

151^a DEFESA DE TESE EM ENGENHARIA INDUSTRIAL

PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA INDUSTRIAL - PEI



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Título: NOVEL BIOREFINING APPROACHES FOR OBTAINING HIGH-VALUE PRODUCTS FROM SUGARCANE FILTER CAKE: Cross-Meta-Analysis Protocol, LCA of the Swenson Process and Ultrasonic Biorefining.

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Resumo:

This doctoral research investigates the biorefinery processing of sugarcane wax and its derivatives, focusing on policosanol (Pc.) extraction technologies. Sugarcane (*Saccharum officinarum* L.) is a globally significant crop, with Brazil as a leading producer. Policosanol compounds are bioactive substances recommended for the prevention and treatment of cardiovascular diseases, among other applications. Extracting high-value bioproducts from sugarcane represents a strategic avenue for advancing sustainable biorefineries. The main Pc. extraction techniques discussed include saponification, solvent extraction, molecular distillation, transesterification, supercritical CO₂, and ultrasonic-assisted extraction. Chapters 1 and 2 apply an original Cross-Meta-Analysis Protocol, registered with PROSPERO (CRD42023425955), enabling regionalized and simultaneous analysis of scientific articles and patents while identifying uncertainties and three critical gaps in the literature. Chapter 3 includes a Life Cycle Assessment (LCA) of the Swenson process for extracting raw wax from sugarcane filter cake, monitoring 16 input and output variables using openLCA© software and the Ecoinvent© database. Alternative solvent analysis was conducted using Hansen solubility theory and HSPiP© software. No toxicity was observed for volatilized heptane in low-density areas, whereas toluene exhibited non-carcinogenic human toxicity potential estimated at 9.29×10^{-6} cases. Monte Carlo simulations (95 % coverage probability) revealed GWP 100 impacts (kg CO₂-eq per t) of the Swenson process: heptane, $(4.9 \pm 1.3) \times 10^3$ kg CO₂-eq/t for Bahia and $(9.6 \pm 2.8) \times 10^3$ for Cuba; toluene showed $(6.1 \pm 1.8) \times 10^3$ for Bahia and $(11.0 \pm 3.4) \times 10^3$ for Cuba. Internal reuse of process inputs makes the process environmentally favorable. Comparative analysis confirms heptane's environmental advantage over toluene in both regions. The final experimental phase focused on biorefining the filter cake using ultrasonic extraction. The high fatty acid and ester content in the lyophilized hydromethanolic extract of Cuban wax qualifies it as a potential biofuel feedstock. Linoleic acid, in particular, has applications in cleaning, chemical, and pharmaceutical products. Mixtures of palmitic and linoleic acids are marketed as adjuvants for foliar agricultural pesticides. The combination of Natural Deep Eutectic Solvents, sonication, and esterification significantly increased Pc. yield and purity with production costs three times lower than current market value - representing an impactful innovation. Yield analysis across 16 raw materials revealed the following categories: (0.51 to 0.70): three methods; moderate (0.38 to 0.51): four; low (0.25 to 0.38): seven. These results provide guidance for future research by biome and cost analysis, supporting laboratories, industry, and policymakers. Future research perspectives include techno-economic modeling of modular biorefineries, socio-environmental impact assessments, and pilot plant development for rural innovation. This thesis positions policosanol biorefinery as a promising frontier in the bioeconomy, integrating scientific rigor, technological innovation, and sustainability principles.

Palavras-chave: Policosanol Biorefinery; Cross-Meta-Analysis; LCA of Swenson Process; Natural Deep Eutectic Solvents; Ultrasonic Extraction.