# ADSORPTIVE BLEACHING AS A CRITICAL STAGE IN COTTONSEED OIL REFINING: STRATEGIES FOR IMPROVING OIL QUALITY AND PROCESS EFFICIENCY

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**Abstract.** Cottonseed oil is more difficult to refine than most vegetable oils because, in addition to chlorophylls and carotenoids, it contains gossypol and related pigments that can become fixed in the oil and resist conventional treatment. Adsorptive bleaching is therefore a decisive stage for the colour, safety and stability of the refined product. This literature-based thesis reviews published research on the bleaching of cottonseed and other vegetable oils in order to identify how adsorbent selection and process conditions influence oil quality and process efficiency. The reviewed studies show that acid-activated and natural bleaching earths differ in pore structure and adsorption behaviour, that alternative adsorbents such as activated carbon and aluminium oxide have been tested for cottonseed oil, and that pretreatment can be necessary when colour is fixed. Temperature, contact time, adsorbent dosage and filtration are discussed as interdependent factors that affect not only pigment removal but also oil losses, energy use, oxidative stability and the formation or removal of process contaminants. The thesis distinguishes established findings from optimisation strategies that still require experimental validation under industrial conditions. No new experimental data are reported.

**Keywords:** cottonseed oil; adsorptive bleaching; bleaching earth; gossypol; process optimisation; spent bleaching earth; oil quality.

**Introduction and relevance.**

Cottonseed is grown mainly for fibre, but its oil is an important edible product in cotton-producing countries, including Central Asia. Crude cottonseed oil has a dark colour and a complex minor-component composition, and its refining is known to be more demanding than that of many other oils. Gossypol, a polyphenolic compound of the cotton plant, is a particular concern because it is toxic to humans and animals (Gadelha et al., 2014) and because gossypol-derived pigments contribute strongly to the colour of the oil. Refining typically includes degumming, alkali neutralisation, bleaching and deodorisation (Chandrasekar et al., 2015). Within this sequence, bleaching is the stage at which residual pigments, traces of soap and phosphatides, metals and oxidation products are removed by adsorption. Its outcome determines whether colour specifications are met and influences the stability and safety of the final oil. Bleaching also incurs costs through adsorbent consumption, heating, filtration and the loss of oil retained in the spent adsorbent. Improving this stage therefore matters both for product quality and for the economics and environmental footprint of cottonseed oil processing.

**Aim.**

The aim of this thesis is to analyse, on the basis of published literature, the role of adsorptive bleaching in cottonseed oil refining and to outline strategies for selecting adsorbents and process conditions that balance impurity removal against oil yield, energy use and product quality. The thesis is theoretical; recommendations are presented as hypotheses for experimental verification.

**Brief overview of the literature and methodological considerations.**

*Adsorbents.* Bleaching earths are clays, mostly of the smectite group, whose adsorption capacity depends on surface area, porosity and surface chemistry. Hussin et al. (2011) reviewed how acid, alkaline,



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thermal, organic and pillaring treatments modify these properties. Almeida et al. (2019) compared an acid-activated and a natural bleaching earth in palm oil and found that the acid-activated earth had greater micropore volume and adsorbed more carotenes per unit mass, with kinetic data indicating that more than one mechanism controlled the process. For cottonseed oil specifically, Chetima et al. (2018) studied activated carbons prepared from agricultural residues for bleaching neutralised oil and described adsorption with kinetic and isotherm models, with the Langmuir model generally fitting well.

*Colour fixation.* Cottonseed oil may develop fixed colour when seeds or crude oil are overheated or stored for long periods, and oil from immature or damaged seeds aggravates the problem (Helmy et al., 1994; Hammad et al., 2011). Hammad et al. (2011) reported that conventional bleaching alone did not reduce fixed colour sufficiently; alkaline or sodium silicate pretreatment followed by bleaching earth was effective, and a column system with aluminium oxide removed much of the colour and gossypol. Suvanova et al. (2024) proposed modified alkaline agents for cottonseed oil refining, showing that the quality of the oil entering bleaching depends on the preceding neutralisation step.

*Contaminants and by-products.* Bleaching interacts with the formation of 3-monochloropropane-1,2-diol esters (3-MCPDE) and glycidyl esters during later high-temperature deodorisation. In a recent review, Yıldız et al. (2024) noted that bleaching earth can remove precursors and esters, but that the effect depends on the earth type and conditions, and that acid-activated earths require attention as a possible source of chloride. The spent bleaching earth retains a substantial amount of oil; Benkhoud and Ben Mansour (2025) showed that part of this oil can be recovered by solvent extraction and that the deoiled earth can be thermally regenerated for reuse in oil bleaching.

*Methodological considerations.* Most published studies are laboratory-scale batch experiments, frequently on palm, soybean or corn oil rather than cottonseed oil, and they evaluate efficiency by colour or pigment reduction. Fewer studies report oil retention, oxidative stability, contaminant formation and energy demand together. Results from other oils therefore need to be transferred to cottonseed oil with caution.

**Discussion.**

*Adsorbent selection.* The literature supports the general principle that adsorbent choice should match the impurity profile of the oil. Acid-activated earths offer higher capacity for pigments (Almeida et al., 2019), but their acidity may promote undesirable reactions and contaminant precursors (Yıldız et al., 2024). Because cottonseed oil contains gossypol-derived pigments in addition to chlorophylls and carotenoids, a single adsorbent may not be optimal. Combinations of bleaching earth with activated carbon, or with pretreatment where colour is fixed, are supported by cottonseed-specific studies (Hammad et al., 2011), although their cost-effectiveness at industrial scale has not been established.

*Temperature and contact time.* Higher temperature lowers oil viscosity and can accelerate mass transfer to the adsorbent; however, adsorption equilibria and pigment stability also depend on temperature, and Chetima et al. (2018) observed temperature-dependent kinetics and equilibrium uptake for cottonseed oil. Prolonged exposure to heat, particularly in the presence of air and acidic surfaces, may favour oxidation. The appropriate temperature and contact time should therefore be defined as an optimisation window for each oil batch and adsorbent rather than as a single fixed value. Conducting bleaching under vacuum to limit oxidation is a common industrial practice, but its specific benefit for cottonseed oil requires confirmation.



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*Adsorbent dosage and oil yield.* Increasing dosage generally improves pigment removal up to the point at which equilibrium limits further gains, but each additional unit of adsorbent also retains oil, increases filtration load and adds to waste. This is the central trade-off of the bleaching stage. Strategies that can reduce dosage include better upstream refining, so that less soap and fewer phosphatides reach the bleacher (Suvanova et al., 2024), the use of higher-capacity adsorbents, and staged or counter-current contact. These strategies are plausible on theoretical grounds but require pilot-scale testing on cottonseed oil.

*Filtration.* Filtration determines how completely fine adsorbent particles are removed and how much oil remains in the filter cake. Incomplete removal may leave particles that catalyse oxidation, while oil retained in the cake is a direct yield loss. Steam or gas blowing of the filter cake, solvent recovery of retained oil and regeneration of spent earth (Benkhoud & Ben Mansour, 2025) are options for recovering value from the cake, but their energy and solvent demands must be weighed against the oil recovered.

**Conclusion and practical implications.**

Adsorptive bleaching is a critical control point in cottonseed oil refining because it determines colour, influences oxidative stability and contaminant levels, and accounts for a substantial share of oil losses and waste. Established findings indicate that adsorbent properties strongly influence pigment removal, that fixed colour in cottonseed oil may require pretreatment or alternative adsorbents, and that bleaching interacts with contaminant formation during deodorisation. On this basis, the following strategies are proposed for experimental validation: (1) characterising each crude oil batch for pigments, gossypol and residual soap before setting bleaching conditions; (2) comparing acid-activated, natural and combined adsorbents on cottonseed oil using criteria that include colour, oil retention, oxidative stability and 3-MCPDE and glycidyl ester levels; (3) defining temperature–time–dosage windows through designed experiments rather than fixed settings; (4) improving upstream neutralisation to reduce adsorbent demand; and (5) assessing oil recovery from and regeneration of spent bleaching earth in terms of yield, energy and environmental impact. Pilot-scale studies that measure quality and efficiency indicators together are needed to turn these proposals into reliable industrial recommendations.

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