Low-Cost Production of Sucrose Fatty Acid Esters from Sugarcane Molasses Using a Non-Aqueous Chemical Process

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Abstract

Sucrose fatty acid esters are biodegradable, non-ionic surfactants widely used in food, pharmaceutical, and cosmetic applications. Conventional production methods typically require purified sucrose and refined fatty acid derivatives, resulting in high processing costs and complex separation steps. This study presents a simplified and cost-effective chemical method for producing sugar esters directly from sugarcane molasses as a low-purity renewable feedstock. Free fatty acids were prepared from corn oil via saponification followed by acidification and purification. Esterification was conducted in a non-aqueous medium using dimethyl sulfoxide and tert-butanol as solvents at 60 °C for 24 h in the presence of molecular sieves to remove water formed during the reaction. The resulting products were separated and characterized using Fourier Transform Infrared Spectroscopy (FTIR). FTIR analysis confirmed the formation of ester bonds, as indicated by a strong absorption band near 1740 cm^{-1} corresponding to C=O stretching of ester groups, alongside characteristic C–H and C–O absorption bands of fatty acid sugar esters. The process was further evaluated through material and energy balance calculations and scaled to a conceptual industrial design with an estimated production capacity of 1000

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tons/year. An economic assessment demonstrated high feasibility due to the use of low-cost raw materials and simplified processing steps. Overall, these findings indicate that molasses can serve as an effective alternative feedstock for sucrose ester production, offering a sustainable and economically viable approach for local chemical manufacturing.

Keywords: Molasse, Esters of fatty acids, Sucrose fatty esters acid, Glucose and fructose esters

1. Introduction

Sucrose fatty acid esters are non-ionic surfactants widely recognized for their biodegradability, low toxicity, and excellent emulsifying properties. Due to their amphiphilic structure, these compounds are extensively used in food processing, pharmaceuticals, cosmetics, and agricultural formulations as stabilizers, solubilizers, and surface-active agents. Their production has attracted increasing attention as industries shift toward sustainable and bio-based chemical products(Csóka *et al.*, 2007; Teng *et al.*, 2021; Zheng *et al.*, 2015).

Industrial manufacturing of sucrose esters is typically performed using purified sucrose and fatty acids through chemical transesterification in organic media. However, the low solubility of sucrose in non-polar systems, high raw material purity requirements, and complex downstream purification steps contribute significantly to production cost. These limitations have motivated research into alternative feedstocks and simplified production strategies that can improve economic feasibility while maintaining product functionality(Cetinkaya *et al.*, 2020; Dirbeba *et al.*, 2021; Geremew Kassa *et al.*, 2024; Stubbs *et al.*, 2022).

Molasses, a by-product of sugar manufacturing, represents an abundant and low-cost renewable resource rich in fermentable sugars, primarily sucrose, glucose, and fructose. Despite its high carbohydrate content, molasses remains underutilized in chemical manufacturing and is often directed toward low-value

applications such as animal feed. Valorization of molasses as a direct substrate for esterification processes offers a promising pathway for producing high-value bio-based surfactants while reducing dependence on purified raw materials (Gutiérrez *et al.*, 2018; Jamir *et al.*, 2021; Mordenti *et al.*, 2021; Palmonari *et al.*, 2020).

Previous studies have primarily focused on sucrose ester synthesis using refined substrates or enzymatic catalysis under controlled conditions. While enzymatic methods provide high selectivity, their industrial implementation is limited by enzyme cost, reaction time, and substrate solubility constraints. Chemical methods remain the dominant industrial approach due to their scalability and robustness, yet opportunities remain for improving feedstock flexibility and reducing process complexity (Csóka *et al.*, 2007; Geremew Kassa *et al.*, 2024; Hyla and Janek, 2025; Neta *et al.*, 2015; Otache *et al.*, 2022).

This study proposes a simplified chemical method for producing sugar fatty acid esters directly from sugarcane molasses without prior sugar purification. The process employs free fatty acids derived from vegetable oil and conducts esterification in a non-aqueous solvent system under moderate temperature conditions. Product formed was verified using Fourier Transform Infrared Spectroscopy (FTIR), and the process was evaluated through material and energy balance analysis as well as conceptual industrial scale design and

economic assessment. The objective of this work is to demonstrate the technical feasibility and economic potential of molasses-based sucrose ester production as a sustainable approach for local chemical manufacturing.

2. Materials and Methods

2.1 Raw Materials and Instruments

Sugarcane molasses was used as the primary carbohydrate source due to its high content of sucrose, glucose, and fructose. The molasses was used without prior purification to evaluate its feasibility as a low-cost industrial feedstock. Corn oil served as the lipid source for fatty acid production. Dimethyl sulfoxide (DMSO) and tert-butanol were used as reaction solvents due to their ability to enhance miscibility between hydrophilic sugars and hydrophobic fatty acids. Sodium hydroxide, sodium carbonate, ethanol, and hexane were of analytical grade and used without further purification. The use of non-refined substrates was intended to simulate practical industrial conditions for bio-based surfactant production (Molasses: Types, Production and Uses).

The synthesized products were characterized using Fourier Transform Infrared Spectroscopy (FTIR) to confirm ester formation and identify functional groups. Spectral analysis focused on characteristic absorption bands of ester carbonyl groups, hydroxyl groups, and aliphatic chains. FTIR is widely used for structural

confirmation of carbohydrate-based esters and surfactants due to its sensitivity to functional group transformations.

2.2 Extraction of Corn Oil

Corn oil was extracted from ground corn using a Soxhlet extraction apparatus with hexane as the solvent. Extraction was conducted at approximately 50 °C using a solvent-to-solid ratio of 6 mL g^{-1}. After extraction, hexane was removed by evaporation to obtain crude corn oil. This method is widely used for efficient recovery of vegetable oils intended for chemical processing and fatty acid production.

2.3 Preparation of Free Fatty Acids

Alkaline saponification was used to get free fatty acids from extracted corn oil, which was then acidified. The oil was heated with a sodium hydroxide solution (40% w/v) in 95% ethanol to produce sodium soaps in aqueous solution. The reaction mixture was then acidified to produce free fatty acids, which were separated using a separating funnel and rinsed with hot distilled water to remove any remaining contaminants. This process yields fatty acids appropriate for esterification reactions in organic media(Bailey, 1951; Bockisch, 2015; Dutta *et al.*, 2007).



Figure.1: Free fatty acid extracting

2.4 Synthesis of Sugar Fatty Acid Esters

Molasses was dissolved in DMSO to solubilize the sugar components. Tert-butanol was used as a co-solvent to promote the solubility of fatty acids and phase compatibility. Molecular sieves were used for removing water produced during esterification, shifting the equilibrium toward ester formation. The reaction mixture containing free fatty acids, molasses, and tert-butanol was shaken at 200 rpm and 60 °C for 24 h in an incubator. After completion, the mixture was centrifuged at 5000 rpm to achieve phase separation. The upper phase containing the esterified products was collected and stored at −20 °C prior to analysis (Teng *et al.*, 2021).

2.5 Industrial Process Description for Sucrose Esters Production

The process begins by feeding a mixture of reactants and solvents into a batch reactor run at a temperature of 60 °C for 24 hours, as shown in **Figure**.2. Molecular sieves absorb excess water during the esterification reaction, leading to the production of sugar esters. After completion, transport the reaction mixture to a centrifuge for phase separation (Park *et al.*, 2018; Teng *et al.*, 2021). The heavy phase is discarded, while the light phase, which includes unreacted fatty acids, solvents, and esters, is used for further processing.

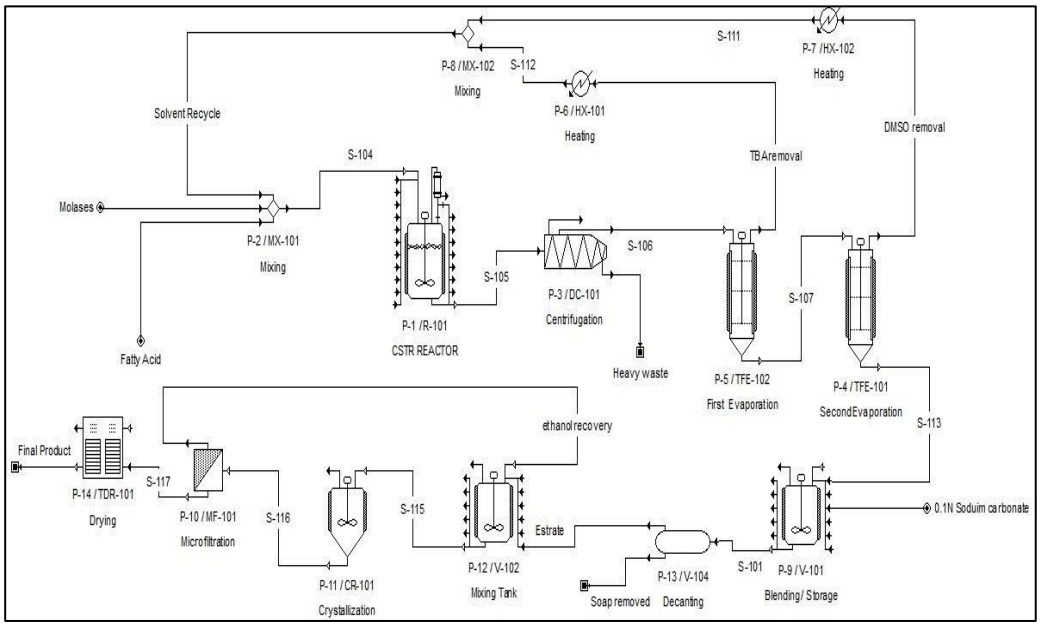


Figure.2: Sucrose esters production flow

The light phase undergoes two stages of vacuum evaporation to recover the solvents: first, TBA is removed and recovered at 50 °C and 0.2 atm. Second, the

mixture enters to separate and recover of DMSO at 60°C and 0.05 atm. The residual mixture containing free fatty acids and sugar esters is transfered to a mixer and add an aqueous solution of sodium carbonate (1N). This solution interacts with free fatty acids to create soap, resulting in two immiscible layers: aqueous soap and an organic layer with esters. The mixture is transferred to a phase separator to remove the soap layer. The remaining ester-rich phase is transferred to a crystallizer and pure ethanol is added. The temperature is slowly reduced to -5°C, selectively crystallizing the sucrose esters while leaving other esters in industrial process description to produce sucrose esters solution. The crystallized sucrose esters are separated with a filter, and the ethanol filtrate is transferred for recovery. The ester crystals are dried in a vacuum dryer to produce pure sucrose ester product (Gutiérrez *et al.*, 2018; Sasayama *et al.*, 2021).

2.6 Process Evaluation and Scale-Up Design

Material balance and energy balance calculations were performed to evaluate process feasibility and support conceptual industrial scale-up. The process flow included batch esterification, centrifugal separation, solvent recovery by vacuum evaporation, saponification of residual fatty acids, crystallization, and drying. Economic feasibility was assessed based on raw material consumption, equipment cost estimation, and projected production capacity (Park *et al.*, 2018)

. Integration of laboratory synthesis with process design is essential for evaluating the industrial applicability of bio-based surfactant production systems (Introduction to Chemical Equipment Design).

3. Results and Discussion

3.1 Synthesis of Sugar Fatty Acid Estere's

The purpose of this stage was to produce sucrose esters by reacting free fatty acids with the high sucrose content of molasses. The aim of this approach is to produce sucrose esters in a more economical way by utilizing locally available and inexpensive raw materials compared to other methods, resulting in lower-cost and more sustainable products.

3.2 Confirmation of Ester Formation by FTIR

Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the successful formation of sugar fatty acid esters from molasses-derived sugars and free fatty acids. The spectrum exhibited a strong absorption band near 1740 cm^{-1}, corresponding to the C=O stretching vibration of ester functional groups. This peak is a primary indicator of ester bond formation and confirms the occurrence of the esterification reaction.

A broad absorption band around 3400 cm^{-1} was observed, attributed to O–H stretching vibrations of residual hydroxyl groups within the sugar structure. The persistence of hydroxyl groups is consistent with partial esterification, which is commonly reported in sucrose ester synthesis due to the multiple reactive sites present in sugar molecules.

Additional absorption bands at 2920 and 2850 cm^{-1} were assigned to aliphatic C–H stretching vibrations of fatty acid chains, confirming the incorporation of lipid components into the final product. Strong bands within the range of 1050–1250 cm^{-1} correspond to C–O stretching vibrations associated with ester linkages and carbohydrate structures. The absence of a broad carboxylic acid O–H band in the region 2500–3000 cm^{-1} indicates involvement of free fatty acids during ester formation (Hu *et al.*, 2022).

These spectral features collectively confirm the successful synthesis of sugar fatty acid esters and are consistent with previously reported FTIR signatures for carbohydrate-based surfactants.

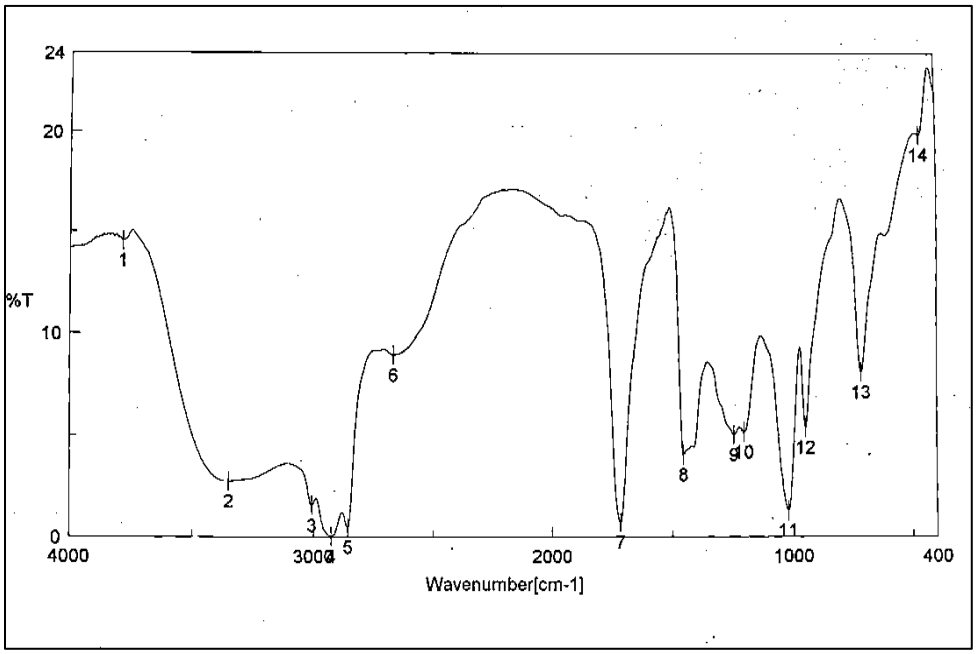


Figure.2: Fourier transform infrared spectroscopy (FTIR) for Fatty acids– Sugars esters.

3.3 Effect of Using Molasses as a Non-Purified Feedstock

The direct utilization of molasses as a sugar source represents a key innovation of this study. Unlike conventional processes that rely on purified sucrose, the present method demonstrates that esterification can proceed effectively in the presence of mixed sugars and non-sugar components (Addai *et al.*, 2020; Zhang *et al.*, 2021).

Molasses contains sucrose, glucose, fructose, minerals, and organic compounds that may influence reaction kinetics and product composition. Despite this complexity, successful ester formation indicates that high-purity substrates are not strictly required for the industrial production of sugar esters (El Asri and Farag, 2023). This finding supports the feasibility of employing low-cost industrial by-products as alternative feedstocks in bio-based surfactant synthesis. The use of non-refined substrates significantly reduces upstream processing requirements and may contribute to improved economic and environmental performance. Similar approaches emphasizing feedstock flexibility have been identified as critical factors for sustainable chemical manufacturing (El Asri and Farag, 2023; Phasha, 2025) (Molasses: Types, Production and Uses).

3.4 Reaction Conditions and Process Efficiency

Esterification was successfully achieved at 60 °C in a non-aqueous solvent system consisting of DMSO and tert-butanol. This moderate reaction

temperature demonstrates that effective ester formation can occur without extreme thermal conditions typically required in solvent-free systems.

The presence of molecular sieves played a crucial role in removing water generated during the reaction and shifting equilibrium toward product formation. This approach is widely recognized as an effective strategy for enhancing esterification efficiency in systems involving hydrophilic reactants.

Partial esterification observed in the FTIR analysis suggests the formation of a mixture of mono-, di-, and poly-esters. Such product distributions are commonly reported in chemical synthesis routes and are often desirable in industrial formulations due to their balanced hydrophilic–lipophilic properties.

3.5 Industrial Feasibility and Process Design Implications

Material and energy balance calculations support the technical feasibility of scaling the process to an industrial production. The proposed process integrates batch esterification, phase separation, solvent recovery, saponification of residual fatty acids, crystallization, and drying into a coherent production system.

The estimated production capacity of approximately 1000 ton/year demonstrates the potential of molasses-based synthesis for large-scale manufacturing. Economic evaluation indicates strong profitability driven by low-cost feedstock utilization and simplified processing steps.

The integration of laboratory synthesis with process design provides a comprehensive framework for evaluating the industrial applicability of sugar ester production from renewable resources. Process intensification through solvent recovery and raw material recycling further enhances both process sustainability and economic performance (Introduction to Chemical Equipment Design).

3.6 Comparison with Conventional Production Approaches

Traditional industrial production of sucrose esters typically employs purified sucrose and fatty acid methyl esters under controlled conditions. While these methods yield high product consistency, they require extensive purification steps and refined raw materials.

In contrast, the present method demonstrates that acceptable ester formation can be achieved using raw molasses and free fatty acids under moderate conditions. This approach simplifies raw material preparation and reduces process complexity while maintaining functional product characteristics (Plat and Linhardt, 2001).

The results suggest that molasses-based production represents a viable alternative pathway for manufacturing bio-based surfactants, particularly in regions with abundant sugar industry by-products.

3.7 Material balance

3.7.1 Process Production Capacity

The average production capacity of the plant was estimated based on the annual production rate and the number of operating days per year. The average daily capacity was calculated to be roughly 3300 kg/day by converting the annual output into kilograms and distributing it over the effective working days, as equation:

$$\textbf{Production Capacity} = 1000 \frac{ton}{year} \times \frac{1000\ kg}{1\ ton} \times \frac{1\ Year}{300\ day} = 3300\ \textbf{kg/day}$$

Molasses was selected as the primary carbohydrate feedstock due to its high sugar content. By weight, molasses typically includes 50% sucrose, 6.5% glucose, and 8% fructose. In addition, molasses is characterized by a high carbohydrate content, mostly made up of sucrose, along with small amount of fructose and glucose, which contributes to its applicability as a substrate in different industrial and biotechnological applications.

3.7.2 Mole balance for Sugars Esterification with oleic acid

3.7.2.1 Sucrose Esterification with Oleic Acid

$$C_{12}H_{22}O_{11} + 8\ C_{18}H_{34}O_2 \longrightarrow C_{12}H_6(OCO\text{-}R)_8 + 8\ H_2O$$

Where R = $C_{17}H_{33}$ (oleic acid chain)

Molecular formula of sucrose ($C_{12}H_{22}O_{11}$) = ~ 342.3 g/mol, and molecular formula of oleic acid ($C_{18}H_{34}O_2$) is ~ 282.5 g/mol. Sucrose has 8 hydroxyl (-

OH) groups, allowing reaction with up to 8 moles of oleic acid (Teng *et al.*, 2021).

Reactant molar quantities: -

1 mol sucrose (342.3 g) + 8 mol oleic acid (8 × 282.5 = 2260 g)

3.7.2.2 Glucose Esterification with Oleic Acid

Balanced Reaction:

$$C_6H_{12}O_6 + 5\ C_{18}H_{34}O_2 \longrightarrow C_6H_2(OCO\text{-}R)_5 + 5\ H_2O$$

Molecular formula of glucose ($C_6H_{12}O_6$) **is** ~ 180.2 g/mol. Glucose has 5 hydroxyl (-OH) groups.

Reactant molar quantities: -

1 mol glucose (180.2 g) + 5 mol oleic acid (5 × 282.5 = 1412.5 g)

3.7.2.3 Fructose Esterification with Oleic Acid

Balanced Reaction:

$$C_6H_{12}O_6 + 5\ C_{18}H_{34}O_2 \longrightarrow C_6H_2(OCO\text{-}R)_5 + 5\ H_2O$$

Molecular formula of fructose ($C_6H_{12}O_6$) **is** ~ 180.2 g/mol. Fructose, like glucose, has 5 hydroxyl (-OH) groups.

Reactant molar quantities: -

1 mol fructose (180.2 g) + 5 mol oleic acid (1412.5 g)

In practical and industrial applications for the synthesis of sugar using fatty acids, full theoretical molar calculations which assume esterification of all

hydroxyls (-OH) groups in the sugar molecule are generally not applied due to various technical and economic considerations. Therefore, it is common in industrial practice to use a fatty acid-to-sugar weight ratio ranging from 1.5 to 2.0, as follows: 1.5 kg of fatty acid per 1 kg of sugars (whether pure or as part of raw materials like molasses): to achieve moderate esterification, mainly producing mono- and di-esters. 2.0 kg of fatty acid per 1 kg of sugars: to increase the degree of esterification and obtain tri- or poly-esters (Cetinkaya *et al.*, 2020).

3.8 Reactor Feed Composition

The feed composition for the esterification reactor consisted of molasses, oleic acid, and two organic solvents used to improve the miscibility between hydrophilic sugars and hydrophobic fatty acids as shown in **Tables 1-4**.

Table .1: Reactor feed composition

Component	Input (kg)	Output (kg)
Molasses	4300	1821
Oleic acid	4100	410
DMSO	1260	1260
Tert-butanol	2940	2940
Sucrose ester	0	3400
Glucose ester	0	573
Fructose ester	0	763
Molecular sieves	1000	1000

The presence of DMSO and tert-butanol significantly improves the solubility of sugars and enhances mass transfer between reactants, which is essential for efficient esterification reactions involving carbohydrate substrates.

Table .2: Reactor feed composition on centrifugal

Component	Input (kg)	Output (kg)
Molasses	1821	1821
Oleic acid	410	410
DMSO	1260	1260
Tert-butanol	2940	2940
Sucrose ester	3400	3400
Glucose ester	573	573
Fructose ester	763	763

Table .3: Reactor feed composition on first evaporator

Component	Input (kg)	Output (kg)
Oleic acid	410	410
DMSO	1260	1260
Tert-butanol	2940	2940 (vapor)
Sucrose ester	3400	3400
Glucose ester	573	573
Fructose ester	763	763

Table .4: Reactor feed composition on second evaporator

Component	Input (kg)	Output (kg)
Oleic acid	410	410
DMSO	1260	1260 (vapor)
Sucrose ester	3400	3400
Glucose ester	573	573
Fructose ester	763	763

3.9 Conversion of Sugars in the Esterification Reactor

Mole balance of saponification reaction on blending tank

$$2\ C_{17}H_{33}COOH + Na_2CO_3 \longrightarrow 2\ C_{17}H_{33}COONa + H_2O + CO_2$$

2 mole oleic acid (2 x 282.460 g/mol) + mole sodium carbonate (105.99 g/mol) ⟶ 2 moles sodium oleate (2 x 304.44 g/mol) + 1 mole water (18.015g/mol) + 1mole CO_2 (44.01 g/mol)

Sodium carbonate needed to saponify 410 kg of oleic acid 410 x 1000 = 410000 g

410000/282.460 = 1451.5 mol

Sodium carbonate = 1451.5/2 =726 mole

=726 x 105.99 =77 kg For 1N Sodium carbonate

77 kg of pure Sodium carbonate = 763kg of 1N Sodium carbonate solution.

Table .5: Reactor feed composition on Dryer

Component	Input	Output
Sucrose ester	3400 kg	3400 kg

3.10 Conversion of Sugars in the Esterification Reactor

The molasses feed contained three major sugars: sucrose, glucose, and fructose. The esterification reaction was carried out at 60 °C for 24 h with pressure 1 atm. Thus, 90% of sugars were converted to esters**,** which is considered relatively high for heterogeneous sugar esterification systems (Gutiérrez Sánchez, 2018).

Table .6: Initial sugar composition

Sugar	Mass (kg)	Moles
Sucrose	2150	6281.5
Fructose	344	1909.4
Glucose	258	1432.1
Total sugars	2752	9623

3.11 Ester Product Distribution

The material balance around the reactor indicates the formation of three types of sugar esters. Sucrose esters represent the dominant product due to the higher concentration of sucrose in molasses (Bento *et al.*, 2019; Phasha, 2025). The formation of glucose and fructose esters confirms that all fermentable sugars in molasses participate in esterification**,** which significantly improves overall raw material utilization.

Table .7: Ester products from the reactor

Product	Mass (kg)
Sucrose ester	3400
Glucose ester	573
Fructose ester	763
Total esters	**4736 kg**

3.12 Solvent Recovery and Process Efficiency

After esterification, the reaction mixture underwent centrifugal separation followed by two evaporation stages for solvent recovery. The first evaporator

removed tert-butanol**,** while the second evaporator removed DMSO**,** enabling solvent recycling and reducing operating costs (Graczová *et al.*, 2020). The recovered solvents represented a significant fraction of the process mass balance:

Table .8: Total volume of reaction mixture

Solvent	Recovered mass
tert-butanol	2940 kg
DMSO	1260 kg

Efficient solvent recovery is essential for improving the economic viability of sugar ester production processes.

3.12 Energy Requirements of the Process

Energy balance calculations revealed that the esterification reactor represents the largest energy demand in the process**,** with a total heat duty of approximately:

$Q=8.14\times10^{6}$ kJ

This heat duty includes both sensible heating and the heat of reaction associated with ester bond formation. Additional energy requirements were associated with solvent evaporation and drying stages, particularly during tert-butanol removal in the first evaporator. Conversely, the crystallization stage exhibited a significant cooling requirement due to the exothermic crystallization of sucrose esters from the ethanol solution. These results highlight the importance of

energy integration and heat recovery in future industrial optimization(Rawlings and Ekerdt, 2002; Wangler *et al.*, 2022).

3.13 Economic Feasibility

Economic analysis indicated that the total production cost for 3400 kg of sucrose ester per day was approximately: 8436.63 USD/day. Raw materials represented the largest portion of operating costs, particularly oleic acid. Assuming an international market price of 6000 USD per ton, the annual revenue from a 1000-ton production capacity would reach approximately: 6,000,000 USD. After subtracting operating costs, depreciation, and taxes, the estimated net annual profit was approximately: 2.78 million USD. These results demonstrate that the proposed process has strong economic potential, particularly in regions where molasses is available as a low-cost by-product of the sugar industry.

4. Conclusion

This study demonstrated the feasibility of producing sugar fatty acid esters directly from sugarcane molasses using a simplified non-aqueous chemical process. The successful formation of ester bonds was confirmed by FTIR analysis, which identified characteristic absorption bands corresponding to ester carbonyl groups, aliphatic chains, and residual hydroxyl functionalities consistent with partial esterification. The FTIR results confirm that the esterification reaction between the fatty acid and the sugar alcohol was

successful. The formation of the ester group is clearly observed, and the presence of residual hydroxyl groups on the sugar is consistent with the partial esterification typically observed in sugar esters.

The results indicate that molasses can serve as an effective alternative feedstock for sucrose ester production without prior purification. The ability to utilize a low-cost and non-refined carbohydrate source represents a significant advantage over conventional production methods that rely on purified sucrose and refined fatty acid derivatives. The use of moderate reaction conditions and common organic solvents further supports the practicality of the proposed method.

Process evaluation through material and energy balance calculations demonstrated the technical viability of scaling the system to industrial production. Economic analysis indicated strong profitability driven primarily by the low cost of raw materials and simplified processing steps. These findings highlight the potential of molasses valorization as a sustainable pathway for manufacturing bio-based surfactants in regions with established sugar industries.

Overall, the study provides an integrated framework combining laboratory synthesis, process design, and economic assessment for the development of locally sourced chemical products. The proposed approach contributes to sustainable chemical manufacturing by promoting waste utilization, reducing reliance on imported raw materials, and enabling value addition to industrial by-products.

References

Addai, F. P., Lin, F., Wang, T., Kosiba, A. A., Sheng, P., Yu, F., . . . Shi, H. (2020). Technical integrative approaches to cheese whey valorization towards sustainable environment. *Food & function, 11*(10), 8407-8423.

Bailey, A. E. (1951). Industrial oil and fat products.

Bento, H. B., Carvalho, A. K., Reis, C. E. R., & De Castro, H. F. (2019). Microbial biodiesel production: From sucrose-based carbon sources to alkyl esters via enzymatic transesterification. *Process Safety and Environmental Protection, 121*, 349-356.

Bockisch, M. (2015). *Fats and oils handbook (Nahrungsfette und Öle)*: Elsevier.

Cetinkaya, S., Yenidünya, A. F., Başoğlu, F., & Sarac, K. (2020). D-Glucose-fatty acid ester synthesis with or without a Biocatalyst in the same organic media. *Journal of Oleo Science*, *69*(7), 737-742.

Csóka, G., Marton, S., Zelko, R., Otomo, N., & Antal, I. (2007). Application of sucrose fatty acid esters in transdermal therapeutic systems. *European journal of pharmaceutics and biopharmaceutics*, *65*(2), 233-237.

Dirbeba, M. J., Brink, A., Lindberg, D., Hupa, M., & Hupa, L. (2021). Thermal conversion characteristics of molasses. *ACS omega*, *6*(33), 21631-21645.

Dutta, P. C., Przybylski, R., Eskin, M. N., & Appelqvist, L.-Å. (2007). Formation, analysis, and health effects of oxidized sterols in frying fat. In *Deep frying* (pp. 111-164): Elsevier.

El Asri, O., & Farag, M. A. (2023). The potential of molasses from different dietary sources in industrial applications: A source of functional compounds and health attributes, a comprehensive review. *Food Bioscience, 56*, 103263.

Geremew Kassa, M., Asemu, A. M., Belachew, M. T., Satheesh, N., Abera, B. D., & Alemu Teferi, D. (2024). Review on the application, health usage, and negative effects of molasses. *CyTA-Journal of Food, 22*(1), 2321984.

Graczová, E., Šulgan, B., & Steltenpohl, P. (2020). tert-Butanol–water mixture separation by extractive distillation: Application of experimental data in process simulations. *Separation and Purification Technology, 251*, 116968.

Gutiérrez, M. F., Orjuela, Á., Rivera, J. L., & Suaza, A. (2018). Production of sucroesters using solvent-free reactive systems containing emulsifiers. *Ingeniería e Investigación, 38*(1), 16-23.

Gutiérrez Sánchez, M. F. (2018). Sucrose esters production in a solvent-free reaction system by transesterification of sucrose and fatty acid methyl esters.

Hu, Y., Ma, C., Liu, J., Bai, G., Guo, S., & Wang, T. (2022). Synthesis, physical properties, and in vitro-simulated gastrointestinal digestion of hydrophilic β-sitosterol sugar esters. *Journal of agricultural and food chemistry*, *70*(27), 8458-8468.

Hyla, K., & Janek, T. (2025). Sugar Esters of Fatty Acids: Chemo-Enzymatic Synthesis and Biological Activity. *Molecules*, *30*(15), 3123.

Jamir, L., Kumar, V., Kaur, J., Kumar, S., & Singh, H. (2021). Composition, valorization and therapeutical potential of molasses: a critical review. *Environmental technology reviews*, *10*(1), 131-142.

Mordenti, A. L., Giaretta, E., Campidonico, L., Parazza, P., & Formigoni, A. (2021). A review regarding the use of molasses in animal nutrition. *Animals*, *11*(1), 115.

Neta, N. S., Teixeira, J. A., & Rodrigues, L. R. (2015). Sugar ester surfactants: Enzymatic synthesis and applications in food industry. *Critical reviews in food science and nutrition*, *55*(5), 595-610.

Otache, M. A., Duru, R. U., Ozioma, A., & Abayeh, J. O. (2022). Catalytic methods for the synthesis of sugar esters. *Catalysis in Industry*, *14*(1), 115-130.

Palmonari, A., Cavallini, D., Sniffen, C., Fernandes, L., Holder, P., Fagioli, L., . . . Mammi, L. (2020). Characterization of molasses chemical composition. *Journal of dairy science*, *103*(7), 6244-6249.

Park, K.-M., Lee, S. J., Yu, H., Park, J.-Y., Jung, H.-S., Kim, K., . . . Chang, P.-S. (2018). Hydrophilic and lipophilic characteristics of non-fatty acid moieties: Significant factors affecting antibacterial activity of lauric acid esters. *Food Science and Biotechnology*, *27*(2), 401-409.

Phasha, M. J. (2025). *Conversion of sugar cane A-molasses and lignocellulosic biomass to value-added products: Techno-economics and greenhouse gas emissions*. Stellenbosch: Stellenbosch University,

Plat, T., & Linhardt, R. J. (2001). Syntheses and applications of sucrose-based esters. *Journal of Surfactants and Detergents*, *4*(4), 415.

Rawlings, J. B., & Ekerdt, J. G. (2002). Chemical reactor analysis and design fundamentals. *(No Title)*.

Sasayama, T., Hiromori, K., Takahashi, A., & Shibasaki-Kitakawa, N. (2021). Process for continuous production of sugar esters of medium-chain fatty acid: Effect of residence time on productivity and scale-up design.

Journal of Food Engineering, 305, 110608. doi:https://doi.org/10.1016/j.jfoodeng.2021.110608

Stubbs, S., Yousaf, S., & Khan, I. (2022). A review on the synthesis of bio-based surfactants using green chemistry principles. *DARU Journal of Pharmaceutical Sciences, 30*(2), 407-426.

Teng, Y., Stewart, S. G., Hai, Y.-W., Li, X., Banwell, M. G., & Lan, P. (2021). Sucrose fatty acid esters: Synthesis, emulsifying capacities, biological activities and structure-property profiles. *Critical reviews in food science and nutrition, 61*(19), 3297-3317.

Wangler, T., Pileggi, R., Gürel, S., & Flatt, R. J. (2022). A chemical process engineering look at digital concrete processes: critical step design, inline mixing, and scaleup. *Cement and Concrete Research, 155*, 106782.

Zhang, S., Wang, J., & Jiang, H. (2021). Microbial production of value-added bioproducts and enzymes from molasses, a by-product of sugar industry. *Food Chemistry, 346*, 128860.

Zheng, Y., Zheng, M., Ma, Z., Xin, B., Guo, R., & Xu, X. (2015). Sugar fatty acid esters. In *Polar lipids* (pp. 215-243): Elsevier.

الملخص:

تُعدّ إسترات الأحماض الدهنية للسكروز موادًا غير أيونية خافضة للتوتر السطحي قابلة للتحلل الحيوي، وتُستخدم على نطاق واسع في تطبيقات الأغذية والأدوية ومستحضرات التجميل. تتطلب طرق الإنتاج التقليدية عادةً إسكروزًا نقيًا ومشتقات أحماض دهنية مُكرّرة، مما يؤدي إلى ارتفاع تكاليف المعالجة وتعقيد خطوات الفصل. تُقدّم هذه الدراسة طريقة كيميائية مُبسّطة وفعّالة من حيث التكلفة لإنتاج إسترات السكر مباشرةً من دبس قصب السكر كمادة خام متجددة منخفضة النقاوة. تم تحضير الأحماض الدهنية الحرة من زيت الذرة عن طريق التصبن، متبوعًا بالتحميض والتنقية. أُجريت عملية الأسترة في وسط غير مائي باستخدام ثنائي ميثيل سلفوكسيد والبوتانول الثلاثي كمذيبات عند 60 درجة مئوية لمدة 24 ساعة في وجود مناخل جزيئية لإزالة الماء المتكون أثناء التفاعل. تم فصل المنتجات الناتجة وتوصيفها باستخدام مطيافية الأشعة تحت الحمراء . أكد تحليل FTIR تكوّن روابط الإستر، كما يتضح من حزمة امتصاص قوية قرب 1740 سم$^{-1}$ تُعزى إلى رابطة C=O في مجموعات الإستر، بالإضافة إلى حزم امتصاص C–H وC–O المميزة لإسترات سكريات الأحماض الدهنية. وقد خضعت العملية لمزيد من التقييم من خلال حسابات توازن المواد والطاقة، وتمّ توسيع نطاقها لتصميم صناعي مبدئي بطاقة إنتاجية تقديرية تبلغ 1000 طن/سنة. وأظهر التقييم الاقتصادي جدوى عالية نظرًا لاستخدام مواد خام منخفضة التكلفة وخطوات معالجة مبسطة. وتُشير النتائج إلى أن دبس السكر يُمكن أن يكون مادة خاما بديلة فعّالة لإنتاج إسترات السكروز، مما يُوفر نهجًا مستدامًا ومجديًا اقتصاديًا للتصنيع الكيميائي المحلي.

الكلمات المفتاحية: دبس السكر، إسترات الأحماض الدهنية، إسترات السكروز الدهنية، إسترات الجلوكوز والفركتوز