Comparative Experimental Investigation for the Separation of Tartaric Acid by Natural and Conventional Solvents

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Abstract

Tartaric acid (TA), a valuable organic acid with widespread applications in food, pharmaceutical, and chemical industries, is predominantly found in grapes and winery by-products. This study investigates the physical extraction of TA from aqueous solutions using both conventional solvents (oleyl alcohol, toluene) and natural, non-toxic solvents (rice bran oil, sesame oil). Extraction experiments were conducted at varying acid concentrations (0.04–0.198 mol/L) to determine key separation parameters including distribution coefficient (K_D) and extraction efficiency (E%). Among the solvents tested, oleyl alcohol exhibited the highest extraction efficiency (21.72%) and distribution coefficient (0.181), attributed to its amphiphilic nature and low viscosity, which enhance mass transfer and solute interaction. In contrast, sesame oil showed the lowest performance due to its high viscosity and poor polarity. While extraction efficiencies were lower compared to reactive extraction methods, the use of bio-based solvents presents an environmentally sustainable alternative. These results demonstrate the possibility of enhancing acid recovery procedures by using green solvent systems.

Keywords: *Tartaric acid, Liquid–liquid extraction, Distribution coefficient, Extraction efficiency*

1. Introduction

Tartaric acid (chemical formula: $C_4H_6O_6$; systematic name: 2,3-dihydroxybutanedioic acid) is a white, crystalline organic acid that is commonly found in tamarinds, avocados, currants, bananas, gooseberries, apples, oranges, and widely in grapes. Tartaric acid is found naturally as L-(+)-tartaric acid, while the D-(−)-form and its mirror-image enantiomers can be obtained synthetically (Toth et al., 2015). TA's potential as an antioxidant has not been fully investigated, despite the fact that it is a significant component of common fruits, including tamarind, grapes, bananas, apples, and certain citrus fruits (fruits high in antioxidant capacity) as well as beverages like wine. In addition to being an antioxidant, TA also works in metal chelation and in concert with other antioxidants. In addition to its anticancer properties, consumption of tartaric acid has been shown to reduce the formation of kidney stones (Jantwal et al., 2022). TA is one of the organic acids that is least antimicrobial, preventing microbial development and rendering fewer microorganisms inactive (Bhanot et al., 2017). In grapes, tartaric acid (TA) is the most prevalent and potent organic acid. It can serve as a "fingerprint" indicator to find out whether grape juice is present (Ghasempoura et al., 2017). A significant quantity of TA is accumulated by grapes during fruit development, which increases flavor compounds, lengthens the

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Manuscript History:
Received 22 August, 2025, Revised 4 November, 2025, Accepted 4 November, 2025, Published 30 April, 2026

https://doi.org/10.33736/jaspe.10607.2026

e-ISSN: 2289-7771

hanging fruit duration, encourages sugar accumulation, and improves wine stability and flavor (Li et al., 2023). Furthermore, tartaric acid serves as a powerful antioxidant and is frequently incorporated into a variety of foods to enhance their flavor with a delightful sourness. There is a lot of interest in recovering tartaric acid as a useful product from wastewater and vineyard wastes (Marchitan et al., 2010).

Organic acids like fumaric acid (FA), tartaric acid (TA), citric acid (CA), and malic acid (MA) serve as examples of widely used food ingredients. Because of its mild acidity, excellent stability, affordability, and wider range of applications, TA is seen to be a better food additive (Yalcin et al., 2008). Compared to D-TA, L-TA holds a larger market share in the food business due to its widespread presence in nature. L-TA is commonly used to flavor baked goods and drinks like soda. It can also be used as food coloring to provide a vivid green hue when coupled with ferrous oxide and citric acid (Li et al., 2024). Applications for tartrates are numerous in science and technology, including dielectric, photonic, ferroelectric, and ferroelastic applications. They are used in many linear and non-linear devices, including transducers. Also, because of the presence of enantiomeric pairs, these materials have uses in the pharmaceutical, medical, and industrial sectors, including chelating agents for the fertilizer and electrochemical industries, corrosion-resistant formulations for refrigeration, and plastic light stabilizers (Sachdev et al., 2022; Kumar et al., 2020) (Figure 1). Distillation, precipitation, organic extraction, adsorption, electrodialysis, reverse osmosis, reactive extraction, supported membranes, anion-exchange distillation, and other methods are employed for the recovery of carboxylic acids (Antony et al., 2018).

In terms of TA output, Germany, Spain, France, and Italy rank among the top countries in the globe. The demand for TA is anticipated to experience a consistent increase at an average annual rate of 5.54% from the year 2018 to 2026 (Nayaka et al., 2016). Liquid-liquid extraction is the process of separating the components of a liquid combination by using an extractant that allows selective separation of one or more of the desired components (Antony et al., 2020). Carboxylic acids can be isolated from fermentation broths or from various industrial processes through the use of different extractants (Mohadikar et al., 2022, Keshav et al., 2008). According to the literature, liquid–liquid extraction is a well-established method for separating carboxylic acids from aqueous streams and fermentation broths. Based on the relative solubility of solute molecules in two phases, the solute is extracted by adding a water-immiscible extractant to the solution. The choice of solvent is essential to the liquid-liquid extraction process (Mohomed et al., 2002; Keshav et al., 2009). For bio separation, an aqueous two-phase system has been used instead of organic solvents (Yanagisawa et al., 2018; Rewatkar et al., 2016). Solvent extraction, recognized as one of the earliest methods of separation, remains one of the most frequently utilized techniques in industrial environments (Athankar et al., 2012). Applications for liquid-liquid extractions can be seen in a number of industries, including the pharmaceutical, food, polymer, chemicals and bio-products, and commercial equipment. The liquid-liquid extraction technique, which has easy operating conditions and easy process control, is especially well-suited for bio refinery processes (via conversion employing microorganisms) (Kumar et al., 2021). To improve efficiency, liquid–liquid extraction has adopted a range of intensification strategies, including reactive extraction, hybrid processes, and the application of ionic liquids DES etc (Antony et al., 2021; Athankar et al., 2013, Kumar et al., 2020 a).

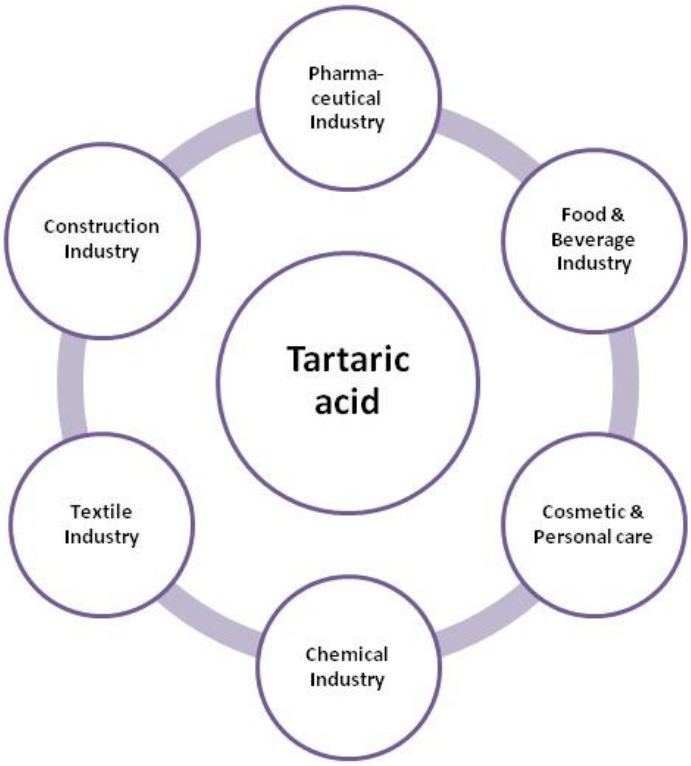

Figure 1: Various applications of Tartaric acid

The objective of this study is to comparatively evaluate the extraction performance of natural, environmentally friendly solvents (rice bran oil and sesame oil) against conventional solvents (oleyl alcohol and toluene) for tartaric acid recovery, focusing on distribution coefficient and extraction efficiency across varying acid concentrations.

2. Material and Methods

2.1. Chemicals

Tartaric acid of laboratory grade was obtained from HI Media and used to prepare tartaric acid in the aqueous phase at different concentrations. Toluene was obtained from Merck Life Science Private Limited, and oleyl alcohol was procured from Tokyo Chemical Lab. Rice bran oil and sesame oil were obtained from Patanjali Ayurved Ltd. Sodium hydroxide pellets were procured from SRL India Private Limited for the titration, while oxalic acid was acquired from SRL India Private Limited. For the normalization of NaOH solution, oxalic acid was required. Every time fresh 0.01 N of NaOH solution was prepared for titration, all the chemicals used were not purified or pre-treated beforehand. The indicator for titration, Phenolphthalein was supplied by Merck Life Science Private Limited, India.

Table 1. List of the chemicals used and their properties

Chemicals	M_w (g/mol)	S_{water} (g/L)	Density (g/cm^3)	Viscosity (cP)	pK_a	CAS no.	Supplier
Tartaric acid	150.087	1330	1.737	-	4.04	147-71-7	HI Media laboratories
Toluene	92.141	0.519	0.8623	0.56	-	108-88-3	Merck life science Private Limited
Oleyl alcohol	268.485	-	0.845-0.855	28.32	-	143-28-2	Tokyo Chemical Lab
Rice bran oil	368.34	-	0.92	28	-	68553-81-1	Patanjali Ayurved Ltd
Sesame oil	138.12	-	0.919	25.1	-	8008-74-0	Patanjali Ayurved Ltd

2.2. Experimental procedure

Aqueous solution of TA was prepared by dissolving the different amount of TA in double distilled water varying in range of concentration (0.040 mol/L–0.1980 mol/L). The acid's spectrum of starting concentrations matched the industrial concentrations found in winemaking waste streams (Marinova et al.,2005). Solvents like rice bran oil, sesame oil, toluene and oleyl alcohol were used individually as solvents in organic phase for solvent extraction. The samples of organic and aqueous both were prepared in conical flask at ratio 1:1(5 ml of aqueous solution mixed with 5 ml of organic phase) until the equilibrium has reached. For establishment of equilibrium the samples were placed in orbital shaking incubator set to operate continuously at 220 rpm, at temperature of 298.15 K and under atmospheric pressure for four hours. The samples were moved to tubes as soon as the two phases had separated, as expected. The two stages were then further separated by centrifuging them for 600 seconds at 4000 rpm (Wasewar et al.,2011). After that for calculating the concentration of tartaric acid in the aqueous phase was determined by titrating it with a solution of 0.01 N NaOH. Through the application of mass balance calculations, the concentration of tartaric acid in the organic phase was assessed. The experimental procedure is summarized in Figure 2.

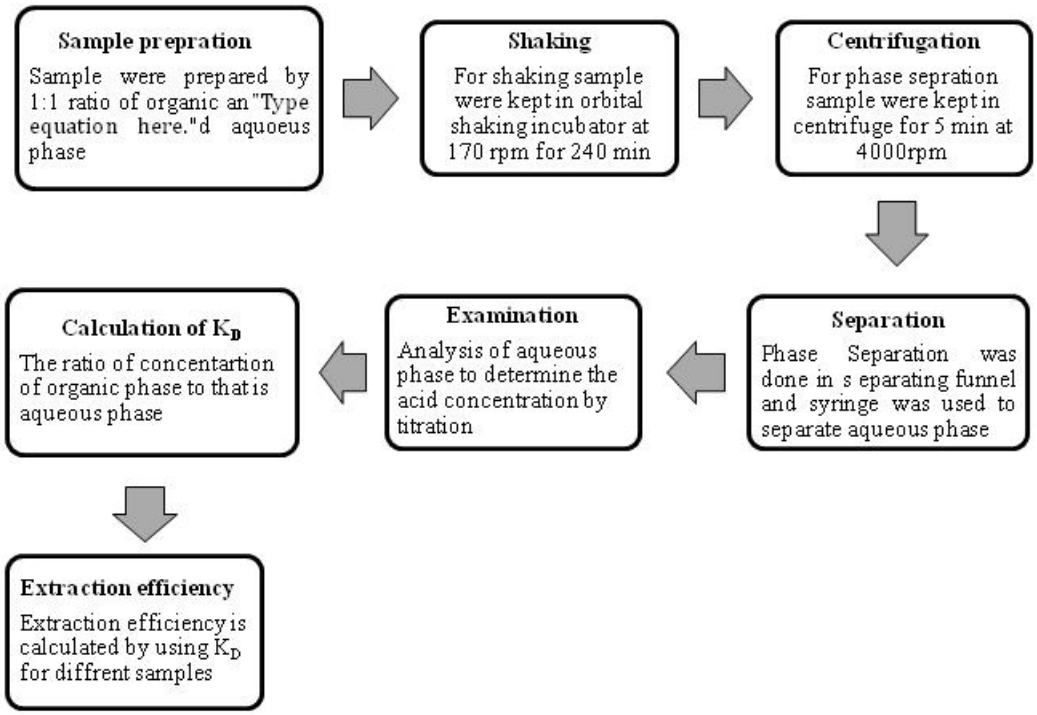

Figure 2. Experimental procedure performed for the physical extraction of Tartaric acid

3. Result and Discussion

The study involved physical extraction, equilibrium study of tartaric acid (TA) using naturals oils specifically rice bran oil and sesame oil and organic solvents like toluene and oleyl alcohol as organic phase. The experimental findings for the physical extraction are demonstrated in Table 2 , where $[CA]_{in}$ denote the initial concentration of tartaric acid, $[CA]_{org}$ refers to concentration of acid in organic phase and $[CA]aq$ stands for the concentration of acid in the aqueous phase. The concentrations in the organic phase were ascertained by mass balancing using the concentrations in the aqueous phase:

$$[CA]_{in} - [CA]_{aq} = [CA]_{org} \quad (1)$$

The distribution coefficient (K_D) and extraction efficiency $(E\%)$ were used to define the experimental results related to the separation of TA. The ratio of organic phase and aqueous phase under equilibrium conditions is known as the distribution coefficient and can be defined as follows:

$$K_D = \frac{[CA]_{org}}{[CA]_{aq}} \quad (2)$$

where $[CA]_{org}$ and $[CA]_{aq}$ denotes the tartaric acid concentration in the organic and aqueous phase, respectively, in mol/L.
Extraction efficiency can be defined in terms of the distribution coefficient (K_D) as follows:

$$E\% = \frac{K_D * 100}{1 + K_D} \quad (3)$$

Table 2. The equilibrium data for tartaric acid extraction with different solvents.

SOLVENTS	$[CA]_{in}$	$[CA]_{aq}$	$[CA]_{org}$	K_D	E%	Avg K_D	Avg E%	P	D
Sesame Oil	0.041	0.039	0.001	0.025	2.512	0.048	4.615	0.017	0.276
	0.082	0.077	0.003	0.038	3.753				
	0.121	0.115	0.006	0.052	4.958				
	0.155	0.146	0.009	0.061	5.806				
	0.198	0.186	0.012	0.064	6.060				
Rice Bran Oil	0.041	0.038	0.002	0.052	5.165	0.106	9.516	0.043	0.590
	0.082	0.073	0.007	0.095	8.752				
	0.121	0.108	0.013	0.120	10.743				
	0.155	0.138	0.017	0.123	10.967				
	0.198	0.174	0.024	0.137	12.121				
Toluene	0.041	0.037	0.003	0.081	7.525	0.150	12.885	0.023	1.253
	0.082	0.073	0.007	0.095	8.752				
	0.121	0.105	0.016	0.152	13.223				
	0.155	0.129	0.026	0.201	16.774				
	0.198	0.162	0.036	0.222	18.181				
Oleyl alcohol	0.041	0.036	0.004	0.111	10.743	0.181	15.145	0.038	1.453
	0.082	0.071	0.009	0.126	11.258				
	0.121	0.104	0.017	0.163	14.049				
	0.155	0.126	0.029	0.230	18.709				
	0.198	0.155	0.043	0.277	21.717				

In Table 2, the extraction efficiency and distribution behavior of a solute across aqueous and organic phases are compared for the following solvents: oleyl alcohol, rice bran, toluene, and sesame. For a range of initial solute concentrations, important characteristics are noted, including distribution coefficient *(K_D)*, and extraction efficiency *(E%)*. Sesame oil shows the lowest extraction efficiency (*E%* avg = 4.62%) and average distribution coefficient (K_D avg = 0.048) among the solvents, showing minimal solute transport from the aqueous to the organic phase. Oleyl alcohol, on the other hand, has the highest Avg K_D (0.181) and Avg *E%* (15.15%) values, indicating that it is the most efficient extraction solvent in this situation. The equilibrium isotherm is depicted in Figure 3.

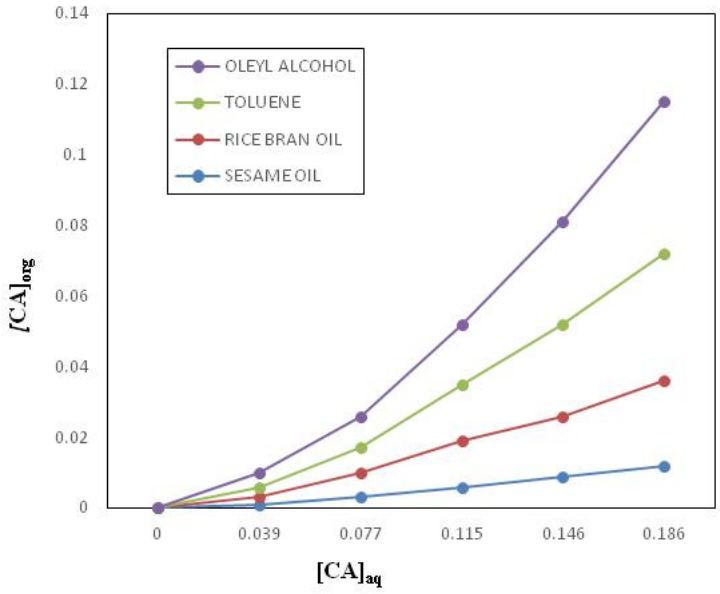

Figure 3. Equilibrium data for the separation of tartaric acid using various solvents

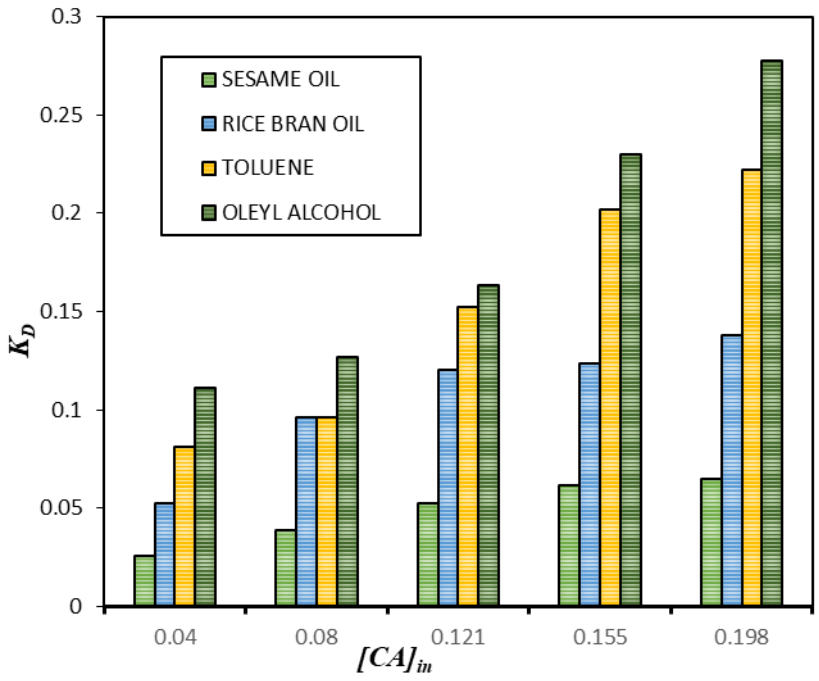

Figure 4. Variation in the distribution coefficient with respect to the initial tartaric acid concentration.

The solute's preference for the organic phase over the aqueous phase is a critical factor for evaluating solvent efficacy in liquid–liquid extraction. The distribution coefficient (K_D), which represents the equilibrium concentration ratio of solute between the organic and aqueous phases, provides key insight into this behavior. In Figure 4, all solvents show a positive trend in K_D with increasing initial solute concentration, indicating that higher feed enhances partitioning into the

organic phase. Oleyl alcohol achieves the highest K_D (0.181), reflecting strong solute affinity and efficient mass transfer. Rice bran oil and sesame oil record average efficiencies of 0.106 and 0.048, respectively, while toluene ranks second at 0.150. Sesame oil's lower K_D and *E%* are attributable to its high viscosity, complex triglyceride composition, and low polarity, which hinder solute diffusion and limit interfacial transport (Tamjidi et al., 2013; De et al., 2018). These structural and physicochemical traits create additional resistance at the aqueous organic interface, making sesame oil a less effective medium for tartaric acid extraction (Kumar et al.,2020 b). Overall, solvents with higher K_D values not only promote better solute distribution but also show strong correlation with higher extraction efficiencies, consistent across the *E%* data (Thakre et al., 2025a).

Extraction efficiency (E%) measures how effectively a solvent transfers solute from the aqueous to the organic phase. The graph in Figure 5 shows that oleyl alcohol routinely attains the greatest *E%*, up to 21.72%, greatly surpassing the other solvents at all tested concentrations. Several important physicochemical characteristics of oleyl alcohol are responsible for this exceptional performance. Its long hydrophobic hydrocarbon tail (C18 chain) enhances solubility of non-polar solutes via favorable van der walls interactions (Gehling & Kolbe, 1997). It also has a hydroxyl group (-OH) at one end, conferring slight polarity. Oleyl Alcohol's dual nature makes it amphiphilic, enabling it to interact with solutes possessing both polar and non-polar regions, unlike solvents such as toluene or triglyceride-based oils (Hildebrand & Scott, 1951; Kolbe & Gehling, 1997).

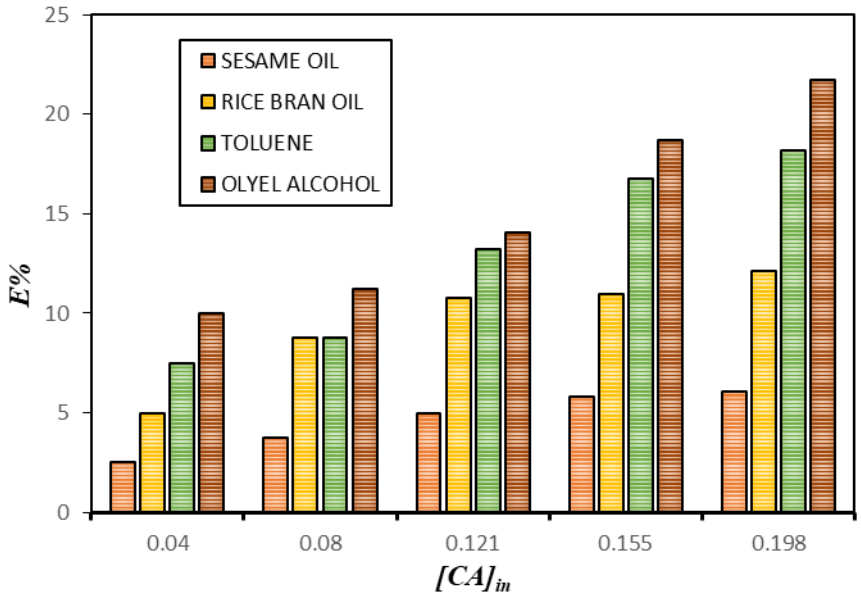

Figure 5. Variation in the extraction efficiency against the initial concentrations of tartaric acid

Additionally, oleyl alcohol's low viscosity promotes efficient mass transfer and faster diffusion of the solute across phases (Treybal, 1980). Research on similar dicarboxylic acids has shown that oleyl alcohol can achieve significantly higher distribution coefficients and extraction efficiencies compared to vegetable oils primarily to its ability to form hydrogen bonds through the hydroxyl group and its effectiveness in reducing interfacial tension between phases (Thakre et al., 2025b). In contrast, rice bran and sesame oils are more viscous, less polar, and composed of large triglyceride molecules, which limits their ability to solvate polar solutes (Kar et al., 2017). Even though toluene has a lower viscosity, its entirely non-polar nature decreases its compatibility with polar solutes (Wasewar and Shende,2010). Thus, oleyl alcohol stands out as a superior solvent for the physical extraction of tartaric acid due to its amphiphilicity, low viscosity, and strong solute interaction capabilities.

4. Conclusion

Tartaric acid was separated from the aqueous phase through a physical extraction process using oleyl alcohol, toluene, rice bran oil, and sesame oil as solvents. While oleyl alcohol achieved the highest extraction efficiency (E% = 21.72%) and distribution coefficient (K_D =0.181), the natural solvents demonstrated lower but measurable extraction capabilities. Rice bran oil showed moderate performance (E% = 9.52%, K_D = 0.106) and outperformed sesame oil, which exhibited the lowest extraction efficiency (E% = 4.62%, K_D = 0.048). This comparison highlights that although natural solvents are less efficient than oleyl alcohol and toluene, rice bran oil, in particular, presents a promising greener alternative for extracting tartaric acid. Their advantages include low toxicity, ease of handling, and compatibility with environmentally friendly practices. The absence of harsh chemicals in these systems reduces environmental risk and makes the process more sustainable and safer for industrial or biochemical applications.

Conflict of Interest

We declare no conflict regarding the publication of the study.

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