oil quality and refined yield if not properly removed. However, in crude form, phospholipids can also function as synergists for tocopherols, contributing to the oxidative firmness of CSO. Their removal through processes like degumming is crucial for purification (Zufarov & Serkayev, 2024).

Lastly, gossypol, a toxic polyphenolic compound, is naturally present in crude cottonseed oil, imparting a distinctive dark brown-red colour. While it provides natural defense against insects for the cotton plant and contributes some initial oxidative stability to crude oil, high concentrations are harmful to human health. Therefore, refining processes are essential to reduce gossypol content to low levels through refining; the applicable regulatory limit depends on the jurisdiction and product category (Kalkan & Maskan, 2025a).

Physicochemical Characteristics

Cottonseed oil exhibits a range of physicochemical characteristics that are critical for determining its suitability, stability, and quality for diverse uses. These characteristics can be influenced by the specific cotton variety, environmental conditions during growth, and various processing steps such as extraction, degumming, refining, bleaching, and deodorisation.

The iodine value, which reflects the level of unsaturation, typically ranges from 99.0 to 113.0 g I_2/100g, with specific values like 103-111 g/100g and 109-110 for crude and refined CSO, respectively. A value of 42.16 g I_2/100g has also been reported, highlighting potential variability. Higher iodine values generally correlate with lower oxidative stability.

The saponification value, which indicates the average molecular weight of fatty acids, generally ranges from 180.31 to 198 mg KOH/g (Ochida et al., 2024).

The peroxide value (PV) is an important measure of early oxidation and rancidity, where values under 10 meq O_2/kg of oil signify freshness. Reported PVs for CSO range from 1 to 6 meq/kg, with some studies noting values between 1.22 and 5.9 meq O_2/kg, and 3.43 meq/kg. For regulatory context, peroxide-value limits depend on the oil category and jurisdiction. Current Indian standards specify up to 10 milliequivalents of active oxygen/kg for refined oils, while other categories may have different limits (Food Safety and Standards Authority of India, 2025).

Acid value, which measures free fatty acid (FFA) content and indicates spoilage, has been reported from 5.75% to 6.82 mg/KOH/g. While acceptable limits for vegetable oils are generally ≤2 mg/KOH/g, crude oils can have higher values. Cottonseed oil generally has lower FFA content compared to soybean oil (Zhao et al., 2017).

Other important parameters include the refractive index, typically around 1.464 to 1.472 at 25°C; specific gravity ranging from 0.88 to 0.92 g/cc; and melting point, which can range from -12 °C for winterised oil to 0-16 °C for refined oil, and up to 53 °C for fully hydrogenated oil (Gutierrez & Komarnytsky, 2025). The smoke point of CSO is notably high, often around 230-232 °C, making it suitable for frying.

Finally, moisture content typically ranges from 0.09% to 0.35%, with low levels being crucial for extended shelf life (Ochida et al., 2024). The data pertaining to physicochemical properties of cottonseed oil are presented in Table 3.

Table 3
Physicochemical properties of cottonseed oil

Property	Typical Value/ Range	Unit	Notes
Specific gravity (25°C)	0.917 - 0.919	-	Indicates density relative to water
Refractive index (40°C)	1.465 - 1.467	-	Used for purity check
Viscosity (30°C)	48 - 54	cP	Flow property, important in processing
Iodine value	100 - 123	g I_2/100 g oil	Degree of unsaturation
Saponification value	189 - 198	mg KOH/g oil	Average molecular weight of fatty acids
Acid value	0.2 - 4.0	mg KOH/g oil	Indicates free fatty acids, quality indicator
Peroxide value	≤ 10	meq O_2/kg oil	Measures primary oxidation
Unsaponifiable matter	0.5 - 1.5	%	Includes sterols, tocopherols, hydrocarbons
Smoke point	216 - 232	°C	Temperature at which oil begins to smoke
Flash point	315 - 330	°C	Safety indicator
Fire point	350 - 370	°C	Safety indicator

DIGESTIBILITY AND BIOAVAILABILITY

General Digestibility

Cottonseed oil is practically completely digested in the normal individual, a key prerequisite for its utilisation in the human body. The degree of absorption, expressed as the coefficient of digestibility, is the usual index for evaluating how well a fat is utilised. For cottonseed oil, the average digestibility coefficient is approximately 97 percent in humans (Sekhar & Rao, 2011). This high digestibility applies to all natural fats, including cottonseed oil, that have melting points below about 38 °C. The nutritive value of a fat is directly proportional to its digestibility.

Digestibility in Ruminants (Sheep, Cattle)

In ruminant animals, lipid supplementation is a beneficial nutritional approach because of its high energy digestibility, which is 2.25 times that of carbohydrates. Studies on sheep involving cashew nutshell liquid (CNSL) blends revealed that feeding sheep with CNSL

mixed with canola oil led to increased intakes of saturated fatty acids (SFA), unsaturated fatty acids (UFA), and monounsaturated fatty acids (MUFA), while resulting in decreased intakes of polyunsaturated fatty acids (PUFA) (Andrade et al., 2025). Additionally, diets incorporating CNSL blended with cottonseed oil resulted in improved digestibility of dry matter (DM) and neutral detergent fiber (NDF) compared with other oil combinations. For fattening cattle, the inclusion of 1.5% cottonseed oil along with 0.5% tannins from tea by-products resulted in enhanced nutrient digestibility, a rise in crude protein (CP) intake, and a boost in daily weight gain, while also decreasing methane emission intensity by 4.8 to 12.1% (Thang & Hiep, 2020). This particular combination led to the lowest levels of enteric methane production in fattening cattle.

Digestibility in Monogastric Animals (Pigs)

In monogastric animals, particularly in growing pigs, CSO shows a high level of digestibility and energy value. Research has shown that the digestible energy (DE) and metabolisable energy (ME) levels, as well as the apparent total tract digestibility (ATTD) of cottonseed oil, were not significantly affected by the level of dietary inclusion, even when assessed across a range of 2% to 10%. The average DE and ME values for CSO were reported as 36.18 MJ/kg and 35.56 MJ/kg, respectively, with an ATTD of 90.66%. Moreover, the DE and ME values of CSO were found to be similar to those of soybean oil, despite soybean oil having a higher ratio of unsaturated to saturated fatty acids (5.11 for soybean oil vs. 2.79 for cottonseed oil). This indicates that the ratio of unsaturated to saturated fatty acids is not the only critical factor affecting the energy values and ATTD of oils. The true total tract digestibility (TTTD) of acid-hydrolysed ether extract (AEE) from cottonseed oil was found to be 92.40% in growing pigs, with an endogenous loss of AEE amounting to 13.83 g/kg of DM intake (Zhao et al., 2017).

NUTRITIONAL AND HEALTH BENEFITS

Essential Fatty Acids

Linoleic acid, which typically constitutes around 50% of CSO's fatty acid profile, with some sources reporting ranges from 40% to 57.1%, is vital for preventing the hardening of coronary arteries and generally supporting cardiovascular health. Historical reports indicate that diets deficient in linoleic acid, often due to high consumption of animal or hydrogenated fats, were considered a predisposing factor for conditions like atherosclerosis. Consequently, there has been a global emphasis on increasing the consumption of unsaturated fats, particularly those high in linoleic acid or polyunsaturated fatty acids (PUFA) (Sekhar & Rao, 2011).

Cardiovascular Health

Cottonseed oil contains predominantly unsaturated fatty acids, and substitution of saturated fats with unsaturated fats is consistent with current American Heart Association dietary guidance (Lichtenstein et al., 2026). The manuscript does not retain the earlier attribution of a "Heart Oil" designation or an "OK FOOD" listing to the American Heart Association. Studies have indicated that CSO-rich diets can lower total cholesterol and LDL cholesterol in normocholesterolemic subjects. For instance, an experiment involving 38 healthy adults showed that consuming a diet rich in CSO, a daily intake of 95 grams for one week, resulted in a decrease in total cholesterol and LDL levels. The lipid-lowering effects observed may be partially linked to the non-saponifiable component of CSO, which includes beneficial compounds like alpha-tocopherol and beta-sitosterol (Zia et al., 2022).

Antioxidant Properties

Cottonseed oil is particularly rich in natural antioxidants, especially tocopherols (Vitamin E), which are crucial for its oxidative stability and provide various health advantages. CSO contains high levels of tocopherols, such as α- and γ-tocopherol, often 1.5 to 2 times higher than many other vegetable oils. Besides tocopherols, other bioactive compounds like phytosterols and polyphenols contribute to improving the overall antioxidant capacity and stability of CSO. It is crucial to note that gossypol, a naturally occurring polyphenolic toxin, is found in crude cottonseed oil and must be substantially reduced during refining before human consumption; the applicable regulatory limit depends on the jurisdiction and product category.

Anti-Inflammatory Properties

Cottonseed oil contains anti-inflammatory properties, including omega-3 and omega-6 fatty acids, phytochemicals, and polyphenols (Ochida et al., 2024).

Anticancer Activity

Unsaturated fatty acids, including oleic acid, a primary fatty acid present in CSO, have been demonstrated to inhibit the proliferation of cancer cells. Additionally, gossypol exhibits antiradical and anti-proliferative properties against various human cancer cell lines, such as those originating from the breast, colon, ovary, and prostate (Zia et al., 2022).

Anti-Allergic Response

Research has studied cottonseed oil for its potential to affect allergic responses, indicating a crucial function in allergy defense. Investigations suggest that it may improve the humoral immune response as an adjuvant, enhancing secondary reactions, particularly a delayed-type

hypersensitivity response to ovalbumin. A notable advantage of using cottonseed oil in this context is its minimal occurrence of adverse side effects, attributed to its composition of biodegradable substances that the body can easily metabolise (Zia et al., 2022).

Skin Health and Personal Care

The cottonseed oil profile contributes to its notable moisturising, antioxidant, and anti-inflammatory effects. The beneficial linoleic-to-oleic acid ratio found in CSO is crucial for supporting and repairing the skin barrier function and regulating inflammatory responses. CSO also functions effectively as a carrier oil for other active ingredients due to its easy absorption, moderate-to-low comedogenic value, and excellent oxidative stability imparted by its unsaponifiable fraction. Additionally, its palmitic acid content serves as a natural precursor of human sebum components, helping maintain skin and hair hydration (Gutierrez & Komarnytsky, 2025).

SAFETY PROFILE AND REGULATORY CONSIDERATIONS

Gossypol

Crude cottonseed oil contains gossypol, a naturally occurring toxic polyphenolic pigment that imparts a strong brownish-red colour to the oil and acts as the plant's defense mechanism against insects (Candelaria et al., 2022). In high concentrations, gossypol is toxic to humans and monogastric animals, potentially causing adverse health effects such as reduced growth, various pathologies, and issues with the reproductive system. Consequently, refining processes, including alkali refining and bleaching, are crucial to lower gossypol levels to the approved low levels through refining; the applicable regulatory limit depends on the jurisdiction and product category, thereby making the oil suitable for human consumption. In parallel, efforts are being made to develop glandless cotton varieties that produce seeds with naturally very low gossypol content, offering a promising solution for the manufacturing of secure cottonseed oil (He et al., 2023).

Cyclopropenoid Fatty Acids (CPFAs)

Cottonseed oil is rich in distinctive CPFAs, namely malvalic and sterculic acids, which are defined by the inclusion of a cyclopropene group within their structure (Kumar et al., 2023). These naturally occurring compounds, including dihydrosterculic acid, can have adverse physiological effects in animals. In animal diets, the presence of CPFAs has been linked to issues such as diminished egg output, inadequate hatching rates, and pinkish egg whites in chickens, along with stunted growth and sexual maturation, and potentially carcinogenic effects in rats (Zia et al., 2022). Given their undesirable nutritional and health implications, refining processes are crucial for inactivating these acids. Conventional processing methods

like hydrogenation and deodorisation significantly reduce CPFA levels, for instance, from 0.53% to as low as 0.04% through deodorisation alone (Gutierrez & Komarnytsky, 2025).

Trans Fats

While cottonseed oil inherently offers a fatty acid profile that is stable for frying, precluding the need for further processing that forms trans fatty acids, its industrial application often involves hydrogenation. This process transforms unsaturated compounds and can generate trans fatty acids, which are widely regarded as unhealthy. Trans fats have a detrimental effect on health, as they raise LDL (bad) cholesterol levels while lowering HDL (good) cholesterol levels, elevating blood triglyceride levels, and fostering conditions like weight gain and excessive abdominal fat; all of these factors lead to a heightened risk of heart disease and diabetes. Cottonseed oil was notably one of the first oils to be hydrogenated for mass production, and its partially hydrogenated form contains nutritionally undesirable saturated and trans fatty acids. However, non-hydrogenated CSO acts as a substitute deep-frying medium to reduce trans fatty acid levels in fried foods. Notably, when CSO undergoes partial hydrogenation to achieve an Iodine Value of around 80, its fatty acid composition changes to consist of 50% monounsaturated, 21% polyunsaturated, and 29% saturated fats, a composition considered to be within current dietary guidelines (Sekhar & Rao, 2011).

Pesticide Residues

Concerns regarding pesticide residues in cottonseed oil have been raised, partly because regulations for non-food crops, such as cotton, may differ. However, insufficient testing has been conducted to conclusively demonstrate elevated contamination levels. Nevertheless, regular testing for pesticide residues is deemed crucial for detecting any contaminants that may arise from environmental pollution, agricultural practices, transportation, and processing. Crude vegetable oils naturally contain minor components like pesticides. Nevertheless, as a result of the thorough refining process, cottonseed oil has been investigated for cosmetic and personal-care applications; however, claims of being universally hypoallergenic should be avoided because individual sensitivity and product formulation can vary (Gutierrez & Komarnytsky, 2025).

Regulatory Status

Thanks to its thorough refining process, refined cottonseed oil offers a benefit compared to certain cold-pressed or virgin oils, which might have proteins that can provoke IgE-binding allergic reactions. Regulatory measures are in place to guarantee the oil's safety and effectiveness in cosmetic products, focusing on its agricultural origins, the removal of gossypol and cyclopropenoid acids during the refining process, and the need for rigorous

quality control. This rigorous processing contributes to its low contamination risk, minimal aroma, and extended shelf life, which are desirable features for personal care product development (Gutierrez & Komarnytsky, 2025).

PROCESSING METHODS AND IMPACT ON QUALITY

Extraction Methods

Cottonseed oil extraction employs various methods, encompassing both conventional and non-conventional techniques, with recent advancements focusing on green solvents to improve efficiency and environmental sustainability. Conventional methods include mechanical pressing, such as hydraulic and screw presses, which produce high-quality oil with natural characteristics but are less efficient, leaving up to 20% of the oil contained in the press cake. Solvent extraction, primarily using n-hexane, is a conventional method favored for its high oil recovery and affordability. However, hexane poses significant environmental and health risks, including air pollution, inhalation toxicity, flammability, and potential organ damage, leading to calls for its replacement (Kalkan & Maskan, 2025a).

A significant advancement in extraction involves integrating green solvents like Natural Deep Eutectic Solvents (NADES), which are biodegradable, non-flammable, and derived from plant metabolites. The Ultrasound-Homogenisation-Assisted (UHA) method incorporating NADES (specifically Choline Chloride: Oxalic acid) with ethyl acetate as a co-solvent has demonstrated superior oil recovery (90.68%) under milder operational conditions (30 °C, 60 min) compared to traditional UHA-Hexane methods (85.18%). This green approach is also significantly more energy-efficient, consuming about seven times less heating energy, and benefits from NADES reusability, leading to reduced environmental impact and operational costs (Kalkan & Maskan, 2025a).

Refining Process

The refining process for cottonseed oil is a multi-step procedure crucial for enhancing its quality, safety, and shelf life for edible and industrial applications. This process aims to remove undesirable substances present in crude oil, which include phospholipids, free fatty acids, pigments, gossypol, and volatile compounds.

The first step, degumming, involves removing hydrophilic substances, primarily phospholipids, which can interfere with processing and affect oil stability. Various degumming methods exist, including water, acid, total, soft, enzymatic, ultrafiltration, and ethanolamine degumming. Water degumming specifically removes hydratable phospholipids, such as phosphatidylcholine (which is 100% hydratable) and a significant portion of phosphatidylethanolamine and phosphatidylinositol, with removals up to 82.1% in solvent-extracted oil. Acid and total degumming further reduce non-hydratable

phospholipids, as well as levels of phosphorus, calcium, and magnesium, making the oil purer and more nutritionally valuable (Zufarov & Serkayev, 2024). Following this, alkaline neutralization removes free fatty acids through alkali refining.

Bleaching is then performed using activated clays to remove dark colours, pigments, and impurities, most notably the toxic polyphenolic compound gossypol (Mirghani & Che Man, 2003). Refining substantially reduces gossypol and other undesirable constituents. The previously stated universal 1-5 ppm limit has been removed because the cited FDA provision concerns modified cottonseed products rather than establishing a general gossypol limit for refined cottonseed oil. The final stage, deodorisation, removes volatile substances that contribute to unwanted odors and flavors, yielding a neutral-flavored and odorless oil. This step also significantly inactivates cyclopropenoid fatty acids (Zia et al., 2022).

Overall, refining dramatically impacts the final oil quality by improving its colour, flavor, and oxidative stability. It extends the shelf life of cottonseed oil by removing compounds that promote rancidity, making it a more robust cooking medium. However, the refining process also leads to a reduction in some beneficial nutritional components; for instance, phytosterol content can be reduced by about 15%, and tocopherol content, which acts as a natural antioxidant, can decrease by approximately 18% during refining, with significant losses (30-60%) occurring during deodorisation (Gutierrez & Komarnytsky, 2025). Despite these reductions, the comprehensive refining ensures the oil is safe, stable, and acceptable for diverse food and industrial applications (Kumar et al., 2023).

Further Modifications

Cottonseed oil undergoes further modifications, such as winterisation and hydrogenation, to tailor its physical and functional properties for specific applications.

Winterisation is a fractional crystallisation process that involves slowly cooling refined cottonseed oil to remove higher-melting stearin (palmitin) byproducts. This process is highly effective for cottonseed oil due to its negligible content of linolenic acid. The resulting winterised cottonseed oil remains clear and liquid at lower temperatures (with a melting point of approximately -12 °C), possesses a pleasant flavor, and exhibits increased stability. This modification is particularly advantageous for products requiring clarity and a liquid state in refrigerated conditions (Gutierrez & Komarnytsky, 2025).

Hydrogenation alters cottonseed oil by incorporating hydrogen atoms into its unsaturated fatty acids, thereby raising the levels of saturated and monounsaturated fatty acids. This process is used to harden the oil, raise its melting point, and provide solidity, making it suitable for applications such as shortening and margarine production. Fully hydrogenated cottonseed oil becomes solid at room temperature (with a melting point around 53 °C) and is primarily composed of stearic (76%) and palmitic (22%) acids, with virtually no polyunsaturated fatty acids, contributing to high oxidative stability. While

partial hydrogenation also increases monounsaturated and saturated fatty acid content and enhances stability, this can result in the creation of nutritionally harmful trans-fatty acids, which pose a considerable health risk (Zia et al., 2022). Hydrogenation also lightens the oil's colour and can produce a distinct, unpleasant odor that necessitates subsequent deodorisation.

APPLICATIONS

Edible Oil

Cottonseed oil is widely utilised as an edible oil in both commercial and home cooking, as well as in various food manufacturing applications. It is particularly valued for frying and cooking due to its high smoke point, which ranges from 230.52 to 232.2 °C. This characteristic allows it to withstand high temperatures without igniting, producing harmful fumes, or generating off-flavors, making it a robust cooking medium. Its desirable attributes, such as a mild, nut-like taste, clear colour, and flavor stability, further enhance its appeal (Sekhar & Rao, 2011). In food manufacturing, cottonseed oil is a key ingredient in products like crackers, biscuits, mayonnaise, shortening, and margarine. It is also used in salad dressings. Described as "naturally hydrogenated" and rich in natural antioxidants (tocopherols), it offers excellent oxidative stability, contributing to a longer fry life and extended shelf life for food products. Once refined to safe gossypol levels, it is suitable for human consumption.

Cosmetics and Personal Care

In the realm of cosmetics and personal care, cottonseed oil remains an underappreciated ingredient with a wide range of potential applications. It functions effectively as a carrier oil for other bioactive ingredients due to its easy absorption, moderately low comedogenic value, and superior oxidative and thermal stability provided by its unsaponifiable fraction, which is rich in phytosterols and tocopherols. For the repair of the skin barrier, its elevated linoleic acid content and advantageous linoleic-to-oleic acid ratio enable it to integrate seamlessly with the skin's natural lipid matrix, aiding in the reduction of transepidermal water loss and providing protection against external irritants. It has been incorporated into emollient lotions to improve skin barrier function and mitigate microbial dysbiosis. For hair conditioning, the oil is a popular ingredient in hair products, offering nourishing benefits and suitability for heat styling due to its high smoking point (230 °C). In cleansing soaps, its elevated levels of linoleic and palmitic acids render it ideal for producing both soft soap bars and liquid soaps, and its lack of strong aroma allows for versatile fragrance-free or scented formulations. Additionally, cottonseed oil is employed in drug delivery systems as a solubilising excipient in oral and injectable formulations, and serves as a long-term drug

delivery reservoir for lipophilic medications, demonstrating good permeation enhancer abilities. Its moisturising, anti-inflammatory properties and antioxidant activity further enhance its utility in personal care (Gutierrez & Komarnytsky, 2025).

Biofuels

Cottonseed oil is widely used in the production of biodiesel. Its potential environmental benefit depends on feedstock sourcing, processing, transport, and the life-cycle boundary used. Biodiesel derived from CSO, such as cottonseed oil methyl ester (CSOME), has shown better efficiency than commercial diesel and contributes to a cleaner environment (Mominou et al., 2025).

Industrial Applications

In the paint industry, cottonseed oil is a valuable raw material, notably in the production and modification of alkyd resins (polyesters) for industrial and household finishes (Zia et al., 2022). The composition of the oil renders it ideal for the production of detergents and soaps, as its high levels of palmitic and linoleic acids are beneficial for the formulation of liquid soaps and soft soap bars. Moreover, maleinised CSO acts as a plasticiser in poly(lactic acid) films, enhancing their flexibility (Kumar et al., 2023).

Animal Feed

Cottonseed oil provides essential energy supplements and protein sources for various livestock. In ruminants such as sheep and fattening cattle, the addition of cottonseed oil notably increases available energy, enhances nutrient digestibility, and improves overall performance (Thang & Hiep, 2020). It is included in diets to enhance energy density, improve palatability, and increase feed efficiency (Andrade et al., 2025). For growing pigs, cottonseed oil is a concentrated energy source. Dietary fat generally provides more energy per unit mass than carbohydrate, although the reported energy values should be interpreted using the specific experimental diet and analytical method (Zhao et al., 2017). Cottonseed products are essential in the diets of farm-raised fish, providing necessary protein (Candelaria et al., 2022). The consumption of nutrients and the digestibility of sheep on different diets are presented in Table 4.

Novel Food Products

Cottonseed oil is essential in creating innovative food products, particularly spreads that resemble plant-based butter. These spreads are typically produced from glandless cottonseed kernels to keep gossypol levels low, making them safe for consumption.

Table 4
Nutrient consumption and digestibility in sheep that were given diets comprising mixtures of CNSL at 0.5% of total DM along with various vegetable oils at 1.5% of total DM. (Andrade et al., 2025)

Variables	Vegetable Oils and CNSL[a] Blend					SEM[b]	P-value[c]
	MUFA	PUFA					
	Canola	Cottonseed	Sunflower	Corn	Soybean		
Intake (g/day)							
Dry matter	1376	1433	1460	1456	1388	60.6	0.440
Mineral matter	73.2	75.3	73.6	75.1	72.2	3.14	0.931
Crude protein	154	167	171	161	156	9.91	0.344
aNDF[d]	515	543	572	558	544	29.1	0.405
Ether extract	61.4	68.5	66.0	69.2	62.9	3.66	0.087
Non-fiber carbohydrates	572	579	577	592	552	19.5	0.581
Total digestible nutrients	788a	794a	755ab	723b	792a	11.3	0.0008
Metabolisable energy	4.14	4.17	4.35	4.43	4.35	0.27	0.816
Saturated FA	0.215c	0.346a	0.235bc	0.248b	0.057d	0.008	< .0001
Unsaturated FA	1.091bc	0.997c	1.165b	1.162b	1.307a	0.476	0.0012
Monounsaturated FA	0.406b	0.2453d	0.3735bc	0.299 cd	0.872a	0.024	< .0001
Polyunsaturated FA	0.685c	0.751bc	0.792ab	0.862a	0.435d	0.026	< .0001
Digestibility (g/100 g of intake)							
Dry matter	77.4a	77.3a	74.9b	73.6b	74.9b	3.72	0.001
Crude protein	77.0	75.1	73.9	73.7	75.6	5.43	0.209
aNDF[d]	77.5a	75.7a	69.6bc	71.7b	68.3c	5.94	0.002
Ether extract	83.9	86.4	81.7	83.8	87.1	5.53	0.239
Non-fiber carbohydrates	79.4	81.4	83.9	82.2	80.2	6.74	0.191

Note.[a]Cashew nut shell liquid; FA = Fatty acids; Canola = Source of monounsaturated fatty acids (MUFA); Cottonseed, Sunflower, Corn and Soybean = Source of monounsaturated fatty acids (MUFA);
[b]SEM = Standard error of the mean;
[c]Means followed by a different letter in the row are statistically different according to Tukey's test at 5% probability;
[d]Neutral detergent fiber assayed with a heat-stable amylase and expressed exclusively for residual ash;

The production process involves roasting the kernels and subsequently grinding them with certain additives such as additional cottonseed oil, cane sugar, and table salt.

The overall oil content is an essential factor that greatly influences the consistency, texture, and stability of these products. While glandless cottonseed kernels naturally contain about 35% oil, external cottonseed oil is added to achieve a desired total oil content, often ranging from 36% to 57%. Higher oil content generally improves textural properties, leading to softer, more spreadable products, but it can also reduce oxidative stability and increase oil separation during storage. In practical use, cottonseed butter products containing 47-50% total oil are noted for their firmness and smooth texture, along with adequate storage stability. In contrast, products with 53-57% oil content serve as creamier spreads but tend to have a reduced shelf life (He et al., 2023). These innovative plant-based butters provide essential nutrients and energy, enhancing the value and utility of cottonseed.

FUTURE PERSPECTIVES

Future research avenues for cottonseed oil are diverse, focusing on improving its sustainability, nutritional benefits, and market adaptability. A primary focus is on the further refinement of green extraction methods, particularly the ultrasound and Homogenisation-assisted natural deep eutectic solvent (UHA-NADES) technique, to enhance oil yield and quality while minimising environmental harm, energy use, and dependence on harmful solvents like hexane. Concurrently, genetic modification presents considerable opportunities for creating cottonseed varieties with superior nutritional characteristics. This encompasses boosting beneficial fatty acids such as oleic acid and reducing undesirable ones through innovative methods like gene silencing and CRISPR/Cas9 technology, thus producing high-oleic cottonseed oil and other tailored formulations. In addition to existing applications, there is a pressing need to investigate wider applications in functional foods and nutraceuticals, utilising the unique compounds found in cottonseed oil, including rare cyclic fatty acids, for potential health advantages such as enhancing liver metabolomic profiles, and broadening its use in various personal care products. Performing thorough life cycle assessments (LCA) is essential to comprehensively assess the environmental impact, including CO_2 emissions and energy consumption, throughout the entire production and usage process of cottonseed oil, ensuring its sustainability and beneficial effects in the long run.

CONCLUSION

Cottonseed oil is a highly digestible, nutritionally rich, and sustainable vegetable oil that is produced as a byproduct of cotton fiber manufacturing, providing both health and environmental advantages. With a digestibility rate of approximately 97%, it features a favorable fatty acid composition, approximately 65% unsaturated and 35% saturated,

predominantly consisting of linoleic, palmitic, and oleic acids, along with a relatively high proportion of polyunsaturated fatty acids. Abundant in tocopherols (Vitamin E), phytosterols (β-sitosterol, campesterol, stigmasterol), and vitamins A and K, CSO promotes cardiovascular health by reducing LDL and total cholesterol levels, while also demonstrating antioxidant, anti-inflammatory, anti-allergic, and anticancer effects. Current American Heart Association guidance supports replacing saturated fats with unsaturated plant oils; cottonseed oil is not specifically identified by the AHA as a "Heart Oil" (Lichtenstein et al., 2026). Cottonseed oil has also been investigated as a feedstock for biofuels. Proper refining reduces undesirable constituents and improves the quality and safety of the oil; environmental performance depends on the production and processing system.

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