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Microwave-Assisted Kinetic Resolution of Homochiral (Z)-Cyclooct-5-ene-1,2-diol and (Z)-2-Acetoxyoct-4-enyl Acetate Using Lipases

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Hervé Rouillard, Emmanuel Deau, Lisiane Domon, Jean-René Chérouvrier, Marianne Graber, et al.. Microwave-Assisted Kinetic Resolution of Homochiral (Z)-Cyclooct-5-ene-1,2-diol and (Z)-2-Acetoxyoct-4-enyl Acetate Using Lipases. *Molecules*, 2014, 19, pp.9215-9227. 10.3390/molecules19079215 . hal-01070424

HAL Id: hal-01070424

<https://hal.science/hal-01070424v1>

Submitted on 1 Oct 2014

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6 *Article*

7 **Microwave-Assisted Kinetic Resolution of Homochiral (Z)-**
8 **Cyclooct-5-ene-1,2-diol and (Z)-2-Acetoxy-cyclooct-4-enyle**
9 **Acetate using Lipases**

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17 *Received: / Accepted: / Published:*

18

19 **Abstract:** Over the last decade, the use of biocatalysts has become an attractive alternative
20 to conventional chemical methods, especially for organic synthesis, due to their unusual
21 properties. Among these enzymes, lipases are the most widely used, because they are
22 cheap, easily available, cofactor-free, and have broad substrate specificity. Combined to
23 microwave heating in non-aqueous medium, recent results suggest that irradiation may
24 influence the enzyme activity. This Letter reports the benefits of lipases and the microwave
25 irradiation on the kinetic resolution of racemic homochiral (Z)-cyclooct-5-ene-1,2-diol and
26 (Z)-2-acetoxy-cyclooct-4-enyle acetate. In order to best achieve the kinetic resolution,
27 different parameters were studied including the type of lipase, the temperature, the impact
28 of microwave power compared to conventional heating. Optimization of the reaction
29 parameters lead to the obtainment of highly enriched or enantiopure diols and diesters in a
30 clean, efficient and safe way.

31 **Keywords:** biocatalysis; microwave irradiation; lipase; homochiral diols; kinetic
32 resolution

33

34 **1. Introduction**

35 Enantiomerically pure vicinal diols are versatile chemical scaffolds for the production of flavors
36 and fragrances. As part of our work on the enantioselective synthesis of methyl jasmonate derivatives
37 from optically active bicyclo[3.3.0]octane derivatives by transannular cyclization, we first needed to
38 prepare enantiopure homochiral (1*R*,2*R*) and (1*S*,2*S*) 5-cyclooctene-1,2-diols. In recent years, the

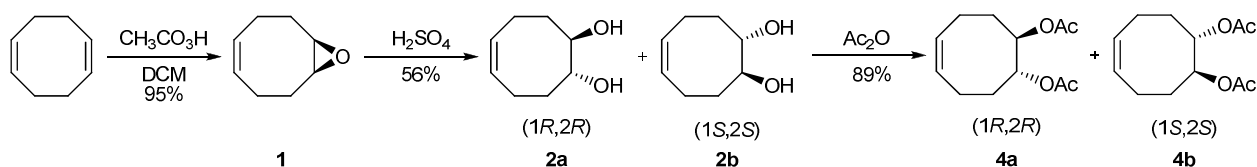
1 development of biocatalysts for organic synthesis has become an attractive alternative to conventional
 2 chemical methods. Among those biocatalysts, lipases have become very popular in both academic and
 3 industrial sectors because they are inexpensive, easily available, cofactor free and have a broad
 4 substrate specificity [1]. We decided to focus our interest on microwave-assisted lipase-mediated
 5 kinetic resolution involving CaLB (lipase B from *Candida antarctica*) or PS (*Pseudomonas cepacia*)-
 6 catalyzed acetylation of diol. The use of microwave irradiation in biocatalysis can enhance the enzyme
 7 activity, for example in resolution reaction, in specific oxido-reduction reaction or hydrolysis.
 8 Combined to non-aqueous medium, recent results suggest that microwave irradiation can have also
 9 influence the enzyme stability and activity, in addition to altering/enhancing reaction rates and/or
 10 enantioselectivities, called non thermal microwave effects [2-8]. However, the exact role of microwave
 11 irradiation on enzymes still remains unraveled [9]. To have a better comprehension of the influence of
 12 the microwave irradiation on a biocatalyst, we decided to compare the lipase-catalyzed resolution of a
 13 difunctionalized compound, under conventional and microwave irradiation heating We herein report
 14 our studies on lipase resolution of homochiral (1*R*,2*R*) and (1*S*,2*S*) 5-cyclooctene-1,2-diols (**2**) and
 15 their diesters (**4**), by varying the irradiation power and reaction temperature

16

17 2. Results and Discussion

18 In the context of the growing general interest for reducing energy costs, heating chemical reactions
 19 under microwave irradiation is a useful approach for achieving higher reaction kinetics and
 20 synthesizing cleaner products [10-13]. In combination with microwave technology and lipases, we
 21 wished to examine the synthesis of chiral cyclooctenic diols and diesters starting from cycloocta-1,5-
 22 diene using microwave technology. Rac-diol (**2**) and rac-diacetate (**4**) were initially prepared from
 23 cycloocta-1,5-diene in a three-steps sequence including epoxidation, ring opening with aqueous
 24 sulfuric acid followed by acetylation with acetic anhydride [14-15].

25

26
27

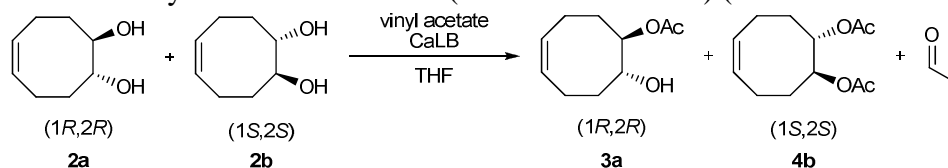
28 **Scheme 1.** Epoxidation and hydrolysis of cyclo-octa-1,5-diene leading to racemic diols (**2**) and
 29 acetylation in diacetate (**4**)

30

31 The preparation of optically active 5-cyclooctene-1,2-diol **2** was first conceived by using microwave-
 32 assisted lipase-catalyzed desymmetrization of *meso*-symmetric diol **2** using vinyl acetate as the
 33 acylating agent in THF as solvent rather than isooctane or 2-methylbutan-2-ol, that gave lower results.
 34 In order to perform the reaction under microwave irradiation, we decided to choose thermostable
 35 immobilized lipases capable of withstanding microwave irradiation: Novozyme 435® (CaLB
 36 immobilized on acrylic resin) and PS-D (*Pseudomonas cepacia* immobilized on diatomite). The goal
 37 was to obtain an enantioselective enhancement with immobilized lipases, as previous studies
 38 performed in our laboratory showed that resolution of rac-diol **2** with free *Pseudomonas cepacia* lipase
 39 at 55°C in THF during 7 days afforded with a good conversion rac-monoacetate **3** (47%, 0% ee) and
 40 rac-diol **2** (51%, 0% ee) but with no selectivity at all. Indeed, by immobilization of enzymes onto solid
 41 supports, enhanced enzyme activity, selectivity, stability, and reusability in organic media may be
 42 achieved compared to the native enzyme [16].

43

1 Performed at 35°C under conventional heating immobilized CaLB-enzymatic acylation of rac-diol (**2**)
 2 afforded after 3 weeks 28% of (1*R*,2*R*)-monoacetate **3a** (42% ee) and 6 % of (1*S*,2*S*)-diacetate **4b** with
 3 an excellent 99% ee. A higher temperature (50°C) led after 7 days to modest yields of monoacetate **3a**
 4 and a real enhancement of yield for diacetate **4b** (20% with ee >99%) (Scheme 2 and Table 1).

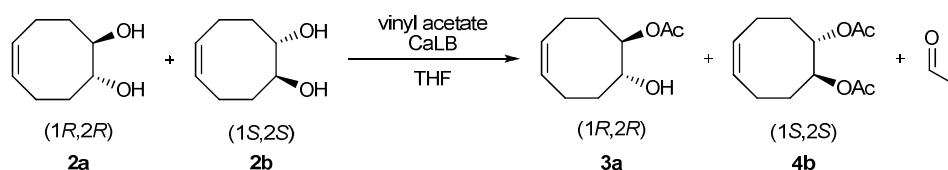


5
 6 **Scheme 2.** : Enantioselective acetylation of diol (**2**) using immobilized CaLB lipase and vinyl acetate
 7 by classical heating at various temperatures
 8

Heating mode	Temperature (°C)	Time	Monoacetate 3a		Diacetate 4b	
			yield (%)	ee (%)	yield (%)	ee (%)
Classical	35	3 weeks	28	42	6	>99
Classical	50	7 days	30	50	20	>99
Classical	50	14 hours	traces		-	

9 **Table 1.** : Enantioselective acetylation of diol (**2**) using immobilized CaLB lipase and vinyl acetate by
 10 classical heating at various temperatures

11
 12 Under microwave irradiation at 35°C (5W), racemic diol **2** proceeded to (1*R*,2*R*)-monoacetate **3a**
 13 (32%, 45% ee), trace amounts of (1*S*,2*S*)-diacetate **4b** (5%, >99% ee) and 65% of diol **2** (23% ee). In
 14 order to study the influence of the irradiation power on the biocatalytic media, we decided to apply a
 15 constant power (up to 300W) while maintaining the temperature at 35 °C by using a microwave oven
 16 combined with a Cool mate®. We noticed an enhancement of the yield and the enantiomeric ratio of
 17 (1*R*,2*R*)-monoacetate **3a** (42%, 67% ee) and diol **2** (51%, 50% ee) and only 2% of diacetate **4b** (99%
 18 ee). At 50°C (10W, 14 hours) the same reaction yielded only esters: 58% of (1*R*,2*R*)-monoacetate **3a**
 19 with 55% ee and 37% of diacetate **4b** (99% ee). A higher temperature (80°C, 40W, 14h) afforded a
 20 decrease of diacetate yield with a lower enantiomeric excess (30% of **4b** with 94% ee) (Scheme 3 and
 21 Table 2).



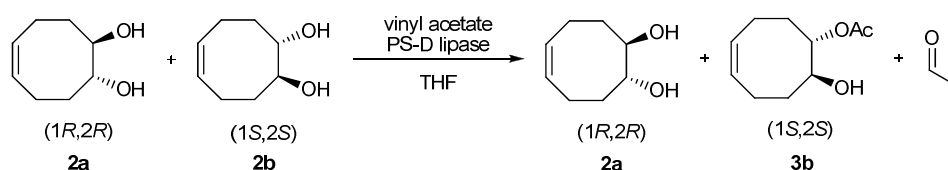
23
 24 **Scheme 3.** : Enantioselective acetylation of diol **2** using immobilized CaLB with vinyl acetate lipase
 25 under microwave irradiation

Power (W)	Incubation time (h)	Temperature (°C)	Monoacetate 3a		Diacetate 4b	
			yield (%)	ee (%)	yield (%)	ee (%)
5*	14	35	32	45	5	99
10*	14	50	58	55	37	99
20*	14	80	55	57	30	94
40*	14	100	-	-	-	-
300*	14	35	42	67	2	>99

Table 2 : Enantioselective acetylation of diol **2** using immobilized CaLB lipase under microwave irradiation in a large range of temperatures. *Constant power when the temperature is reached (max :300 W and 2 minutes) ** Using Cool mate

These results suggest that, at higher temperature (100°C), there is a loss of enzyme activity due to its denaturation. At 80°C, it was shown that the immobilized-CalB (Novozym 435) is very stable, keeping 90% of its activity after an incubation in diphenylether for 24h[17]. The irradiation power appears to display a key role in enzyme properties, and best enhancement of monoacetate yield and ee was observed at 35°C with 300W. Compared to conventional heating, the microwave irradiation as already shown to lead to much better conversion and enantiomeric excesses, in the case of lipase-catalyzed kinetic resolution of racemic secondary alcohols through acetylation.[18]

At 50°C under conventional heating, enzyme-catalyzed acylation of rac-diol **2** with immobilized PS-D provided both (1*S*,2*S*)-monoacetate **3b** and (1*R*,2*R*)-diol **2a** in poor enantiomeric purity (respectively 45% ee for **3b** and 3% ee for **2a**) and poor conversion (6%). At higher temperatures (80, 100°C), PS-D proved to be ineffective and lost all enzymatic activity. Under microwave irradiation at 50°C (15W), lipase resolution of racemic diol **2** afforded (1*S*,2*S*)-monoacetate **3b** (41%, 50% ee) and (1*R*,2*R*)-diol **2a** (57% , 35% ee). The microwave irradiation method gave a higher conversion compared to conventional heating. At 80°C (35W), the reaction yielded 12% of **3b** (35% ee) and 66% of diol with no selectivity (5% ee) (Scheme 4 and Table 3).



Scheme 4. : Acetylation of diol **2** using immobilized PS lipase (PS-D)

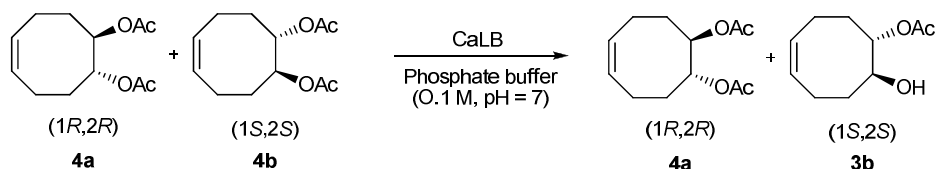
Heating mode	Temperature (°C)	Diol 2a ee (%)	Monoacetate 3b	
			yield (%)	ee (%)
Classical	50	3	6	45
	80	-	-	-
	100	-	-	-
Microwave	50 (15W*)	35	41	50
	80 (35W*)	5	12	35
	100 (closed vessel) (40W*)	-	-	-

Table 3: Acetylation of diol **2** using immobilized PS lipase (PS-D) (incubation time :14h). Effect of the heating mode and temperature on the conversion and kinetic resolution of rac-**2** into diol **2a** and monoacetate **3b**. *Constant power when the temperature is reached (max :300 W and 2 minutes).

Noteworthy, PS-D exhibited a reverse enantiopreference for the monoacetate (1*S*,2*S*) compared to CaLB.

Following these preliminary results, we then investigated the lipase-catalyzed kinetic hydrolytic resolution of rac-diacetate **4** according to Suemune procedure [19]. Instead of using PFL (*Pseudomonas fluorescens* lipase), we used immobilized CaLB and PS-D in order to perform later the

1 reaction under microwave. Performed at various temperature (35, 50 and 80°C) under conventional
 2 heating CaLB-catalyzed hydrolysis of rac-diacetate (**4**) in phosphate buffer (0.1M, pH 7.0) led only to
 3 traces of monoacetate at 50°C. Compared to conventional heating, the microwave irradiation at 50°C.
 4 during 14 hours led to a higher conversion (20%) with excellent enantiomeric excess for monoacetate
 5 (ee: 97% for **3b** (1*S*,2*S*)) besides diacetate **4a** (ee: 34%) (Scheme 5 and Table 4).



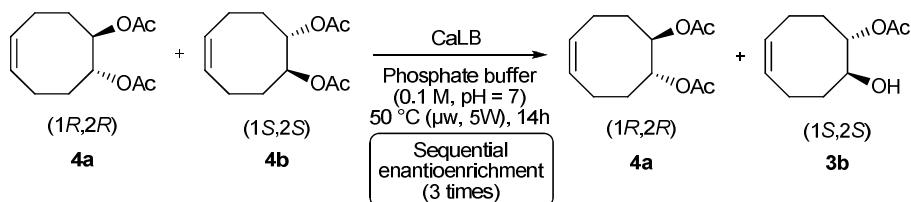
9
10 **Scheme 5.** : Hydrolysis of diacetate **4** using immobilized CaLB lipase in phosphate buffer (0.1 M, pH
 11 7). For detailed conversion and ee, see table 4.

12

Heating mode	Temp. (°C)	Conversion	Diacetate 4a ee (%)	Monoacetate 3b ee (%)
Classical	35	-	-	-
	50	Traces	-	-
	80	-	-	-
Microwave	35 (1-5W*)	-	-	-
	50 (5W*)	20%	34 [α] _D = +29°	97 [α] _D = +6°
	80 (10W*)	-	-	-

13 **Table 4** : Hydrolysis of rac-diacetate **4** using immobilized CaLB lipase (incubation time : 14h). Effect
 14 of the heating mode and temperature on the conversion and kinetic resolution of rac-**4** into diacetate **4a**
 15 and monoacetate **3b**. *Constant power when the temperature is reached (max :300 W and 2 minutes).

16
17 Given the promising results obtained during the first enantioenrichment of rac-**4** with CaLB, the
 18 recovered (1*R*,2*R*)-diacetate **4a** with 34% ee was submitted twice to the same enzymatic hydrolysis
 19 under microwave irradiation (2 x 14h, 50°C, 5W). Enantiopure (1*R*,2*R*)-diacetate **4a** was obtained in
 20 49% yield from rac-**4** (Scheme 6 and Table 5).



22
23
24 **Scheme 6.** : Sequential enantioenrichment of diacetate **4a**.

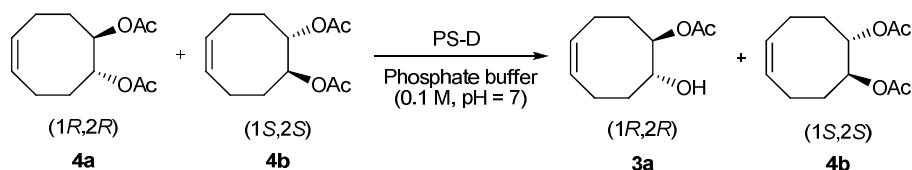
25

	Monoacetate 3b			Diacetate 4a		
	yield (%)	ee (%)	[α] _D	yield (%)	ee (%)	[α] _D
1 st enrichment	20	97	+5,8°	80	34	+25°

2nd enrichment	41	98	+6°	57	72	+57°
3 rd enrichment	51	97	+5,7°	49	>99	+81°

Table 5 : Sequential enantioenrichment of diacetate **4a**.

CaLB and the PS-D were finally compared for their ability to carry out an effective kinetic resolution of rac-**4** diester. The hydrolysis using PS-D was conducted in the same manner. In classical conditions whatever the temperature (35, 50, 80°C) and the reaction time (14h, 7 days), in no case conversion to monoacetate **3** was observed. Interestingly, under microwave irradiation at 50°C (14h), rac-**4** was desymmetrized into (1*R*,2*R*) monoacetate **3a** with 81% ee and (1*S*,2*S*)-diacetate **4b** (28% ee), highlighting a non-thermal effect. (Scheme 7 and Table 6)

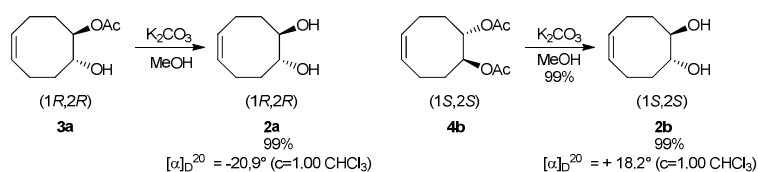
**Scheme 7** : Hydrolysis of diacetate **4** using PS-D lipase in phosphate buffer (0.1M, pH 7)

Mode of heating	Temp. (°C)	Conversion	Monoacetate 3a ee (%)	Diacetate 4b ee (%)
Classical	35	-	-	-
	50	-	-	-
	80	-	-	-
Microwave	35 (1-5W*)	-	-	-
	50 (5W*)	10%	81 [α] _D = -4°	28 [α] _D = -24°
	80 (10W*)	-	-	-

Table 6 : Hydrolysis of diacetate **4** using PS-D lipase (incubation time : 14h). Effect of the heating mode and temperature on the conversion and kinetic resolution of rac-**4** into monoacetate **3a** and diester **4b**. *Constant power when the temperature is reached (max :300 W and 2 minutes).

The microwave-assisted hydrolysis seems to enhance the enzyme activity compared to classical heating. Comparing the results with Suemune et al. [19], the CaLB seems to be a convenient enzyme in microwave irradiation resulting in the obtention of enantiopure monoacetate **3a** in a quick and clean way. However, the same reaction with PS-D needed to be optimized to obtain a better ee.

Finally, the isolated enantiopure monoacetates **3a**, **3b** and diacetates **4a** and **4b** were then quantitatively converted into (1*R*,2*R*)-diol **2a** and (1*S*,2*S*)-diol **2b** with >99% ee by methanolysis[7] (Scheme 8).



1 **Scheme 8.** : Isolation of enantiopure diols **2a** and **2b** by methanolysis of monoacetate **3a** and diacetate
2 **4b**.

3 **3. Experimental Section**

4 Lipases from *Pseudomonas cepacia* (immobilized on diatom MKBB3465, 500 PLU⁻¹) and *Candida*
5 *antarctica* (immobilized on acrylic resin 077K1155, 10 000 PLU⁻¹ Novozym 435[®] or free form) were
6 purchased from Sigma Aldrich. All chemicals were purchased from Sigma Aldrich and were used
7 without further purification except in the case of vinyl acetate which was used after fresh distillation.

8 IR spectra were recorded on a Perkin–Elmer Spectrum 100 IRFT-ATR instrument. ¹H and ¹³C NMR
9 were recorded on a JEOL JNM LA400 (400 MHz) spectrometer. Chemical shifts (δ) are reported in
10 parts per million (ppm) downfield from tetramethylsilane (TMS) which was used as internal standard.
11 Coupling constants J are given in Hz. The high resolution mass spectra (HRMS) were recorded on a
12 Varian MAT311 spectrometer in the Centre Régional de Mesures Physiques de l’Ouest (CRMPO),
13 Université de Rennes. Analytical thin layer chromatography (TLC) was performed on Merck Kieselgel
14 60 F254 aluminum packed plates.

15 Enantiomeric ratios were determined by gas chromatography (Agilent 7890A) equipped with an
16 autosampler (7688B) and flame ionization detector (FID). For the experiment, a CP-Chirasil-Dex
17 (0.25mm x 25m x 0.25μm, Chromopack) column was used. The injector and the detector were kept at
18 180°C. Nitrogen was used as gas carrier at a flow of 1.5 mL/min. Hydrogen, air and nitrogen were
19 supplied to the FID at 35 mL.min⁻¹, 350 mL.min⁻¹ and 25 mL.min⁻¹ respectively. The products are
20 analyzed at 110°C. The enantiomeric ratio and yields were calculated by taking the average of two
21 duplicates, with an error <2%.

22 High performance liquid chromatography (HPLC) was carried out in a Waters 600s combined with
23 an autosampler (Waters 717 plus). The Chiralpak–AD column (Amylose tris-(3,5-
24 dimethylphenylcarbamate) coated on 10 μm silica-gel, Daicel Chemical, 250 x 4.6 mm) at a flowrate
25 (n-Heptane/EtOH, 9/1) of 1 mL.min⁻¹ is used. Products were analyzed using a differential
26 refractometer (Waters 410)

27 Optical rotations were measured on a Perkin Elmer 341 polarimeter.

28 Microwave reactions were conducted using a CEM Discover[®], mode operating systems working at
29 2.45 GHz, with a programmable power ranging from 1 to 300W. The microwave can be equipped with
30 a Cool mate[®] system allowing reactions with high power input (up to 300 W) while maintaining the
31 reaction media at 35 °C. This system is cooled by a cryogenic fluid (Galden HT-55[®]).

32 In closed vessel mode, microwave irradiation experiments were carried out using a single-mode
33 microwave instrument (Initiator, Biotage) working at 2.45 GHz, with a power programmable from 1 to
34 450 W (0-20 bars).

35

36 *(Z)*-(1*S*,8*R*)-9-oxa-bicyclo[6.1.0]non-4-ene (**1**)

37 Under inert atmosphere, to a solution of cycloocta-1,5-diene (20 g, 0.161 mol) and sodium carbonate
38 (117.6 g, 1.11 mol) in dichloromethane (560 mL) stirred at 0°C was added dropwise a solution of
39 peracetic acid (42.7 mL, 0.222 mol) in dichloromethane (500 mL) during 2 hours. The mixture was
40 stirred for 8 hours at 0°C and 12 hours at room temperature. The mixture was quenched with 500mL of

1 water and extracted with (3x250 mL) of dichloromethane. The organic layers were dried with
2 magnesium sulfate anhydrous and concentrated under reduced pressure. The crude residue was
3 purified by column chromatography (silica gel, petroleum ether/ethyl acetate 90/10) to provide the (Z)-
4 (1*S*,8*R*)-9-oxa-bicyclo[6.1.0]non-4-ene **1** (5.697g, 67% yield) as a colorless oil; ν_{\max} (cm⁻¹): 3003,
5 2906, 2887, 1655, 1445, 1428, 1228, 1669, 1099, 1039, 934, 762, 743; δ_{H} (400 MHz, CDCl₃) 5.56–
6 5.60 (2H, m, CH=CH), 3.00–3.02 (2H, m, CHCH), 2.41–2.47 (2H, m, CH₂), 2.08–2.15 (2H, m, CH₂),
7 1.98–2.17 (4H, m, 2xCH₂); δ_{C} (100 MHz, CDCl₃) 128.6, 56.2, 27.8, 23.4.

8

9 *(Z)*-cyclooct-5-en-1,2-diol (**2**)

10 Under inert atmosphere, to the (Z)-(1*S*,8*R*)-9-oxa-bicyclo[6.1.0]non-4-ene (**1**) (5.697 g, 45.9 mmol)
11 vigorously stirred was added a solution of sulfuric acid 2M (25.3 mL, 50.47 mmol). After 4 hours
12 under stirring, the mixture was extracted with 3x75 mL of ethyl acetate. The organic layers were
13 washed with a saturated solution of sodium hydrogenocarbonate (40 mL), brine (40 mL), dried with
14 magnesium sulfate and concentrated under vacuum. The crude residue was purified by column
15 chromatography (silica gel, petroleum ether/ethyl acetate 60/40) to give the rac-(Z)-cyclooct-5-en-1,2-
16 diol **2** (3.691 g, 57% yield) as a colorless oil; ν_{\max} (cm⁻¹): 3362, 3014, 2964, 2861, 1651, 1427, 1429,
17 1400, 1271, 1202, 1010, 994, 976, 947, 868, 732, 719; δ_{H} (400 MHz, CDCl₃): 5.55–5.59 (2H, m,
18 CH=CH), 3.57–3.61 (4H, m, CHOHCHOH), 2.29–2.35 (2H, m, CH₂), 2.00–2.12 (4H, m, 2xCH₂),
19 1.52–1.58 (2H, m, CH₂); δ_{C} (100 MHz, CDCl₃): 128.9, 73.8, 33.1, 22.6; HRMS: calculated for
20 C₈H₁₄O₂ [M]⁺: 142.09938, Found : 142.1001 (5 ppm).

21

22 *(1*R*,2*R*)-(Z)*-1-hydroxy-cyclooct-4-enyle acetate (**3a**)

23 Compound **3a** was obtained as a colorless oil [α_{D}^{20} -3.0° (c 1.00 CHCl₃). ν_{\max} (cm⁻¹): 3449, 3012,
24 2936, 1717, 1654, 1430, 1235, 1030, 971, 933, 720; δ_{H} NMR (400 MHz, CDCl₃): 5.59–5.69 (2H, m,
25 CH=CH), 4.95 (1H dt, *J*=8.8 Hz, 4.0Hz, CHOAc), 3.90 (1H, dt, *J*=2.1 Hz, CHOH), 2.54 (1H, s, OH),
26 2.38–2.42 (m, 2H, CH₂), 2.04–2.25 (m, 7H, 2xCH₂ and CH₃), 1.68–1.75 (m, 2H, CH₂); δ_{C} (100 MHz,
27 CDCl₃): 170.9, 129.6, 128.6, 77.3, 72.1, 32.8, 30.0, 22.8, 22.8, 21.2. GC: Cromopack column *t_R* = 59.7
28 min HRMS: calcd for C₈H₁₄O₂ [M-CH₂CO]⁺: 142.09938, Found : 142.0993 (0 ppm).

29

30 *(1*S*,2*S*)-(Z)*-1-hydroxy-cyclooct-4-enyle acetate (**3b**)

31 Compound **3b** was obtained as a colorless oil. [α_{D}^{20} +3.2° (c 1.00 CHCl₃). ν_{\max} (cm⁻¹): 3449, 3012,
32 2936, 1717, 1654, 1430, 1235, 1030, 971, 933, 720; δ_{H} NMR (400 MHz, CDCl₃): 5.59–5.69 (2H, m,
33 CH=CH), 4.95 (1H dt, *J*=8.8 Hz, 4.0Hz, CHOAc), 3.90 (1H, dt, *J*=2.1 Hz, CHOH), 2.54 (1H, s, OH),
34 2.38–2.42 (m, 2H, CH₂), 2.04–2.25 (m, 7H, 2xCH₂ and CH₃), 1.68–1.75 (m, 2H, CH₂); δ_{C} (100 MHz,
35 CDCl₃): 170.9, 129.6, 128.6, 77.3, 72.1, 32.8, 30.0, 22.8, 22.8, 21.2. GC: Cromopack column *t_R* = 56.6
36 min HRMS: calcd for C₈H₁₄O₂ [M-CH₂CO]⁺: 142.09938, Found : 142.0993 (0 ppm).

37

38 *(1*R*,2*R*)-(Z)*-2-acetoxy-cyclooct-4-enyle acetate (**4a**)

39 Compound **4a** was obtained as a colorless oil. [α_{D}^{20} +81.0° (c 1.00 CHCl₃). ν_{\max} (cm⁻¹): 3016,
40 2938, 2866, 1732, 1654, 1431, 1370, 1226, 1244, 1032, 978, 946, 735, 722; δ_{H} (400 MHz, CDCl₃):
41 5.69–5.62 (2H, m, CH=CH), 5.05–5.08 (2H, m, 2xCHOH), 2.35–2.41 (2H, m, CH₂), 2.12–2.18 (2H,
42 m, CH₂), 2.01–2.04 (2H, m, CH₂), 1.96 (s, 6H, 2x CH₃), 1.73–1.76 (2H, m, CH₂). δ_{C} (100 MHz,

1 CDCl₃): 170.1, 128.6, 73.6, 29.9, 22.7, 20.9; [α]_D: +83.9° (c = 1.00 CHCl₃) GC Cromopack column t_R
2 = 61.2 min

3
4 *(1S,2S)-(Z)-2-acetoxy-cyclooct-4-enyle acetate (4b)*

5 Compound **4b** was obtained as a colorless oil; [α]_D: -79.0° (c 1.00 CHCl₃). v_{max} (cm⁻¹): 3016, 2938,
6 2866, 1732, 1654, 1431, 1370, 1226, 1244, 1032, 978, 946, 735, 722; δ _H (400 MHz, CDCl₃): 5.69–
7 5.62 (2H, m, CH=CH), 5.05–5.08 (2H, m, 2xCHOH), 2.35–2.41 (2H, m, CH₂), 2.12–2.18 (2H, m,
8 CH₂), 2.01–2.04 (2H, m, CH₂), 1.96 (s, 6H, 2x CH₃), 1.73–1.76 (2H, m, CH₂). δ _C (100 MHz, CDCl₃):
9 170.1, 128.6, 73.6, 29.9, 22.7, 20.9; GC: Cromopack column t_R = 59.4 min; HRMS calcd for C₁₀H₁₆O₃
10 [M-CH₂CO]⁺ : 184.10994 , Found : 184.1091 (4 ppm).

11

12 *General procedure for enantioselective acetylation of racemic (Z)-cyclooct-5-en-1,2-diol (2) using*
13 *lipase*

14

15 Under inert atmosphere, to a solution of racemic diol **2** (0.2 g, 1.41 mmol) solubilized in 2.5 mL of
16 THF were added the vinyl acetate (1.3 mL, 14 mmol) and the appropriate immobilized lipase (50 mg).
17 The mixture was stirred at the required temperature under classical heating or microwave irradiation
18 (see Table 1, Table 2, Table3). The mixture was filtrated, extracted with ethyl acetate (3x7 mL). The
19 organic layers were washed with 3 mL of HCl 5%, 3 mL of sodium hydrogenocarbonate, brine, dried
20 with magnesium sulfate and concentrated under reduced pressure. The crude residue was purified by
21 column chromatography (silica gel, petroleum ether/ethyl acetate 60/40) to give the (1R,2R)-(Z)-1-
22 hydroxy-cyclooct-4-enyle acetate **3a**, **3b**, **4b**.

23

24 *General procedure for the hydrolysis of (Z)-2-acetoxy-cyclooct-4-enyle acetate (4) by Candida*
25 *antarctica lipase B*

26

27 Under inert atmosphere, to a solution of racemic (Z)-2-acetoxy-cyclooct-4-enyle acetate **4** (0.2 g,
28 0.88 mmol) in 2.5 mL of phosphate buffer 0.1 M, pH=7.0, was added the lipase (50 mg). The mixture
29 was stirred at 50°C under microwave irradiation (see Table 4, Table 5, Table 6). The mixture was
30 filtrated, extracted with ethyl acetate (3x7 mL). The organic layers were washed with 3 mL of HCl 5%,
31 3 mL of sodium hydrogenocarbonate, brine, dried with magnesium sulfate and concentrated under
32 reduced pressure. The crude residue was purified by column chromatography (silica gel, petroleum
33 ether/ethyl acetate 60/40) to give **3a**, **3b** and **4a**, **4b**.

34

35 *Diacetate enrichment*

36 The enriched (Z)-2-acetoxy-cyclooct-4-enyle **4a** is solubilized in 2.5 mL of phosphate buffer 0.1M,
37 pH=7.0. *Candida antarctica* lipase B (50 mg) was added and the mixture was stirred at 50°C during 14
38 hours by microwave irradiation (open vessel). The mixture was filtrated, extracted with ethyl acetate
39 (3x7mL), The combined organic layers were washed with 3 mL of HCl 5%, 3 mL of sodium
40 hydrogenocarbonate, brine, dried with magnesium sulfate and concentrated under reduced pressure.
41 The crude residue was purified by chromatography column (silica gel, petroleum ether/ethyl acetate

60/40) to give the (Z)-(1S,2S)-2-hydroxy-cyclooct-4-enyle **3b** acetate in 49% overall yield (0.098g, ee>99%) and **4a** in 51 % overall yield (0.083g, ee>99%).

Influence of the power of the microwave for the acetylation of (Z)-cyclooct-5-en-1,2-diol (2)

The cryogenic fluid (Garlon 80[®]) of Cool mate[®] was cooled by dry ice, and maintained at 7°C. To a solution of racemic diol **2** (0.2 g, 1.406 mmol) solubilized in 2.5 mL of THF was added vinyl acetate (1.3 mL, 14 mmol) and *Candida antarctica* lipase (50 mg). The mixture was irradiated with an internal temperature set to 35°C, leading to an irradiation power of 300 W. After 7 hours of irradiation, the mixture was filtrated, extracted with ethyl acetate (3x7 mL). The organic layers were washed with 3 mL of HCl 5%, 3 mL of sodium hydrogenocarbonate, brine, dried with magnesium sulfate and concentrated under reduced pressure. The crude residue was purified by column chromatography (silica gel, petroleum ether/ethyl acetate 60/40) to give the (Z)-(1R,2R)-1-hydroxy-cyclooct-4-enyle acetate **3a** in 42% yield (0.108 g, ee=67%), (Z) (1S,2S)-2-acetoxy-cyclooct-4-enyle acetate **4b** in 2% yield (ee=99%) and (Z)-cyclooct-5-en-1,2-diol in 51% yield (0.102g, ee=50%).

Synthesis of diols by saponification of esters

Under inert atmosphere, to a solution of enantiopure (Z)-(1R,2R)-2-acetoxy-cyclooct-4-enyle acetate **4b** (0.2 g, 17.3 mmol) or enantiopure monoacetate **3a** (0.2g, 12.0 mmol) in methanol (10 mL) was added potassium carbonate anhydrous (4 mg, 0.86. mmol). The mixture was stirred 8 hours at 0°C, and 10 mL of hydrochloric acid 1M are added. The aqueous layer was extracted with ethyl acetate (3x8 mL), washed with a saturated solution of sodium hydrogenocarbonate (5 mL) and brine (5 mL). The organic layers were dried with magnesium sulfate, concentrated under reduced pressure.

(1R,2R)-(Z)-Cyclooct-5-ene-1,2-diol (2a)

The crude residue was purified by column chromatography (silica gel, petroleum ether/ethyl acetate 60/40) to give the (Z)-(1R,2R)-cyclooct-5-ene-1,2-diol **2a** (0.152g, 99% yield) as a white solid; $[\alpha]_D^{20}$ -20,9° (c 1,00 CHCl₃); ν_{\max} (cm⁻¹): 3362, 3014, 2964, 2861, 1651, 1427, 1429, 1400, 1271, 1202, 1010, 994, 976, 947, 868, 732, 719; δ_H (400 MHz, CDCl₃): 5.55–5.59 (2H, m, CH=CH), 3.57–3.61 (m, 4H, 2xCHOH), 2.29–2.35 (2H, m, CH₂), 2.00–2.12 (2H, m, CH₂), 1.52–1.58 (2H, m, CH₂); δ_c (100 MHz, CDCl₃): 128.9, 73.8, 33.1, 22.6; HRMS: calculated for C₈H₁₄O₂ [M]⁺: 142.09938, Found : 142.1001 (5 ppm). HPLC t_R = 11.9 min

(1S,2S)-(Z)- Cyclooct-5-ene-1,2-diol (2b)

The crude residue was purified by column chromatography (silica gel, petroleum ether/ethyl acetate 60/40) to give the (Z)-(1S,2S)-cyclooct-5-en-1,2-diol **2b** (0.153 g, 99% yield) as a white solid. $[\alpha]_D$: +18.2° (c = 1,00 CHCl₃) ν_{\max} (cm⁻¹): 3362, 3014, 2964, 2861, 1651, 1427, 1429, 1400, 1271, 1202, 1010, 994, 976, 947, 868, 732, 719; δ_H (400 MHz, CDCl₃): 5.55–5.59 (2H, m, CH=CH), 3.57–3.61 (m, 4H, 2xCHOH), 2.29–2.35 (2H, m, CH₂), 2.00–2.12 (2H, m, CH₂), 1.52–1.58 (2H, m, CH₂); δ_c (100 MHz, CDCl₃): 128.9, 73.8, 33.1, 22.6; HRMS: calculated for C₈H₁₄O₂ [M]⁺: 142.09938, Found : 142.1001 (5 ppm). HPLC t_R = 10.8 min.

1

2 4. Conclusions

3 The kinetic resolution of homochiral (*Z*)-cyclooct-5-ene-1,2-diols and (*Z*)-2-acetoxy-cyclooct-4-
4 enyle acetates has been fulfilled in a clean and rapid way using the microwave-assisted biocatalysis.
5 The enantioselectivity was controlled using two different lipases (CaLB or PS-D) in order to obtain
6 one or the other useful enantiomer. The role of the microwave power has also been highlighted.
7 Finally, by microwave irradiation, this eco-efficient optimization for the resolution of racemic diols,
8 leads to a reduction of the reaction time and a decrease of power consumption, without any toxicity.

9 Acknowledgments

10 The authors would like to thank ANR EXPENANTIO, la “Ligue Nationale Contre le Cancer” for
11 financial supports and the “Ministère de la Recherche et de l’Enseignement Supérieur” for PhD
12 grant (HR).

13 Author Contributions

14 V.T., L.D. and M.G. designed the research. H.R. and E.D. performed the experimental work and
15 participated equally to this work and should be considered as primary co-authors. V.T. wrote the
16 manuscript with the cooperation of E.D. and H.R. All authors discussed, edited and approved the
17 submitted version.

18 Conflicts of Interest

19 State any potential conflicts of interest here or “The authors declare no conflict of interest”.

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36 21.

37

38 *Sample Availability:* Samples of compounds are available from the authors.

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