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# Ultrasound-Assisted Synthesis of Antimicrobial Inulin and Sucrose Esters with 10-Undecylenic Acid

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**Abstract:** An environmentally friendly and sustainable ultrasound-assisted esterification of long-chained inulin and sucrose with monounsaturated 10-undecylenic acid was performed. The obtained esters were characterized by thin-layer chromatography (TLC), Fourier transforms infrared spectroscopy (FTIR), and nuclear magnetic resonance (NMR) spectroscopy. The spectral analyses demonstrated the successful incorporation of the hydrophobic 10-undecylenoyl residue in the water-soluble carbohydrate backbone. Additionally, the antimicrobial potential of 10-undecylenic esters of inulin and sucrose were tested against nine microorganisms (Gram-positive and Gram-negative bacteria, yeasts, and fungi). Both esters inulin 10-undecylenate and sucrose 10-undecylenate (1 mg/ml) inhibited *Bacillus subtilis* ATCC 6633, *Listeria monocytogenes* ATCC 8632, *Staphylococus aureus* 745, *Escherichia coli* 3398, yeast *Candida albicans* 8673, and fungi *Penicillium* sp. Only inulin 10-undecylenate demonstrated antimicrobial activity against *Salmonella typhy* 745. Both esters were inactive against fungi *Aspergillus niger*. The current research demonstrated a new antimicrobial activity of inulin esters. Moreover, the use of "eco-friendly" synthesized inulin and sucrose esters with 10-undecylenic acid as antimicrobial substances with future applications in pharmaceutical and cosmetic products were demonstrated.

**Keywords:** inulin 10-undecylenic esters; sucroesters; ultrasound-assisted synthesis; antimicrobial activity.



## 1. Introduction

The relation between the chemical structure and biological activity of natural and synthetic compounds remains a challenge. Carbohydrates presented abundant renewable sources for the bioactive ester production with an improved biological and functional activity that found application in cosmetics, agriculture practice, and pharmacy [1–3]. Sucrose esters (also known as sucroesters) found naturally on leaves of Solanaceae plants possessed insecticidal and larvicidal properties [4–6]. However, their isolation from natural sources is not enough for consumers and industrial demands [5]. However, many studies reported enzymatic

and chemical approaches to the production of sucroester [7–16]. Most sucrose esters are biocompatible and biodegradable non-ionic surfactants that find application as emulsifiers, wetting or dispersion agents, solubilization, stabilization in cosmetics as food additives, especially antimicrobial substances applied in canned foods and beverages [7,8,10,13,15]. It was reported that sucrose and fructooligosaccharides esters with saturated long and short-chained fatty acids possessed antimicrobial properties [7–11,17]. Moreover, sugar and inulin esters with a degree of substitution (DS) in the range from 1 to 3 demonstrated interesting properties: hydrophilic-lipophilic balance (HLB), critical micelle concentration, surface tension, emulsifying stability (especially O/Wand some W/O emulsions, multiple emulsions), foaming properties, biological activities, and thermal properties [10,14,16,19–21].

Among the fatty acids, C11 monounsaturated fatty acid, known as 10-undecylenic acid possesses antifungal, antibacterial, and anti-viral activities [22,23]. This fatty acid is obtained from the pyrolysis of ricinoleic acid, the main fatty acid of inedible castor oil [24]. Its esters with sucrose, glycerol, and fructooligosaccharides found application as antimicrobials [11,22,23,26,27] and lubricants [24,25]. Linear diglycerol (DG), pentaerythritol monomethyl ether (PEME), and trimethyloltoluene (TMT) undecylenic esters were synthesized with properties of eco-friendly lubricants, as TMT ester were nontoxic against *Artemia salina* [24]. Moreover, 1`-*O*-(10-undecylenoyl) sucrose is a biodegradable, antimicrobial, and anti-viral substance with surface tension activity [22]. In some previous studies, 10-undecylenoyl sucrose was synthesized using different approaches, including chemical or enzymatic methods [11,22]. In esterification of sucrose or inulin by the chemical way, solvents as dimethyl sulfoxide, dimethylformamide, N-methyl pyrrolidinone were used with a different catalyst (as NaH, $NaOCH_3$, $K_2CO_3$) under conventional heating [5,6,11,12,14,17,19-21,26,27]. Biobased esters can be obtained by esterification of sucrose and inulin with fatty acids, or by transesterification with methyl esters (FAMEs) or fatty acid vinyl (FAVEs) [11-15,17,19]. Many studies were reported for esterification of long-chained inulin with anhydride (succinic, acetic, propionic, and pyromellitic dianhydride) with a pharmaceutical application as a drug carrier, hydrogels [19,28-33], and nano micelles [34]. In earlier research, aliphatic and sucrose, and fructooligosaccharide esters with 10-undecylenic acid were successfully obtained using ultrasonic power [11,26,27]. It was demonstrated that ultrasonic power accelerates the esterification process as it reduces time, saves energy, and improves the esterification reaction's efficiency [3,11,12]. However, until now, inulin esters obtained by ultrasound-assisted esterification were not studied in detail. Therefore, the current study aimed to obtain inulin and sucrose esters with monounsaturated 10-undecylenic acid using ultrasonic irradiation and investigate the antimicrobial potential of resulting esters against pathogenic microorganisms.

## 2. Materials and Methods

### *2.1. Materials.*

Long-chain chicory inulin Raftiline HPX (Beneo, Orafti, Belgium) with an average degree of polymerization 25 was used for the transesterification process. Sucrose, methanol, 10-undecylenic acid, and other solvents were purchased from Sigma-Aldrich (Germany). Sisterna SP70-C was kindly donated by Sisterna. Sodium methoxide ($NaOCH_3$) was prepared freshly before the esterification reaction: 1 g Na was added in 50 ml anhydrous methanol [19,21].

*2.2. Methyl ester of 10-undecylenic acid.*

Methyl ester of 10-undecylenic acid was obtained according to ISO 5509:2000 with a slight modification [35]. In 2 L round-bottom flask 10-undecylenic acid (32.39 g) was mixed with 250 mL n-hexane and 1 L $CH_3OH$ containing 10 mL $H_2SO_4$. The sample was heated in the water bath for 2 h under a reflux condenser. The flask sample was cooled to 25°C, and the pH was adjusted to 7 by adding 10 % $Na_2CO_3$. The obtained sample was washed in triplicate with 25 mL n-hexane in a separatory funnel. The upper hexane layer containing methyl ester was collected, dried with anhydrous $Na_2SO_4$, the solvent was removed by vacuum evaporation. The resulting methyl ester of 10-undecylenic acid was kept at -18°C in a dark bottle under nitrogen before further use.

*2.3. Ultrasound-assisted synthesis of inulin and sucrose esters with 10-undecylenic acid.*

The esters' synthesis was performed into a two-neck round bottom flask, where 5.13 g sucrose (inulin 5 g, respectively) was added to 6 mL DMSO. The flask was connected to a reflux condenser. The digital thermometer was attached to one neck of the flask. The sample was placed into an ultrasonic bath VWR (Malaysia) with ultrasonic frequency operating at 45 kHz, power 30 W at 45°C. After the sucrose was completely dissolved in the DMSO, the methyl ester of 10-undecylenic acid 0.92 g was added by drops, then catalyst $NaOCH_3$ was added. The reaction mixture was sonicated under a nitrogen atmosphere for 1 hour. After the reaction was stopped, DMSO was evaporated by vacuum distillation. The pretreatment of residue was performed as described by Huang et al. [12] with NaCl pretreatment, and liquid-liquid extraction was done with n-butanol and further purification with ethyl acetate. The solvent was removed by vacuum evaporation.

*2.4. Thin-layer chromatography (TLC).*

The thin-layer chromatography was performed on silica gel Kieselgel 60 $F_{254}$ plates (Merck, Germany). Two variants of elution were used with different mobile phases.
Variant A: The TLC plate was developed in three different types of mobile phases as follows: 1. Chloroform: methanol: water 85/13.5/1.5 v/v/v to 2.7 cm; 2. Chloroform/methanol/acetic acid 98.5/1.5/1.4 v/v/v to 5.2 cm and 3. *n*-hexane/diethyl ether/acetic acid 70/30/1 v/v/v to 9 cm).
Variant B: The TLC plate was developed in a mobile phase consisting of ethyl acetate/methanol/water 17:2:1 v/v/v. TLC spots were visualized by spraying with 10% sulfuric acid dissolved in methanol and heating at 120°C for 5 min [22].

*2.5. Degree of substitution.*

The degree of substitution (DS) of inulin and sucrose esters was determinate by AOAC 910.160 method [36].

*2.6. FTIR spectroscopy.*

FTIR spectra of the resulting 10-undecylenic esters were recorded on a Nicolet Avatar spectrometer (Thermo Scientific, USA, ZnSe crystal) on KBr pellets the frequency range from 4000 to 500 $cm^{-1}$, with the resolution 4 $cm^{-1}$ and 132 scans. The absorption was reported in wavenumbers ($cm^{-1}$).

*2.7. $^{1}H$ and $^{13}C$ NMR spectroscopy.*

The $^{1}H$ and $^{13}C$ NMR spectra were recorded on a Bruker spectrometer (500 MHz frequency) in $CDCl_3$ with tetramethylsilane (TMS) as a standard. The chemical shifts (δ) were expressed in ppm.

*2.8. Antimicrobial activity.*

2.8.1. Test microorganisms.

Gram-positive bacteria (*Bacillus subtilis* ATCC 6633, *Bacillus subtilis* 46/H1, *Listeria monocytogenes* ATCC 8632, *Staphylococus aureus* 745), Gram-negative bacteria (*Escherichia coli* 3398, *Salmonella typhy* 745), yeasts (*Candida albicans* 8673) and fungi (*Aspergillus niger and Penicillium* sp.) were used in the antimicrobial screening.

2.8.2. Culture media.

Luria-Bertani agar medium supplemented with glucose (LBG agar). This medium was used for the cultivation of the test bacteria as well as for the implementation of the agar well diffusion assay. Malt extract agar (MEA). This medium was used for the cultivation of the test yeasts and fungi.

2.8.3. Antimicrobial assay.

The antimicrobial activity of inulin and sucrose esters was evaluated by the typical agar well diffusion method [18,37]. The tested bacteria were cultured on LBG agar at 30/37°C for 24 h, while the yeasts and fungi were grown on MEA (at 37°C for 24 h for yeasts and 30°C for 7 days or until sporulation for fungi). The number of viable cells and fungal spores was determined using a bacterial Thoma`s counting chamber. Their final concentrations were $1.0\times10^{8}$ CFU/mL for bacterial/yeast cells and $1.0\times10^{5}$ CFU/mL for fungal spores. Then inoculation was performed in preliminarily melted and tempered at 45–48°C LBG agar media. The inoculated media were transferred in a quantity of 17 ml in sterile Petri plates (d=90 mm) and allowed to solidify. Then six wells (d=6 mm) per plate were cut. Inulin and sucrose esters with 10-undecylenic acid were dissolved in aqueous methanol (80%), then pipetted into the agar wells in the quantity of 60 μL. Aqueous methanol (80%), the antibiotics Ampicillin (10 μg/mL) and Biseptol (400 μg/ml) against the test bacteria, and Chlornitromycin (250 μg/mL) Nystatin (40 μg/mL) against yeasts and fungi were used as controls. The antimicrobial activity was evaluated by the inhibition zones' diameter around the wells of the $24^{th}$ and $48^{th}$ h after incubation. Test microorganisms with inhibition zones of 18 mm or more were listed as sensitive, moderately sensitive - with inhibition zones from 12 to 18 mm; resistant - with inhibition zones up to 12 mm or completely missing [16, 30, 37].

## 3. Results and Discussion

*3.1. Ultrasound-assisted synthesis of sucrose and inulin esters with 10-undecylenic acid.*

The ultrasound-assisted esterification of sucrose and high-molecular inulin with methyl ester of 10-undecylenic acid was illustrated (Figure 1). The results were summarized in Table 1.

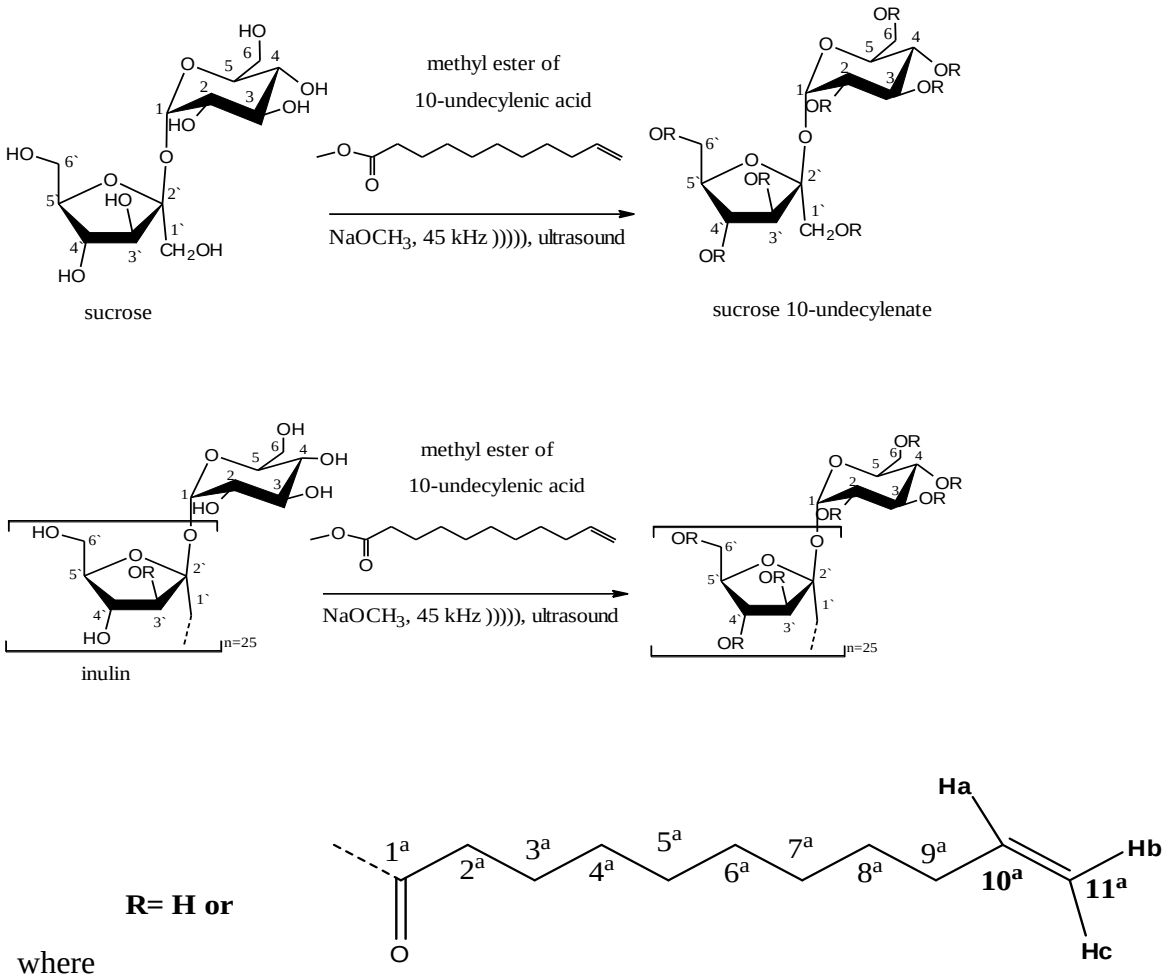


**Figure 1**. Synthesis of 10-undecylenoyl sucrose and inulin esters under ultrasonic irradiation.

At room temperature, the obtained sucrose and inulin undecylenic esters were yellow to faint brown liquids with the specific odor of 10-undecylenic acid. At temperature -18°C, they presented solids crystals with faint yellow color. This observation was near to reported low melting temperature (below -5°C) of linear diglycerol, pentaerythritol monomethyl ether, and trimethyloltoluene (TMT) undecylenic esters [24]. It was found that the obtained sucrose and inulin undecylenic esters were soluble, easily in solvents as $CHCl_3$, methanol, and acetone. A similar observation was reported for inulin acetate [30] solubility and inulin esters with pyromellitic dianhydride [32].

TLC chromatograms of sucrose-10-undecylenate obtained by ultrasonic irradiation with $NaOCH_3$ as a catalyst were shown (Figure 2). The resulting esters presented a mixture of polyesters (Figure 2, spot 5). Monoesters were observed similarly to Sisterna SP 70 (mixed esters containing sucropalmitate and sucrostearate) with 70 % monoesters (Figure 2 spot 8). A possible explanation for this fact that isolated 1`-*O*-(10-undecylenoyl) sucrose is solid with a melting point 114-116°C [22], while in our case, the mixture of polyesters presented a liquid substance. The polyesters were observed on the TLC plate with $R_f$ 0.8 (spot 5, Figure 2 variant B) and $R_f$ 0.7-0.8 (spot 5, Figure 2 Variant A) closer to the front line. Monoesters were with $R_f$ between 0.3 and 0.4 in both plates. Both mobile phase variants demonstrated good separation of esters and their qualitative analysis.

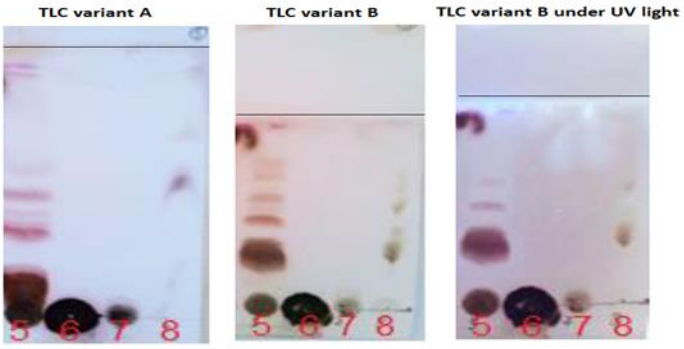


**Figure 2**. TLC chromatograms of sucrose esters with two different variants of mobile phases: Variant A (1. Chloroform: methanol: water 85/13.5/1.5 v/v/v to 2.7 cm; 2. Chloroform/ methanol/acetic acid 98.5:1.5 :1.4 v/v/v to 5.2 cm and 3. *n*-hexane/diethyl ether/acetic acid 70/30/1 v/v/v to 9 cm) and variant B (ethyl acetate/methanol/water 17/2/1 v/v/v), where 5. sucrose 10-undecylenate obtained by ultrasonic irradiation; 6 and 7. sucrose, 8. sucorester Sisterna SP70C (sucroester with 70 % monoesters)

The yields of 10-undecylenic inulin and sucrose esters were above 50 %. The degree of substitution (DS) for inulin esters was lower – 0.05. It was reported that inulin esters possessed a degree of esterification between 0.30-0.05 [38]. The obtained esters were compared with our previous data for inulin and sucroesters with 10-undecylenic acid [26, 27]. The current results demonstrated the higher yield of esters obtained for 1 h in molar ration 1:1 with catalyst $NaOCH_3$ by ultrasonic irradiation (Table 1).

**Table 1.** Physico-chemical characteristics of synthesized inulin and sucrose esters with 10-undecylenic acid with sodium methylate ($NaOCH_3$) as catalyst and molar ratio (carbohydrate: methyl undecylenate) 1:1.

| Ester | Conditions | Reaction Time, h | Temperature, °C | Yield, % | DS[1] | References |
|---|---|---|---|---|---|---|
| **Inulin 10-undecylenate** | **Ultrasound** | **1** | **45** | **51** | **0.05** | **Ibid** |
| Inulin 10-undecylenate | Ultrasound | 2 | 45 | 49 | 0.10 | Petkova et al. [27] |
| **Sucrose 10-undecylenate** | **Ultrasound** | **1** | **45** | **57** | **0.15** | **Ibid** |
| Sucrose 10-undecylenate | Ultrasound | 2 | 45 | 55 | - | Petkova et al. [26] |
| Sucrose 10-undecylenate | Conventional | 2 | 70 | 35 | - | Petkova et al. [26] |

[1] DS- degree of substitution

*3.2. Spectroscopic studies of sucrose and inulin esters with 10-undecylenic acid.*

3.2.1. FTIR spectroscopy.

The structure of the obtained esters was confirmed by FT-IR spectroscopy (Figure 3). The IR-FT spectra of sucrose 10-undecylenate and inulin 10-undecylenate esters showed that the broadband at 3392 $cm^{-1}$ was assigned with O–H stretches of free hydroxyl in carbohydrate structure disappeared due to the esterification of free OH groups. Also, the bands at 2857, 2945, 2923 $cm^{-1}$ (C–H stretch of methyl and methylene) were more intense, which was due to the longer alkyl chain incorporated in sucrose and inulin molecules after esterification. Four new bands were observed as follows: The bands at 3083–3080 $cm^{-1}$ was assigned with the stretching vibrations of =C–H, a new bands at 1743–1745 $cm^{-1}$ was characterized with the stretching vibrations of C=O of ester, the band at 1652 $cm^{-1}$ ν(C=C) and =C–H bends at 917 $cm^{-1}$ were also observed that proved the presence of double bond in the alkyl chain and the stability of double bond at the end of the alkyl chain. All these bands together with those at 1056 $cm^{-1}$,

1107 $cm^{-1}$ (C–O stretch of C–O–C), 955 $cm^{-1}$ (a glycosidic bond stretch of sucrose), and 817 $cm^{-1}$ (2-ketofuranose in inulin structure) revealed the successful esterification of sucrose and inulin, respectively. Similar bands for ester bonds were reported previously for fructooligosaccharide esters with 10-undecylenic acid [11] and 1`-*O*-(10-undecylenoyl) sucrose [22], as well as some other sucrose and inulin esters [3,5,16,17,31,32]. Moreover, the ultrasonic effect and produced cavitation bubbles did not alter C–C bonds and did not cause changes in their stability of isolated double bonds in the undecinoyl alkyl chain [11,12].

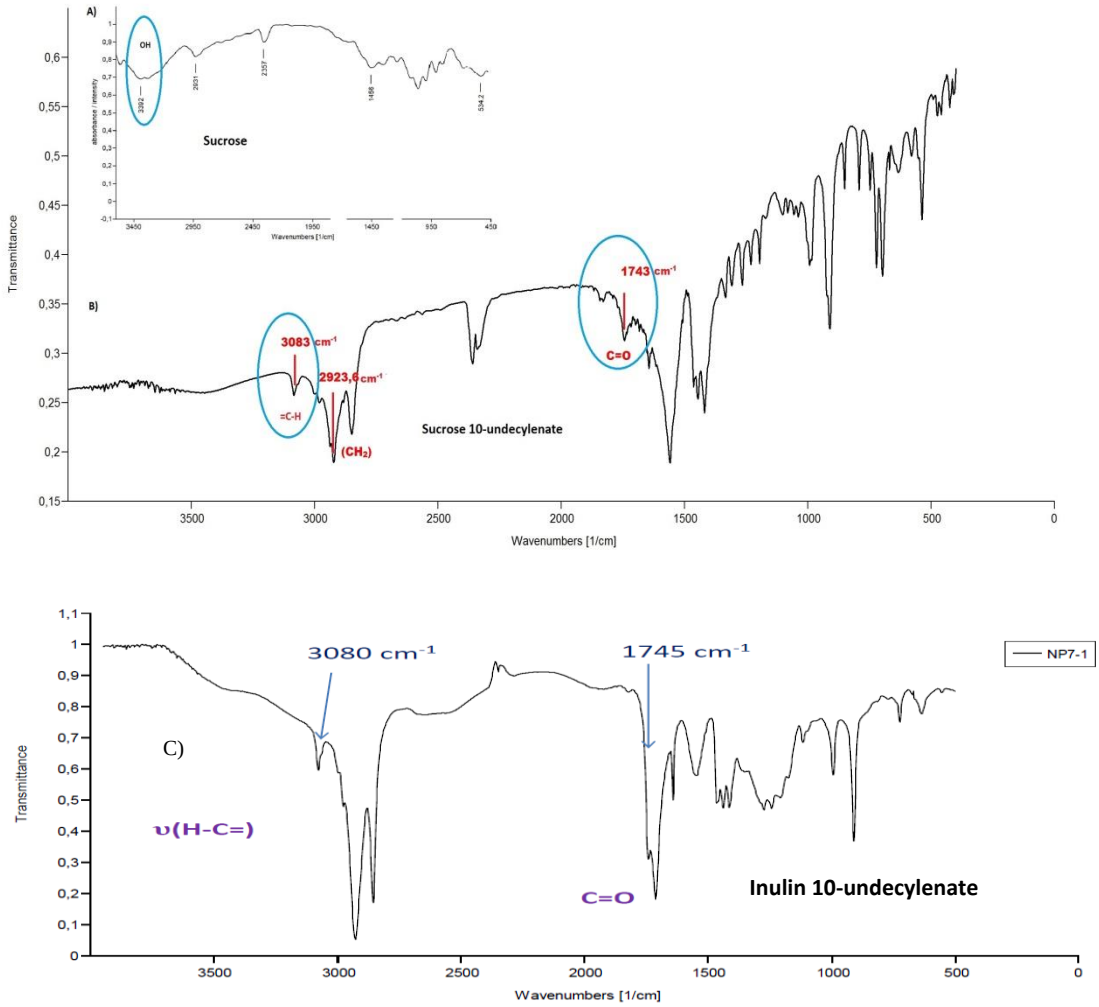


**Figure 3.** IR-FT spectra of sucrose (A), sucrose 10-undecylenate (B) and inulin 10-undecylenate (C).

3.2.2. NMR spectroscopy.

The structure of sucrose 10-undecylenate was confirmed by $^{1}H$ and $^{13}C$ NMR spectroscopy (Figure 4 and Figure 5). The displacements of protons for the vinyl group –$CH=CH_2$ at 4.99 and 5.65 ppm were clearly observed in the $^{1}H$ NMR spectrum of sucrose 10-undecylenate. A similar observation was reported for undecylenic side chain in the undecycilenic ester of pentaerythritol monomethyl ether [24]. The protons from $CH_2$were recorded in the spectrum at 1.10–2.30 ppm, with resonance signals for the $CH_2$ protons connected to the C=O ester group, observed at 2.27–2.30 ppm. Chemical shifts for sucrose were in the range of 3.39 ~ 5.38 ppm (protons of glucose part) and 3.58 ~ 4.39 ppm (protons of fructose residue) (Figure 4).

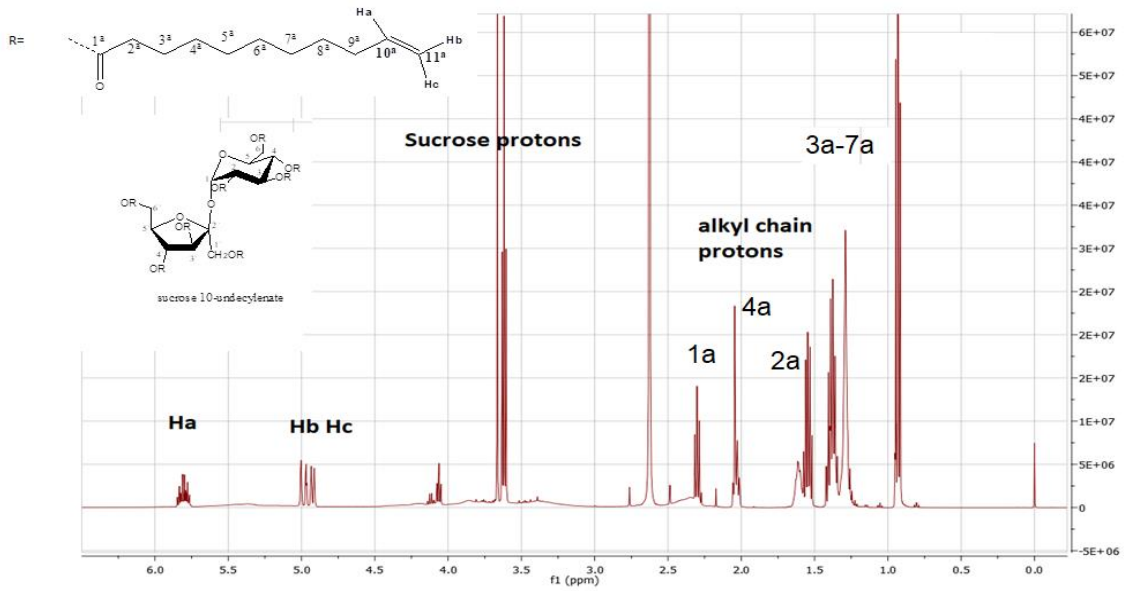


**Figure 4.** $^{1}$H NMR spectrum of sucrose 10-undecylenate.

$^{13}$C NMR (126 MHz, $CDCl_3$) δ 174.33, 174.00, 171.00 (C=O), 139.12 ($CH_2$=), 114.16 (CH=), 104.09 (C-2`), 79.11(C-5′), 77.37, 77.12, 76.87, 70.27, 68.19, 64.32, 64.06, 62.36 (sucrose unit), 34.83, 34.80, 34.34, (1$CH_2$, $CH_2$-CO); 34.04, 33.72, 29.05, 28.98, 28.82, 24.88, 20.95 (8$CH_2$ alkyl chain (C2a-C9a).

The chemical shift characteristic of the ester carbonyl group appeared at δ 174.33, 174.00, 171.00 ppm. The chemical shifts relevant to carbon atoms of sucrose moiety (glucose and fructose residues) were found in the range of 62.36 to 104.09 ppm. Unsaturated sucrose esters showed two typical shifts at 139.12 ppm for (=CH–) group (10a from alkyl chain) and 114.16 ppm (CH=, 11a from alkyl chain) (Figure 5).

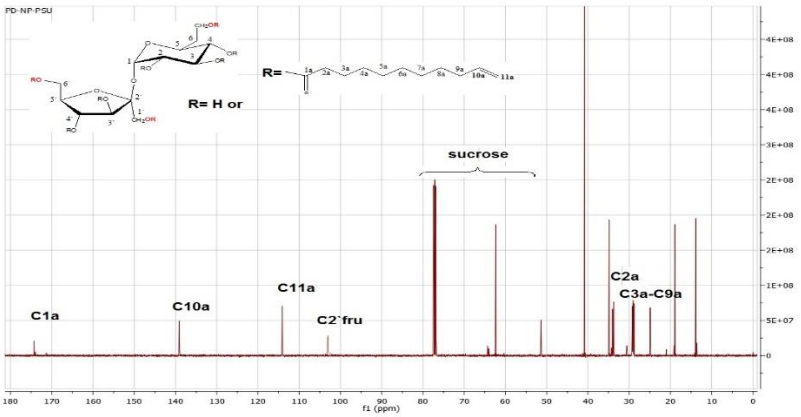


**Figure 5**. $^{13}$C NMR spectrum of sucrose 10-undecylenate.

In $^{1}$H NMR spectra of inulin 10-undecylenate, typical shifts appeared for inulin backbone between 3,0-5,2 ppm (H1`-H6`). The protons from long undecylenic side-chain of inulin ester –CH=$CH_2$ at 4.95 and 5.60 ppm. Methylene protons from the alkyl chain were observed 0.9 to 2.34 ppm. In $^{13}$C NMR spectra, the new chemical shifts for inulin esters was appeared for -$CH_2$ at 20~40ppm, while the characteristic chemical shift of carbonyl appears at ~174.23 ppm. Moreover, the presence of carbon atoms form double bonds also was observed at 139.20 ppm (C10; $CH_2$=), 114.18 ppm (C11; CH=). Carbon atoms of the inulin moiety were found in the range of 61.20 ~ 103.77 ppm.

The reported chemical shifts for sucrose and inulin 10-undecylenate were similar to reported values for other sucrose esters [11,39,40], other inulin esters [19,20,28-31,41]. All chemical shifts confirmed successful esterification of sucrose with 10-undecylenic acid.

*3.3. Antimicrobial activity of sucrose 10-undecylenate and inulin 10-undecylenate.*

The results from the performed study showed that inulin and sucrose esters with 10-undecylenic acid demonstrated medium to high antimicrobial activity against the different test microorganisms (Table 2).

**Table 2.** Antimicrobial activity of inulin and sucrose 10-undecylenate esters in concentration 1 mg/ml expressed as the diameter of zones of inhibition in mm ($d_{well}$ = 6 mm).

| **Test-microorganism** | **Sucrose 10-undecylenate** | **Inulin 10-undecylenate** | **80% Methanol** | **Ampicillin, 10 µg/mL** | **Nystatin, 40 µg/ml** | **Chlornitromycin, 250 µg/ml** | **Biseptol, 400 µg/ml** |
|---|---|---|---|---|---|---|---|
| ***Gram-positive*** | | | | | | | |
| *Bacillus subtilis* ATCC 6633 | 13** | 18*** | - | NA | NA | NA | 12 |
| *Bacillus subtilis* 46/H1 | - | - | - | 20 | NA | NA | NA |
| *Listeria monocytogenes* ATCC 8632 | 16 | 15 | - | NA | NA | NA | 11 |
| *Staphylococus aureus* 745 | 12 | 14 | - | NA | NA | NA | 13 |
| ***Gram-negative*** | | | | | | | |
| *E.coli 3398* | 19 | 14 | - | NA | NA | NA | 16 |
| *Salmonella typhy* 745 | - | 16 | - | NA | NA | NA | 14 |
| ***Yeasts*** | | | | | | | |
| *Candida albicans* 8673 | 18*** | 19*** | - | NA | NA | 19 | NA |
| ***Fungi*** | | | | | | | |
| *Aspergillus niger* | - | - | - | NA | 12 | 19 | NA |
| *Penicillium sp* | 10* | 11* | - | NA | 18 | NA | NA |

*low antimicrobial activity up to 12 mm, **moderate antimicrobial activity (12–18 cm); ***strong antimicrobial effect (>18 cm) "–" no inhibition, N/A–not applied.

Additionally, the antimicrobial potential of tested undecylenic esters was compared with different controls. Both carbohydrate esters showed moderate to high antimicrobial activity against Gram-positive (*Listeria monocytogenes, Staphylococus aureus* 745 and *Bacillus subtilis* ATCC 6633) and Gram-negative (*E.coli 3398*) bacteria, as well as against yeast *Candida albicans* 8673. Only inulin 10-undecylenate in a concentration 1 mg/ml inhibited the growth of *Salmonella typhy 745*, against with sucrose 10-undecylenate was inactive. However, both esters in these concentrations were inactive against fungi *Aspergillus niger* and Gram-positive *Bacillus subtilis* 46/H1. The typical features for sucrose ester with a long-chained alkyl chain is their antimicrobial activity against Gram-positive bacteria [7,8,16,22,23]. However, pyridinic sucrose esters antibacterial activity against Gram-negative bacteria (*E. coli* and *P. aeruginosa*), and they were not active against Gram-positive bacteria (*S. aureus*) [3]. Glucose esters with long-chained fatty acids also revealed weak antibacterial to moderate antifungal activities [42]. Also, lactose esters and long-chained monosaccharide esters demonstrated promising antimicrobial activity with [43- 45], as fructose laurate were active against Gram-positive bacteria as *S.aureus* and *B.subtilis* at 12.5 % concentration [44].

In our previous studies, we reported for the first time antimicrobial activity of sucrose and fructooligosaccharides 10-undecylenate esters against *Bacillus cereus* and *Bacillus subtilis* [11], as well as inulin 10-undecylenate, was active against *Bacillus cereus* and *Gram*-negative bacteria *E. coli* and *Salmonella* [30]. In our case, inulin, 10-undecylenate showed moderate antimicrobial activity against *Staphylococus aureus 745* and *E. coli* (Table 2). However, it was reported that inulin silver nanoparticles showed higher antimicrobial activity against *Escherichia coli* than it was against *Staphylococcus aureus* [46]. In this report, inulin 10-undecylenate was evaluated as more active against *Bacillus subtilis* ATCC 6633 compared to sucrose-10-undecylenate (Table 2).

Moreover, these two esters were moderately active against foodborne pathogens like *Listeria monocytogenes* ATCC 8632 and *Staphylococcus aureus* 745, as their activity was comparable with antibiotics Biseptol (400 µg/ml). The results from this research confirmed that sucrose10-undecylenate esters possess antimicrobial activity against *Candida albicans*, which was reported in some previous research [16,22]. In our earlier research, unsaturated sucrose-10-undecylenic esters and fructooligosaccharides1-0-undecylenic esters at a concentration 1 mg/ml showed strong antimicrobial activity against yeast *Candida albicans*, with 94 and 84% inhibition, respectively [11]. The most important finding was that inulin 10-undecylenate also demonstrated the highest antimicrobial activity against *Candida albicans* 8673 and inhibited the growth of Gram-positive bacteria (*Listeria monocytogenes*, *Staphylococus aureus* 745 and *Bacillus subtilis* ATCC 6633), Gram-negative bacterium (*E. coli* 3398) and fungi *Penicillium*, known as an important food spoilage agent.

Moreover, this is the first detailed report for long-chained inulin esters' antimicrobial activity with 10-undecylenic acid. In conclusion, antimicrobial activity screening showed that all the tested esters possessed mostly antibacterial than antifungal activity. This research demonstrated the potential application of inulin and sucrose 10-undecylenate esters as antimicrobial agents for pharmaceutical and cosmetic purposes.

## 4. Conclusions

The current study demonstrated the ultrasound-assisted synthesis of inulin and sucrose esters with 10-undecylenic acid with catalyst $NaOCH_3$ in DMSO, the molar ratio of 1:1, and a reaction temperature of 45 °C only for 1 hour. The resulting esters presented the yellow liquid at room temperature. The structure of polyesters was elucidated and confirmed by FT-IR and NMR spectroscopy. In this research, the antimicrobial activity of inulin 10-undecylante was demonstrated for the first time. Inulin and sucrose esters with 10-undecylenic acid demonstrated medium to high antimicrobial activity. The antimicrobial activity of 10-undecylenic esters reveals a new aspect of their potential application against some plant and foodborne pathogens.

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## Conflicts of Interest

The authors declare that there are no conflict of interest.

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