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From glycerol to chlorohydrin esters using a solvent-free system. Microwave irradiation versus conventional heating

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ABSTRACT

Esterification–chlorination of glycerol provides chlorohydrin esters in high yields. A ratio of reagents close to equivalence can be used, so that atom economy of the reaction is optimized. The reaction can be carried out using either classical or microwave heating, and no solvent is required. 2-Chloro-1-(chloromethyl)ethyl esters can be obtained in high regioisomeric relationship when either low or moderate temperature is used. In contrast, microwave irradiation allows the use of higher reaction temperatures that render mixtures of both regioisomers in variable relationships. Kinetic control of the process is proposed for classical heating, and experimental results are analyzed with the aid of ab initio calculated values. Non-thermal phenomena can be used to explain the high efficiency of microwave irradiation at low temperature.

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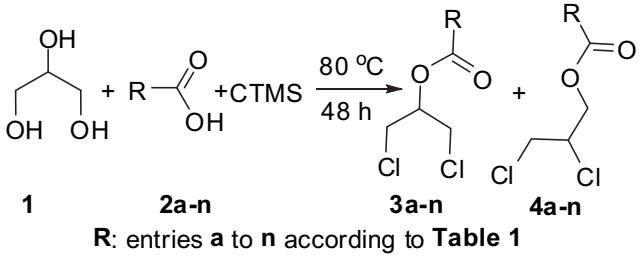
1. Introduction

The interest in new industrial applications of glycerol is increasing parallel to the growth of biodiesel production. Recently, new procedures have been patented to convert this compound to a mixture of chlorohydrin esters and then to epichlorohydrin.[1] One of the main goals of these methods is to use a low-cost renewable feedstock such as glycerol.[2] The transformation of glycerol to dichloropropyl derivatives allows the preparation of several compounds with wide applications.[3]

We have already described how dichloropropyl esters can be obtained by an esterification–substitution reaction from both glycerol and 4-hydroxymethyl-2,2-dimethyl-1,3-dioxolane (solketal), a monoketal from glycerol, using diverse reagents. Among them chlorotrimethylsilane (CTMS) has shown to be the more reliable one.[4] These results have prompted us to study deeply the use of CTMS for a direct esterification–substitution of glycerol to prepare dichloropropyl esters. The use of CTMS as an acidic catalyst in esterification is widely described, and its ability to produce chlorohydrin esters has been demonstrated using different diols[4a] and carboxylic acids.[5] Herein, we report the direct transformation of glycerol (**1**) into dichloropropyl esters (Scheme 1). No solvent is required for the reaction and the energy needed for the reaction can be provided using either classical heating or microwave systems. The mechanism proposed for this transformation is supported by the experimental results and a computational analysis approach. Moreover, the effect of microwave irradiation at low temperature could be explained by considering non-thermal microwave effects.[6]



Scheme 1. Simultaneous esterification and chlorination of glycerol using carboxylic acids, chlorotrimethylsilane (CTMS) and classical heating.

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2. Results and discussion

First, a mixture of glycerol (**1**) with the corresponding carboxylic acid (**2a**–**n**) in a fivefold molar excess of CTMS was heated for 48 h at 80 °C. All of the tested acids led to the formation of the corresponding 2-chloro-1-(chloromethyl)ethyl carboxylates (**3a**–**o**) as the main regioisomer (Table 1). To improve the atom economy of the process, experiments were carried out using a mole ratio of 1.2:1:2.2 glycerol:carboxylic acid:CTMS. Crude yields and regioisomeric ratios were in most cases similar to those obtained with the 2:1:5 mole ratio (Table 1). Only dinitrobenzoic acids exhibited lower yields. In these cases, the corresponding intermediate **9** (Scheme 2) was present in yields of around 30% (determined by ^{1}H NMR). To shorten the reaction time, the same reactions were carried out using a mole ratio of 2:1:5 glycerol:carboxylic acid:CTMS and a pressurized monomode microwave oven at 2.45 GHz. The reaction for most of the compounds synthesized was carried out by programming the microwave oven temperature at 250 °C for 20 min. The microwave reactor automatically controls the reaction pressure, the power irradiation, and the cooling time. Using these conditions, the reaction temperature was 243–247 °C. Reactions using dinitrobenzoic acids (**2i** and **2j**) were carried out at 170–175 °C (microwave oven temperature 175 °C) for 20 min to avoid product decomposition. Although the yields after 20 min of reaction were similar to those obtained by conventional heating, the ratio of regioisomers (**3**:**4**) changed significantly (Table 1). Finally, equivalent experiments were carried out using a mole ratio of 1.2:1:2.2 glycerol:carboxylic acid:CTMS. Crude yields were in most cases lower to those obtained with the 2:1:5 mole ratio (Table 1). Nevertheless, regioisomeric ratios were similar (Table 1). The formation of insoluble materials was observed in these experiments. These materials could be produced from some of the intermediate compounds when temperature is high and CTMS is not present in enough molar excess.

Trying to determine the reason for the different results observed among both energy providing systems, a set of experiments were planned using a microwave reactor and palmitic acid as a model system (Table 2). First, the reaction was carried out at the same temperature as classical heating. After 16 h, the reaction was almost completed, and the 2-chloro-1-(chloromethyl)ethyl regioisomer was the main isomer synthesized. Classical heating provided 64% yield for the same temperature and reaction period. Once we had determined that classical and microwave heating gave similar regioisomeric ratios at 80 °C, experiments at higher temperatures were carried out using microwave irradiation. The reaction period was progressively diminished to avoid product decomposition. Nevertheless, changes introduced in the reaction time were always tested, at the corresponding temperature, to determine that the regioisomeric ratio was not strongly affected by the reaction time. Table 2 shows that 2,3-dichloropropyl ester **4a** increased parallel to temperature increase. Finally, the reaction was carried out at 115 °C for 48 h using classical heating. Crude yield was similar to those obtained at 80 °C. However, the regioisomeric **3a**:**4a** ratio was 88:12 in this case.

Consequently, regioisomeric ratio seems to be dependent of the temperature and independent of the heating system used. Nevertheless, considering that irradiation power in the experiments described above changed automatically to achieve the desired temperature and that non-thermal effects[7] have been adduced to explain some results in microwave irradiation studies, we decided to carry out a new set of experiments using the highest irradiation power yielded by the reactor (300 W) but maintaining the temperature at 30–35 °C. These reactions were carried out in an open vessel provided with a low temperature accessory. Using this approach, we tried to determine if non-thermal microwave effects were able to promote the formation of the 2,3-dichloropropyl esters **4**. Caprylic acid (**2b**) was used in this experiment to assure a liquid homogeneous system.

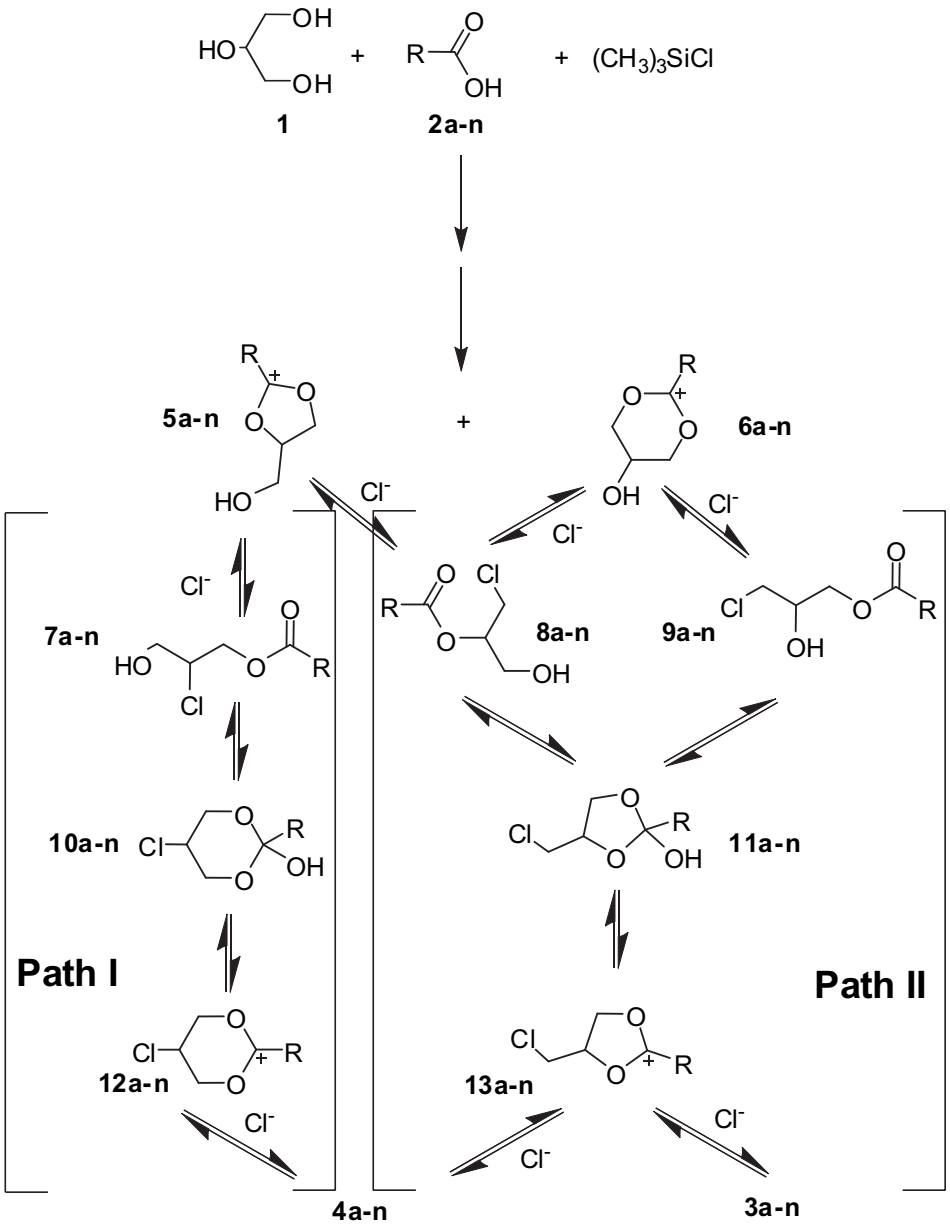
Table 1
Percentage yields and regioisomeric ratio of chlorohydrin esters 3:4 obtained using different reaction conditions and heating systems

Entry	R	Classical[a]		Classical[b]		Microwave[c]		Microwave[d]	
		Isolated yield%	Molar **3**:**4** ratio	Crude yield%[e]	Molar **3**:**4** ratio	Isolated yield%	Molar **3**:**4** ratio	Crude yield%[e]	Molar **3**:**4** ratio
a	$CH_3(CH_2)_{14}$	91	98:2	100	97:3	86	37:63	70	38:62
b	$CH_3(CH_2)_6$	88	85:15	92	81:19	81	39:61	73	35:65
c	$(CH_3)_3C$	95	99:1	94	100:0	90	41:59	62	33:67
d	C_6H_5	88	99:1	96	100:0	80	35:65	64	39:61
e	C_6H_5–CH=CH	80	100:0	83	99:1	73	41:59	64	44:56
f	o–Cl–C_6H_4	85	98:2	100	99:1	78	35:65	61	41:59
g	o–HO–C_6H_4	92	97:3	89	100:0	73	41:59	52	43:57
h	m-NO_2–C_6H_4	90	100:0	91	98:2	78	30:70	60	36:64
i	3,5-$(NO_2)_2$–C_6H_4	77	100:0	52	99:1	77[f]	54:46	57[g]	55:45
j	2,4-$(NO_2)_2$–C_6H_4	81	99:1	30	100:0	75[f]	59:41	65[g]	58:42
k	1-Naphthyl	89	100:0	93	99:1	82	36:64	55	37:63
l	2-Naphthyl	82	100:0	100	100:0	76	37:63	60	41:59
m	2-Furyl	84	96:4	94	98:2	78	35:65	55	33:67
n	2-Thiophencarboxyl	88	99:1	90	100:0	72	36:64	63	39:61

[a] Mole ratio **1**:**2**:CTMS, 2:1:5, reaction temperature 80 °C, reaction time 48 h.
[b] Mole ratio **1**:**2**:CTMS, 1.2:1:2.2, reaction temperature 80 °C, reaction time 48 h.
[c] Mole ratio **1**:**2**:CTMS, 2:1:5, reaction temperature 243–247 °C, reaction time 20 min.
[d] Mole ratio **1**:**2**:CTMS, 1.2:1:2.2, reaction temperature 243–247 °C, reaction time 20 min.
[e] Determined by GC using an internal standard.
[f] Mole ratio **1**:**2**:CTMS, 2:1:5, reaction temperature 170–175 °C, reaction time 20 min.
[g] Mole ratio **1**:**2**:CTMS, 1.2:1:2.2, reaction temperature 170–175 °C, reaction time 20 min.

The different regioisomeric ratios obtained for the various acids could be explained according to the charge density at the carboxylic carbon of the various acids.[5] Moreover, microwave irradiation usually tends to promote thermodynamically stable products.[6] This effect is enhanced when polar intermediates occur during the reaction process.[7] Nevertheless, some experiments show that microwave can also modify activation parameters.[14] Consequently, different compounds can be obtained.

When the reaction was carried out at 30–35 °C and 300 W for 2 h, dichloropropyl caprylates (**3b** and **4b**) were obtained with 95% yield. Similar yields were obtained carrying out the reaction for 48 h at 30–31 °C without microwave irradiation. The **3b**:**4b** regioisomeric ratios, 85:15, were similar in both cases. In conclusion, high microwave irradiation power at low temperature did not produce the increase of 2,3-regioisomeric ester but significantly decreased the reaction time needed to obtain high conversion



Scheme 2. Putative mechanistic pathways to explain the formation of chlorohydrin esters using CTMS as reagent and catalyst.

Table 2
Percentage yields and regioisomeric ratio of chlorohydrin palmitates **3a**:**4a** (in parentheses) obtained at different temperatures and reaction times

Temp °C (SD)[a]	Reaction time[b] (h)					
	1/12	1/3	2	5	8	16
80.0 (0.5)[c]			52% (96:4)	72% (95:5)	85% (95:5)	96% (90:10)
99.9 (0.7)[c]			54% (92:8)			
149.8 (0.6)[c]		96% (85:15)	95% (84:16)			
199.4 (0.8)[c]	95% (62:38)	98% (40:60)				
234.1 (8.3)[c]	96% (57:43)	93% (32:68)				
80.0 (1.0)[d]			9% (94:6)		35% (97:3)	64% (98:2)

[a] Standard deviation.
[b] Yields determined by GC using an internal standard.
[c] Mole ratio 1:2:CTMS, 2:1:5, microwave irradiation.
[d] Mole ratio 1:2:CTMS, 2:1:5, classical heating.

yields. This effect has been extensively described in the literature and is best observed when polar products such as glycerol are present in the reaction medium. Non-thermal processes have been proposed to explain such results.[6b] Glycerol, a highly polar molecule, will instantaneously absorb a high amount of microwave energy.[7] The rotational motion of such molecules is then increased. This causes a kinetic energy increase in the molecules that could drive the reaction to completion faster than using conventional heating.

These results could be explained assuming the kinetic control of the reaction at low temperature. Reaction will be thermodynamic controlled as the temperature increases. Nevertheless, diverse pathways could be proposed to obtain these two regioisomers (Scheme 2). Pathway II will allow a kinetic versus thermodynamic control of the reaction, whereas pathway I will allow a different way to obtain the 2,3-regiosomer. This pathway could be favored by using the microwave reactor.

To propose a feasible mechanism for this one-pot esterification–chlorination reaction, an isomerization set of experiments and a computational analysis were carried out.

2-Chloro-1-(chloromethyl)ethyl palmitate **3a** was heated either in a solvent-free system or in the presence of several solvents to evaluate the putative isomerization of **3a** to **4a** (Scheme 2, Pathway II) in diverse conditions. Table 3 shows that conventional heating at 80 °C for 7 d or no-heating for one year produce no or little isomerization of **3a**–**4a**. However, **3a** can be partially isomerized to **4a** by conventional heating at 150 °C for 48 h or microwave irradiation whatever the reaction medium used. Similar results were described by Derbesy and Naudet[8] studying the isomerization of 1-chloro-2-propyl and 4-chloro-2-butyl esters and for the isomerization of dihalopropyl acetates.[9] In contrast, Nayler[10] described the isomerization of 2,3-dibromopropyl aryl esters to the corresponding 2-bromo-1-(bromomethyl)ethyl esters by classical heating. In this case, none of the 2,3-regioisomers remained at the end of the reaction. Nevertheless, the authors reported that 2,3-dibromopropyl alkyl esters did not isomerize to the 2-bromo-1-(bromomethyl)ethyl esters under the same reaction conditions.

Table 3
Final regioisomeric ratio obtained after 2-chloro-1-(chloromethyl)ethyl palmitate **3a** was subjected to diverse isomerization conditions

Solvent	Reaction time		
	1 h[a]	2 h[a]	≥48 h[a]
None[b]			95:5
None[c]			98:2
None[d]			60:40
None[e]	30:70	—	
Isooctane[e]	60:40	30:70	
Xylene[e]	40:60	—	
Chloroform[e]	30:70	—	
Chlorotrimethylsilane[e]	40:60	40:60	
Hexamethyldisiloxane[e]	70:30	50:50	
Butanone[e]	30:70	—	
tert-Butanol[e]	30:70	—	

[a] Molar **3a**:**4a** ratio determined by GC using an internal standard.
[b] One year at 25 °C.
[c] Classical heating at 80 °C for 7 days.
[d] Classical heating at 150 °C for 48 h.
[e] Microwave irradiation (300 w max, 17 atm max, 243–247 °C).

Once the isomerization process was studied, a B3LYP[11] calculations at the 6–311++G(d,p)[12] level were carried out for the different species using the Gaussian03[13] package.

The calculation of harmonic frequencies was performed to confirm that they were minima. Table 4 shows electronic energies for each different intermediate and the final products for pivalic (**2c**) and benzoic (**2d**) acids as model compounds. These data seem to confirm that the corresponding 2-chloro-1-(chloromethyl)ethyl esters (**3**) are less thermodynamically stable than the 2,3-dichloro propyl esters (**4**) (13.16 kJ mol^{-1} for R=C(CH$_3$)$_3$ and 8.58 kJ mol^{-1} for C$_6$H$_5$). Therefore, classical heating at low temperature will drive the process to the kinetically controlled products, whereas high temperatures, easy reached with microwave heating, favor thermodynamic control of the reaction. Pews and Davis[9] have shown that the 2-chloro-1-(chloromethyl)ethyl acetate can be partially isomerized to 2,3-dichloro-1-propyl acetate at 180 °C, which confirms our hypothesis. However, intermediate **7** is more stable than **8** (59.49 kJ mol^{-1} for R=C(CH$_3$)$_3$ and 46.52 kJ mol^{-1} for C$_6$H$_5$) and **9** (6.99 kJ mol^{-1} and 7.04 kJ mol^{-1}, respectively), both containing the carboxylic group in the α position. Moreover, 1,3-dioxolanic compounds **11** are is more stable than the corresponding 1,3-dioxanic isomers **10** (4.83 kJ mol^{-1} and 4.54 kJ mol^{-1}). Protonation of **10** and **11** proceeds spontaneous to the loose of H$_2$O, giving **12** and **13**, being **13** the most stable compound for both substituents (3.03 kJ mol^{-1} and 5.83 kJ mol^{-1} for R=C(CH$_3$)$_3$ and C$_6$H$_5$), respectively.

Table 4
DFT B3LYP/6-311++G(d,p) electronic energies for the formation of dichloropropyl pivaloates (**c**) and dichloropropyl benzoates (**d**) (a.u.)

Entry	c	d
3	−1384.317846	−1458.135040
4	−1384.322864	−1458.138310
5	−539.454866	−613.274373
6	−539.454574	−613.271013
7	−999.939768	−1073.756168
8	−999.962433	−1073.773905
9	−999.959785	−1073.771218
10	−999.940996	−1073.746778
11	−999.942836	−1073.748508
12	−923.831767	−997.64845
13	−923.832924	−997.650673

These results prompted us to propose that glycerol is transformed to the 2,3-dichlorohydrin regioisomer by the 4-chloro methyldioxolanic (pathway II) rather than the 5-chlorodioxanic (pathway I) whatever the heating system used. Kinetic control will determine the final regioisomeric ratio of the reaction when low temperature is used. The rearrangement process from 1,3- to 2,3-regioisomers will involve a nucleophilic attack of the sp^2 oxygen present in the carboxylic group to form the 1,3-dioxolane cations (**13a**–**n**). A similar rearrangement process was proposed by Nayler[10] and Pews and Davis[9] during the studies described above, and Steblyanko et al.[14] in the polymerization of acyloxymethyl five-member cyclic dithiocarbonates. Non-purely thermal specific MW effects will be consistent with the solvent-free conditions and the polar mechanisms proposed (more polar transition states when compared to their ground states).[7]

3. Summary

Glycerol can be transformed into 2-chloro-1-(chloromethyl)ethyl alkyl and aryl esters through a kinetically controlled process. These esters could be partially transformed to the corresponding 2,3-dichloropropyl regioisomer using a monomode microwave oven and sufficiently high temperature. Microwave irradiation maintaining low temperature dramatically increases the reaction rate, maintaining kinetic control of the reaction. This effect can be explained by assuming non-thermal microwave effects. A plausible mechanism is proposed on the basis of computational and experimental studies.

4. Experimental section

4.1. Material and methods

^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded on a VARIAN 400 spectrometer. All Chemical shifts are reported in delta units (δ), parts per million (ppm) relative to the singlet at 7.26 ppm of $CDCl_3$ for ^{1}H and center line of a triplet at 77.00 ppm for ^{13}C NMR. The following abbreviations are used; s: singlet, d: doublet, t: triplet, q: quartet, quin: quintet, m: multiplet.

GC-FID analyses were performed in an Agilent Technologies 6890 N equipped with a DB5-MS column (J&W) (30 m×0.25 μm×0.25 mm) and He as carrier gas. The following chromatographic conditions were used: constant flow 2 mL/min, split injection ratio 20:1 at 300 °C. Oven started at 50 °C for 5 min, temperature was increased at 5 °C/min to 110 °C, then increased at 10 °C/min until final temperature of 260 °C for 15 min. Tridecane from Aldrich was used as internal standard to carry out GC quantification.

GC–MS analyses were performed in an Agilent Technologies 6890 N equipped with a DB5-MS column (J&W) (30 m×0.25 μm×0.25 mm) coupled to an Agilent Technologies 5973 Network detector and He as carrier gas. The following chromatographic conditions were used: constant flow 2 mL/min, split injection ratio 20:1 at 280 °C. Oven started at 50 °C for 5 min, temperature was increased at 5 °C/min to 110 °C, then increased at 10 °C/min until final temperature of 260 °C for 15 min.

IR spectra were recorded on a Magna IR 560 NicoleT FTIR spectrophotometer in the range 4000–600 cm^{-1} with KBr pellets or with diamond HATR from SpectraTech as specified. Spectra are reported in reciprocal centimeters (cm^{-1}).

High-resolution mass spectral (HRMS) data were obtained by direct infusion on LC-TOF-MS Waters LCT Premier XE using ESI or APCI or on Waters GCT Premier using EI as specified.

Melting points are uncorrected and were determined on a Gallenkamp capillary melting point apparatus.

Elemental analysis of was performed in a Carlo Erba Instruments EA 1108.

4.2. General procedure for dichloropropyl ester synthesis. (3a–n, 4a–n)

The corresponding acid, glycerol, and CTMS (see Table 1) were added in a reaction vial fitted with a PTFE-lined cap. The mixture was either heated at 80 °C for 48 h or irradiated to heat the reaction mixture at 250 °C or 175 °C (maximum power irradiation 300 W, maximum reaction pressure 17 atm, see Table 1) for 20 min using a Discover LabMate microwave reactor (CEM, Matthews, USA) equipped with magnetic stirring and an air cooling system. After cooling, an organic solvent was added, and the mixture was washed three times with water. The organic layer was dried over anhydrous $MgSO_4$, and the solvent was evaporated under vacuum. The crude product was purified by crystallization, distillation, or SiO_2 column chromatography.

4.3. General procedure for 2-chloro-1-(chloromethyl)ethyl palmitate (3a) synthesis studies

Palmitic acid (256 mg, 1 mmol, **2a**), glycerol (184 mg, 2 mmol, **1**), and CTMS (540 mg, 5 mmol) were added to a reaction vial fitted with a PTFE-lined cap. The mixture was heated or irradiated using a Discover LabMate microwave reactor (CEM, Matthews, USA) equipped with magnetic stirring and an air cooling system to reach the corresponding temperature for 1/12, 1/3, 2, 5, 8, or 16 h (see Table 3). After cooling, *t*-butyl methyl ether was added, and the mixture was washed three times with water. The organic layer was dried over anhydrous $MgSO_4$, and the solvent was evaporated under vacuum. The crude product was analyzed by GC/FID using tridecane as the internal standard.

4.4. General procedure for 2-chloro-1-(chloromethyl)ethyl palmitate (3a) isomerization studies

Pure ester **3a** (366 mg, 1 mmol) and the corresponding solvent (5 mmol), when required (see Table 4), were added to a reaction vial fitted with a PTFE-lined cap. The mixture was subjected to diverse reaction conditions (see Table 4). After cooling, when required, *t*-butyl methyl ether was added, and the mixture was washed three times with water. The organic layer was dried over anhydrous $MgSO_4$, and the solvent was evaporated under vacuum. The crude product was analyzed by GC/FID to determine the final regioisomeric ratio.

4.5. General procedure for dichloropropyl caprylates (3b and 4b) synthesis at low temperature

Caprylic acid (144 mg, 1 mmol, **2b**), glycerol (184 mg, 2 mmol, **1**) and CTMS (540 mg, 5 mmol) were added to a reaction vial. The mixture was either classically heated at 30 °C for 48 h or irradiated using the power-time mode of the Discover LabMate microwave reactor (CEM, Matthews, USA). Irradiation power was fixed at 300 W, and the temperature was maintained at 30–35 °C for 2 h using the Cool Mate low temperature accessory (CEM, Matthews, USA). *t*-Butyl methyl ether was added, and the mixture was washed three times with water. The organic layer was dried over anhydrous $MgSO_4$, and the solvent was evaporated under vacuum. The crude product was analyzed by GC/FID using tridecane as the internal standard.

4.6. Analytical data

*4.6.1. 1,3-Dichloro-2-propyl palmitate (**3a**).* [CAS: 72165-62-9]: The analytical and spectroscopic data are in accordance with the literature.[4a]

*4.6.2. 1,3-Dichloro-2-propyl caprylate (**3b**).* ^{1}H NMR ($CDCl_3$), δ: 5.12 (quin, J=5.2 Hz, 1H, O–C*H*), 3.68 (dd, J_1=5.7 Hz, J_2=2.2 Hz, 4H, 2C*H*$_2$–Cl), 2.31 (t, J=7.6 Hz, 2H, C*H*$_{2\ (\alpha)}$ (C=O)), 1.58 (quin, J=7.4 Hz, 2H, C*H*$_{2\ (\beta)}$ (C=O)), 1.24 (m, 8H, C*H*$_2$), 0.82 (t, J=7.2 Hz, 3H, C*H*$_3$). ^{13}C RMN ($CDCl_3$), δ: 173 (*C*=O), 72 (O–*C*H), 42 (*C*H$_2$–Cl), 34.4 (*C*H$_{2\ (\alpha)}$ (C=O)), 32.1 (CH$_2$–*C*H$_2$–CH$_3$), 29.5 (*C*H$_2$), 25 (*C*H$_{2\ (\beta)}$ (C=O)), 22.5 (*C*H$_2$–CH$_3$), 14.5 (*C*H$_3$). GC–MS, *m*/*z*: 254.1 $[M]^+$, 183 $[M\text{-}2Cl]^+$, 143 $[M\text{-}C_3H_5Cl_2]^+$, 127 $[M\text{-}OC_3H_5Cl_2]^+$, 111 $[C_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 2957, 2927, 2856, 1742, 1154, 1102, 1050, 846, 769 cm^{-1}. HRMS (EI+) calculated for $C_{11}H_{20}O_2Cl_2$: 254.0840, found: 254.0836.

*4.6.3. 1,3-Dichloro-2-propyl pivaloate (**3c**).* [CAS: 220499-01-4]: The analytical and spectroscopic data are in accordance with the literature.[15]

*4.6.4. 1,3-Dichloro-2-propyl benzoate (**3d**).* [CAS: 36847-76-4]: ^{1}H NMR ($CDCl_3$), δ: 8.00 (m, 1H, C*H*$_{ar\ (\alpha)}$ (C=O)), 7.53 (m, 1H, C*H*$_{ar}$), 7.39 (m, 2H, C*H*$_{ar}$), 5.36 (quin, J=5.3 Hz, 1H, O–C*H*), 3.82 (m, 4H, 2C*H*$_2$–Cl). ^{13}C RMN ($CDCl_3$), δ: 163.4 (*C*=O), 131.7, 127.9, 127.2, 126.6 (*C*$_{ar}$), 70.1 (O–*C*H), 40.5 (*C*H$_2$–Cl). GC–MS, *m*/*z*: 232 $[M]^+$, 122 $[M\text{-}C_3H_5Cl_2]^+$; 105 $[M\text{-}OC_3H_5Cl_2]^+$; 77 $[M\text{-}CO_2C_3H_5Cl_2]^+$. IR (KBr), ν_{max}: 3078, 2966, 1720, 1249, 1095, 705, 685 cm^{-1}. bp: 100 °C/130 Torr (glass oven B-585 Kugelrohr) (271.7±20.0 °C/760 Torr).[15b] HRMS (EI+) calculated for $C_{10}H_{10}Cl_2O_2$: 232.0058, found: 232.0058.

*4.6.5. 1,3-Dichloro-2-propyl cinnamate (**3e**).* [CAS: 157140-94-8]: The analytical and spectroscopic data are in accordance with the literature.[16]

*4.6.6. 1,3-Dichloro-2-propyl 2-chlorobenzoate (**3f**).* ^{1}H NMR ($CDCl_3$), δ: 7.83 (m, 1H, C*H*$_{ar}$–C=O), 7.40 (m, 2H, C*H*$_{ar}$), 7.28 (m, 1H, C*H*$_{ar}$–Cl), 5.38 (quin, J=5.3 Hz, 1H, O–C*H*), 3.83 (d, J=5.0 Hz, 4H, 2C*H*$_2$–Cl). ^{13}C

RMN ($CDCl_3$), δ: 164.5 (*C*=O), 134.4 (C_{ar}–Cl), 133.4, 131.9, 131.5, 129.1, 126.9 (C_{ar}), 72.9 (O–*C*H), 42.5 (*C*H_2–Cl). GC–MS, *m*/*z*: 266 $[M]^+$, 156 $[M\text{-}C_3H_5Cl_2]^+$; 139 $[M\text{-}OC_3H_5Cl_2]^+$; 111 $[M\text{-}CO_2C_3H_5Cl_2]^+$. IR (KBr), ν_{max}: 3072, 3030, 2968, 1736, 1591, 1436, 1287, 1246, 1115, 1051, 747, 689 cm^{-1}. Elem. Anal. calcd for $C_{10}H_9Cl_3O_2$: C, 44.89; H, 3.39; Cl, 39.75; O, 11.96. Found: C, 45.04; H 3.40; Cl, 40.86; O, 10.70.

*4.6.7. 1,3-Dichloro-2-propyl salicylate (**3g**).* [CAS: 64496-72-6]: ^1H NMR ($CDCl_3$), δ: 7.89 (dd, J_1=8.2 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 7.49 (m, 1H, CH_{ar}), 7.01 (dd, J_1=8.6 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 6.92 (m, 1H, CH_{ar}), 5.46 (quin, *J*=5.1 Hz, 1H, O–*C*H), 3.89 (d, *J*=5.1 Hz, 4H, 2*C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 169.1 (*C*=O), 162.1 (C_{ar}-OH), 136.7, 130.3, 119.7, 117.9, 111.8 (C_{ar}), 72.7 (O–*C*H), 42.5 (*C*H_2–Cl). GC–MS, *m*/*z*: 248 $[M]^+$, 137 $[M\text{-}C_3H_5Cl_2]^+$; 120 $[M\text{-}HOC_3H_5Cl_2]^+$; 93 $[M\text{-}HCO_2C_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3248, 3079, 2962, 1677, 1613, 1677, 1613, 1484, 1289, 1156, 1085, 755, 698 cm^{-1}. mp: 44.3–44.7 °C. (49–50 °C).[17]

*4.6.8. 1,3-Dichloro-2-propyl m-nitrobenzoate (**3h**).* ^1H NMR ($CDCl_3$), δ: 8.81 (t, *J*=2.0 Hz, 1H, CH_{ar}), 8.37 (m, 2H, CH_{ar}), 7.64 (t, *J*=8.2 Hz, 1H, CH_{ar}), 5.43 (quin, *J*=5.1 Hz, 1H, O–*C*H), 3.85 (d, *J*=5.1 Hz, 4H, 2*C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 163.8 (*C*=O), 151.1 (C_{ar}-NO_2), 134.7 (C_{ar}–C=O), 130, 129.8, 122.7 (*C*H_{ar}), 73.3 (O–*C*H), 42.5 (*C*H_2–Cl). GC–MS, *m*/*z*: 278 $[M]^+$, 231 $[M\text{-}NO_2]^+$; 150 $[M\text{-}OC_3H_5Cl_2]^+$; 122 $[M\text{-}CO_2C_3H_5Cl_2]^+$; 104 $[M\text{-}NO_2OC_3H_5Cl_2]^+$; 76 $[M\text{-}NO_2CO_2C_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3111, 2966, 1726, 1525, 1343, 1262, 1100, 1014, 872, 716, 670 cm^{-1}. Elem. Anal. calcd for $C_{10}H_9Cl_2NO_4$: C, 43.19; H, 3.26; Cl, 25.50; N, 5.04; O, 23.01. Found: C, 43.48; H, 3.28; Cl, 24.50; N, 5.08; O, 23.66. mp: 56.5–56.7 °C.

*4.6.9. 1,3-Dichloro-2-propyl 3,5-dinitrobenzoate (**3i**).* ^1H NMR ($COCD_6$), δ: 9.21 (t, *J*=2.3 Hz 1H, CH_{ar}), 9.13 (d, *J*=2.4 Hz, 2H, CH_{ar}), 5.67 (quin, *J*=5.1 Hz, 1H, O–*C*H), 4.12 (d, *J*=4.9 Hz, 4H, *C*H_2–Cl). ^{13}C RMN ($COCD_6$), δ: 164.4 (*C*=O), 149.1 (C_{ar}-NO_2), 134.3 (C_{ar}–C=O), 128, 122.8 (*C*H_{ar}), 76.3 (O–*C*H), 43.5 (*C*H_2–Cl). GC–MS, *m*/*z*: 323 $[M]^+$, 275 $[M\text{-}NO_2]^+$; 229 $[M\text{-}2NO_2]^+$; 252 $[M\text{-}2Cl]^+$; 195 $[M\text{-}OC_3H_5Cl_2]^+$. IR (KBr), ν_{max}: 3099, 2963, 2884, 1735, 1544, 1346, 1275, 1165, 720 cm^{-1}. Elem. Anal. calcd for $C_{10}H_8Cl_2N_2O_6$: C, 37.17; H, 2.50; Cl, 21.95; N, 8.67; O, 29.71. Found: C, 37.23; H, 2.51; Cl, 21.82; N, 8.61; O, 29.83. mp: 131.6–131.8 °C.

*4.6.10. 1,3-Dichloro-2-propyl 2,4-dinitrobenzoate (**3j**).* ^1H NMR ($CDCl_3$), δ: 8.87 (d, *J*=2.0 Hz, 1H, CH_{ar}), 8.58 (dd, *J*=8.2, *J*=2.0 Hz, 1H, CH_{ar}), 7.96 (d, *J*=8.2 Hz, 1H, CH_{ar}), 5.50 (quin, *J*=5.1 Hz, 1H, O–*CH*), 3.88 (d, *J*=4.7 Hz, 4H, *C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 163.2 (*C*=O), 149.8, 147.9 (C_{ar}-NO_2), 132.7 (C_{ar}–C=O), 131.6, 129.1, 120.2 (*C*H_{ar}), 74.3 (O–*C*H), 42.1 (*C*H_2–Cl). GC–MS, *m*/*z*: 323 $[M]^+$, 275 $[M\text{-}NO_2]^+$; 230 $[M\text{-}2NO_2]^+$; 252 $[M\text{-}2Cl]^+$; 195 $[M\text{-}OC_3H_5Cl_2]^+$. IR (KBr), ν_{max}: 3107, 3058, 2960, 2885, 1743, 1541, 1349, 1283, 1110, 834 cm^{-1}. Elem. Anal. calcd for $C_{10}H_8Cl_2N_2O_6$: C, 37.17; H, 2.50; Cl, 21.95; N, 8.67; O, 29.71. Found: C, 37.67; H, 2.50; Cl, 21.90; N, 8.57; O, 29.36.

*4.6.11. 1,3-Dichloro-2-propyl 1-naphthoate (**3k**).* ^1H NMR ($CDCl_3$), δ: 8.93 (dd, J_1=8.8 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 8.28 (dd, J_1=7.6 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 8.07 (d, *J*=8.4 Hz, 1H, CH_{ar}), 7.91 (d, *J*=7.6 Hz, 1H, CH_{ar}), 7.65 (m, 1H, CH_{ar}), 7.54 (m, 2H, 2CH_{ar}), 5.54 (quin, *J*=4.8 Hz, 1H, O–*CH*), 3.96 (d, *J*=4.8 Hz, 4H, 2*C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 166.3 (*C*=O), 134.4, 134.1, 131.6, 131.2, 128.9, 128.4, 126.6, 125.9, 125.8, 124.8 (*C*H_{ar}), 72.4 (O–*C*H), 42.8 (*C*H_2–Cl). GC–MS, *m*/*z*: 282 $[M]^+$, 212 $[M\text{-}Cl_2]^+$; 172 $[M\text{-}C_3H_5Cl_2]^+$; 155 $[M\text{-}OC_3H_5Cl_2]^+$; 127 $[M\text{-}CO_2C_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3051, 2964, 1716, 1509, 1236, 1191, 1126, 1036, 776, 752, 655 cm^{-1}. mp: 65.4–65.8 °C. Elem. Anal. calcd for $C_{14}H_{12}Cl_2O_2$: C, 59.39; H, 4.27; Cl, 25.04; O, 11.30. Found: C, 59.41; H, 4.28; Cl, 24.93; O, 11.38.

*4.6.12. 1,3-Dichloro-2-propyl 2-naphthoate (**3l**).* ^1H NMR ($CDCl_3$), δ: 8.58 (s, 1H, CH_{ar}), 8.01 (dd, J_1=8.8 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 7.92 (d, *J*=8.4 Hz, 1H, CH_{ar}), 7.84 (d, *J*=8.8 Hz, 1H, CH_{ar}), 7.83 (d, *J*=8 Hz, 1H, CH_{ar}), 7.53 (m, 2H, 2CH_{ar}), 5.44 (quin, *J*=4.8 Hz, 1H, O–*CH*), 3.88 (d, *J*=4.8 Hz, 4H, 2*C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 165.8 (*C*=O), 136.0, 132.7, 131.9, 129.7, 128.9, 128.6, 128.0, 127.1, 126.6, 125.4 (*C*H_{ar}), 72.4 (O–*C*H), 42.7 (*C*H_2–Cl). GC–MS, *m*/*z*: 282 $[M]^+$, 212 $[M\text{-}Cl_2]^+$; 172 $[M\text{-}C_3H_5Cl_2]^+$; 155 $[M\text{-}OC_3H_5Cl_2]^+$; 127 $[M\text{-}CO_2C_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3061, 2968, 1717, 1630, 1276, 1192, 1088, 775, 760, 703 cm^{-1}. mp: 62.5–65.9 °C. Elem. Anal. calcd for $C_{14}H_{12}Cl_2O_2$: C, 59.39; H, 4.27; Cl, 25.04; O, 11.30. Found: C, 59.38; H, 4.29; Cl, 24.83; O, 11.50.

*4.6.13. 1,3-Dichloro-2-propyl 2-furoate (**3m**).* ^1H NMR ($CDCl_3$), δ: 7.57 (m, CH_{ar}), 7.21 (dt, J_1=3.5 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 6.48 (m, 1H, CH_{ar}), 5.33 (quin, *J*=5.1 Hz, 1H, O–*C*H), 3.80 (d, *J*=5.1 Hz, 4H, *C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 156.9 (*C*=O), 146.5 (*C*H_{ar}), 143.7 (C_{ar}–C=O), 119.8, 112.1 (*C*H_{ar}), 72.3 (O–*C*H), 43.1 (*C*H_2–Cl). GC–MS, *m*/*z*: 222 $[M]^+$, 187 $[M\text{-}Cl]^+$; 112 $[M\text{-}C_3H_5Cl_2]^+$; 95 $[M\text{-}OC_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3180, 3175, 2960, 1705, 1410, 1261, 1122, 1045, 750, 660 cm^{-1}. HRMS (EI+) calcd for $C_8H_8Cl_2O_3$: 221.9850, found: 221.9840.

*4.6.14. 1,3-Dichloro-2-propyl 2-thiophencarboxylate (**3n**).* ^1H NMR ($CDCl_3$), δ: 7.79 (dd, J_1=3.9 Hz, J_2=1.2 Hz, 1H, CH_{ar}), 7.61 (dd, J_1=5.1 Hz, J_2=1.2 Hz, 1H, CH_{ar}), 7.05 (dd, J_1=5.1 Hz, J_2=3.9 Hz, 1H, CH_{ar}), 5.31 (quin, *J*=5.1 Hz, 1H, O–*CH*), 3.79 (d, *J*=5.1 Hz, 4H, *C*H_2–Cl). ^{13}C RMN ($CDCl_3$), δ: 161.1 (*C*=O), 144.8 (*C*H_{ar}), 143.8 (C_{ar}–C=O), 122.5, 118.1 (*C*H_{ar}), 72.2 (O–*C*H), 42.8 (*C*H_2–Cl). GC–MS, *m*/*z*: 238 $[M]^+$, 202 $[M\text{-}Cl]^+$; 128 $[M\text{-}C_3H_5Cl_2]^+$; 111 $[M\text{-}OC_3H_5Cl_2]^+$. IR (ATR), ν_{max}: 3170, 2988, 1710, 1430, 1251, 1152, 1145, 760, 640 cm^{-1}. HRMS (EI+) calcd for $C_8H_8Cl_2O_2S$: 237.9622, found: 237.9611.

*4.6.15. 1,3-Dichloro-2-propyl palmitate (**3a**) and 2,3-dichloro-1-propyl palmitate (**4a**).* **3a** *Regioisomer*: GC t_r: 32,5 min. ^1H NMR ($CDCl_3$), δ: 5.18 (quin, *J*=5.2 Hz, 1H, O–*CH*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4a** *Regioisomer*: GC t_r: 32,8 min. ^1H NMR ($CDCl_3$), δ: 4.45 (m, 2H, O–*CH*$_2$), 4.18(*m*. 1H, C*H*–Cl), 3.75 (m, 2H, *CH*$_2$–Cl), 2.37 (t, *J*=7 Hz, 2H, *CH*$_{2\,(\alpha)}$ (C=O)), 1.65 (m, 2H, *CH*$_{2\,(\beta)}$ (C=O)), 1.26 (m, 24H, *CH*$_2$), 0.88 (t, *J*=7 Hz, 3H, *CH*$_3$).

*4.6.16. 1,3-Dichloro-2-propyl caprylate (**3b**) and 2,3-dichloro-1-propyl caprylate (**4b**).* **3b** *Regioisomer*: GC t_r: 24,0 min. ^1H NMR ($CDCl_3$), δ: 5.12 (quin, *J*=5.2 Hz, 1H, O–*CH*), 3.80 (dd, J_1=5.7 Hz, J_2=2.2 Hz, 4H, 2*CH*$_2$–Cl). All other NMR signals are hidden by the signals of the **4** regioisomer. **4a** *Regioisomer*: GC t_r: 24,5 min. ^1H NMR ($CDCl_3$), δ: 4.40 (m, 2H, O–*CH*$_2$), 4,25 (*m*, 1H, C*H*–Cl), 3.75 (m, 2H, *CH*$_2$–Cl), 2.37 (t, *J*=7 Hz, 2H, *CH*$_{2\,(\alpha)}$ (C=O)), 1.65 (m, 2H, *CH*$_{2\,(\beta)}$ (C=O)), 1.26 (m, 24H, *CH*$_2$), 0.88 (t, *J*=7 Hz, 3H, *CH*$_3$).

*4.6.17. 1,3-Dichloro-2-propyl pivaloate (**3c**) and 2,3-dichloro-1-propyl pivaloate (**3c**).* **3c** *Regioisomer*: GC t_r: 17,0 min. ^1H NMR ($CDCl_3$), δ: 5.14 (quin, *J*=5.2 Hz, 1H, O–C*H*), 3.76 (m, 4H, 2*CH*$_2$–Cl). All other NMR signals are hidden by the signals of the **4** regioisomer. **4a** *Regioisomer*: GC t_r: 17,9 min. ^1H NMR ($CDCl_3$), δ: 4.38 (m, 2H, O–*CH*$_2$), 4.230 (*m*, 1H, C*H*–Cl), 3.66 (m, 2H, *CH*$_2$–Cl), 2.37 (t, *J*=7 Hz, 2H, *CH*$_{2\,(\alpha)}$ (C=O)), 1.65 (m, 2H, *CH*$_{2\,(\beta)}$ (C=O)), 1.26 (m, 24H, *CH*$_2$), 0.88 (t, *J*=7 Hz, 3H, *CH*$_3$).

*4.6.18. 1,3-Dichloro-2-propyl benzoate (**3d**) and 2,3-dichloro-1-propyl benzoate (**4d**).* **3d** *Regioisomer*: GC t_r: 24,3 min. ^1H NMR ($CDCl_3$), δ: 5.36 (quin, *J*=5.3 Hz, 1H, O–*CH*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4d** *Regioisomer*: GC t_r: 24,8 min. ^1H NMR ($CDCl_3$), δ: 8.00 (m, 1H, C*H*$_{ar\,(\alpha)}$ (C=O)), 7.53 (m, 1H, C*H*$_{ar}$), 7.39 (m, 2H, C*H*$_{ar}$), 4.58 (m, 2H, O–*CH*$_2$), 4.35 (*m*, 1H, C*H*–Cl), 3.82 (m, 2H, *CH*$_2$–Cl).

*4.6.19. 1,3-Dichloro-2-propyl cinnamate (**3e**) and 2,3-dichloro-1-propyl cinnamate (**4e**).* **3e** *Regioisomer*: GC t_r: 27,9 min. ^1H NMR ($CDCl_3$), δ: 5.26 (quin, *J*=5.2 Hz, 1H, O–*CH*), 3.81 (dd, J_1=5.2 Hz, J_2=0.8 Hz, 4H, 2*CH*$_2$–Cl). All other NMR signals are hidden by the

signals of the **4** regioisomer. **4e** *Regioisomer*: GC t_r: 28,3 min. ^{1}H NMR ($CDCl_3$), 7.71 (d, J=16 Hz, 1H, CH_{ar}), 7.48 (t, J=3.5 Hz, 2H, 2CH_{ar}), 7.34 (m, 3H, 2CH_{ar}), 6.45 (dd, J_1=15.8 Hz, J_2=0.9 Hz, 2H, Ph–C*H*=C*H*), 4.47 (m, 2H, O–CH_2), 4.31(*m*, 1H, C*H*–Cl), 3.65 (d, J_1=5.1 Hz, 2H, CH_2–Cl).

*4.6.20. 1,3-Dichloro-2-propyl 2-chlorobenzoate (**3f**) and 2,3-dichloro-1-propyl 2-chlorobenzoate (**4f**).* **3f** *Regioisomer*: GC t_r: 26,3 min. ^{1}H NMR ($CDCl_3$), δ: 5.38 (quin, J=5.3 Hz, 1H, O–C*H*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4f** *Regioisomer*: GC t_r: 26,8 min. ^{1}H NMR ($CDCl_3$), δ: 7.83 (m, 1H, CH_{ar}–C=O), 7.40 (m, 2H, CH_{ar}), 7.28 (m, 1H, CH_{ar}–Cl), 4.60 (m, 2H, O–CH_2, 4.35 (*m*, 1H, C*H*–Cl), 3.81 (m, 2H, CH_2–Cl).

*4.6.21. 1,3-Dichloro-2-propyl salicylate (**3g**) and 2,3-dichloro-1-propyl salicylate (**4g**).* **3g** *Regioisomer*: GC t_r: 25,1 min. ^{1}H NMR ($CDCl_3$), δ: 5.46 (quin, J=5.1 Hz, 1H, O–C*H*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4g** *Regioisomer*: GC t_r: 25,5 min. ^{1}H NMR ($CDCl_3$), δ: 7.89 (dd, J_1=8.2 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 7.49 (m, 1H, CH_{ar}), 7.01 (dd, J_1=8.6 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 6.92 (m, 1H, CH_{ar}), 4.55 (m, 2H, O–CH_2, 1H, C*H*–Cl), 3.91 (m, 2H, CH_2–Cl).

*4.6.22. 1,3-Dichloro-2-propyl m-nitrobenzoate (**3h**) and 2,3-dichloro-1-propyl m-nitrobenzoate (**4h**).* **3h** *Regioisomer*: GC t_r: 28,5 min. ^{1}H NMR ($CDCl_3$), δ: 5.48 (quin, J=5.1 Hz, 1H, O–C*H*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4h** *Regioisomer*: GC t_r: 28,9 min. ^{1}H NMR ($CDCl_3$), δ: 8.81 (t, J=2.0 Hz, 1H, CH_{ar}), 8.37 (m, 2H, CH_{ar}), 7.64 (t, J=8.2 Hz, 1H, CH_{ar}), 4.71 (m, 2H, O–CH_2), 4.39 (m, 1H, C*H*–Cl), 3.95 (m, 2H, CH_2–Cl).

*4.6.23. 1,3-Dichloro-2-propyl 3,5-dinitrobenzoate (**3i**) and 2,3-dichloro-1-propyl 3,5-dinitrobenzoate (**4i**).* **3i** *Regioisomer*: GC t_r: 31,9 min. ^{1}H NMR ($COCD_6$), δ: 9.21 (t, J=2.3 Hz 1H, CH_{ar}), 9.13 (d, J=2.4 Hz, 2H, CH_{ar}), 5.67 (quin, J=5.1 Hz, 1H, O–C*H*), 4.12 (d, J=4.9 Hz, 4H, CH_2–Cl). **4i** *Regioisomer*: GC t_r: 32,3 min. ^{1}H NMR ($CDCl_3$), δ: 4.65 (m, 2H, O–CH_2) 4,43 (*m*, 1H, C*H*–Cl). All other NMR signals are hidden by the signals of the **3** regioisomer.

*4.6.24. 1,3-Dichloro-2-propyl 2,4-dinitrobenzoate (**3j**) and 2,3-dichloro-1-propyl 2,4-dinitrobenzoate (**4j**).* **3j** *Regioisomer*: GC t_r: 31,5 min. ^{1}H NMR ($CDCl_3$), δ: 8.87 (d, J=2.0 Hz, 1H, CH_{ar}), 8.58 (dd, J=8.2, J=2.0 Hz, 1H, CH_{ar}), 7.96 (d, J=8.2 Hz, 1H, CH_{ar}), 5.50 (quin, J=5.1 Hz, 1H, O–C*H*), 3.88 (d, J=4.7 Hz, 4H, CH_2–Cl). **4j** *Regioisomer*: GC t_r: 31,9 min. ^{1}H NMR ($CDCl_3$), δ: 4.67 (m, 2H, O–CH_2), 4.45 (m 1H, C*H*–Cl). All other NMR signals are hidden by the signals of the **3** regioisomer.

*4.6.25. 1,3-Dichloro-2-propyl 1-naphthoate (**3k**) and 2,3-dichloro-1-propyl 1-naphthoate (**4k**).* **3k** *Regioisomer*: GC t_r: 30,0 min. ^{1}H NMR ($CDCl_3$), δ: 5.54 (quin, J=4.8 Hz, 1H, O–C*H*), 3.96 (d, J=4.8 Hz, 4H, 2CH_2–Cl). All other NMR signals are hidden by the signals of the **4** regioisomer. **4k** *Regioisomer*: GC t_r: 30,5 min. ^{1}H NMR ($CDCl_3$), δ: 8.93 (dd, J_1=8.8 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 8.28 (dd, J_1=7.6 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 8.07 (d, J=8.4 Hz, 1H, CH_{ar}), 7.91 (d, J=7.6 Hz, 1H, CH_{ar}), 7.65 (m, 1H, CH_{ar}), 7.54 (m, 2H, 2CH_{ar}), 4.62 (m, 2H, O–CH_2), 4.40 (m, 1H, C*H*–Cl), 3.81 (d, J=4.9 Hz, 2H, CH_2–Cl).

*4.6.26. 1,3-Dichloro-2-propyl 2-naphthoate (**3l**) and 2,3-dichloro-1-propyl 2-naphthoate (**4l**).* **3l** *Regioisomer*: GC t_r: 30,4 min. ^{1}H NMR ($CDCl_3$), δ: 5.44 (quin, J=4.8 Hz, 1H, O–C*H*), 3.88 (d, J=4.8 Hz, 4H, 2CH_2–Cl). All other NMR signals are hidden by the signals of the **4** regioisomer. **4l** *Regioisomer*: GC t_r: 30,8 min. ^{1}H NMR ($CDCl_3$), δ: 8.58 (s, 1H, CH_{ar}), 8.01 (dd, J_1=8.8 Hz, J_2=1.6 Hz, 1H, CH_{ar}), 7.92 (d, J=8.4 Hz, 1H, CH_{ar}), 7.84 (d, J=8.8 Hz, 1H, CH_{ar}), 7.83 (d, J=8 Hz, 1H, CH_{ar}), 7.53 (m, 2H, 2CH_{ar}), 4.65 (m, 2H, O–CH_2), 4.38 (m, 1H, C*H*–Cl), 3.76 (d, J=4.9 Hz, 2H, CH_2–Cl).

*4.6.27. 1,3-Dichloro-2-propyl 2-furoate (**3m**) and 2,3-dichloro-1-propyl 2-furoate (**4m**).* **3m** *Regioisomer*: GC t_r: 22,3 min. ^{1}H NMR ($CDCl_3$), δ: 5.41 (quin, J=5.1 Hz, 1H, O–C*H*), 3.90 (d, J=5.1 Hz, 4H, CH_2–Cl). All other NMR signals are hidden by the signals of the **4** regioisomer. **4m** *Regioisomer*: GC t_r: 22,7 min. ^{1}H NMR ($CDCl_3$), δ: 7.57 (m, CH_{ar}), 7.21 (dt, J_1=3.5 Hz, J_2=0.8 Hz, 1H, CH_{ar}), 6.48 (m, 1H, CH_{ar}), 4.62 (m, 2H, O–CH_2) 4.38 (m, 1H, C*H*–Cl), 3.80 (d, J=5.3 Hz, 2H, CH_2–Cl).

*4.6.28. 1,3-Dichloro-2-propyl 2-thiophencarboxylate (**3n**) and 2,3-dichloro-1-propyl 2-thiophencarboxylate (**4n**).* **3n** *Regioisomer*: GC t_r: 24,3 min. ^{1}H NMR ($CDCl_3$), δ: 5.31 (quin, J=5.1 Hz, 1H, O–C*H*). All other NMR signals are hidden by the signals of the **4** regioisomer. **4n** *Regioisomer*: GC t_r: 24,7 min. ^{1}H NMR ($CDCl_3$), δ: 7.79 (dd, J_1=3.9 Hz, J_2=1.2 Hz, 1H, CH_{ar}), 7.61 (dd, J_1=5.1 Hz, J_2=1.2 Hz, 1H, CH_{ar}), 7.05 (dd, J_1=5.1 Hz, J_2=3.9 Hz, 1H, CH_{ar}), 4.62 (m, 2H, O–CH_2) 4.38 (m, 1H, C*H*–Cl), 3.79 (m, 2H, CH_2–Cl).

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