SUPPORTING INFORMATION

In an attempt to provide an environmentally friendly solvent selection guide for olefin metathesis

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General information

NMR spectra were recorded on Bruker Avance 300 MHz spectrometer in $CDCl_3$; chemical shifts (δ) are given in parts per milion (ppm) downfield from trimethylsilane as referenced to residual protio solvent peaks, coupling constants (*J*) are reported in hertz (Hz). GC analysis: Trace GC Ultra, Thermo Electron Corporation, HP-5 column. MS (ESI): LCT PremierXE Waters mass spectrometer. IR spectra were recorded on a PerkineElmer 1600 FTIR spectrometer.

Catalysts **G-II** (CAS 246047-72-3), **G-II'**(CAS 373640-75-6), **H-II** (CAS 301224-40-8), **H-II'** (CAS 635679-24-2), **N-II** (CAS 502964-52-5), **Ind-II** (CAS 340810-50-6), **Ind-II'** (CAS 1307233-23-3) are commercially available. Catalysts **N-II'**[1] and **E-II**[2] were obtained according to literature procedures.

Synthesis of catalyst **E-II'**
(*E*)-methyl 2-(2-(prop-1-en-1-yl)phenoxy)propanoate (0.389 g, 1.77 mmol) and CuCl (0.238 g, 2.41 mmol) were added to the solution of G-II‘ (1.5 g, 1.6 mmol) in dry, degassed DCM. Reaction mixture was stirred at 30 °C for 30 min. DCM was concentrated and the resiude was purified by column chromatography (elu c-hex/AcOEt 9/1). After removal of solvents product was obtained as a green solid, 1.0 g, 82 % of yield.

Protocols for conducting metathesis reactions

General procedure for RCM of small rings and enyne reaction.
Solution of substrate in appropriate ACS grade solvent (5 ml, 0.1 M) was heated to the desired temperature for 5 minutes prior to addition of stock solution of catalyst in DCM (50 µL, 0.25 or 0.5 mol%). Reaction mixture was stirred for 1 h without protective atmosphere of inert gas. After that time 100 µL of reaction mixture was quenched with excess of ethyl vinyl ether, dilluted with 100 µL of pure solvent and analysed by GC-FID.

*General procedure for RCM reaction in EtOAc with the use of dienes **7** and **9**.*
Solution of substrate and dodecane in ACS grade AcOEt (0.005 M, 40 mL) was heated to 70 °C for 5 minutes prior to addition of catalyst. Syringe was filled with the solution of NII’ (0.5 mol%) in AcOEt (4 ml) and placed in syringe pump. Solution of catalyst was added over 1 h to the solution of substrate maintained at 70 ^{o}C with the flow rate of 4 ml/h. To establish the initial ratio between the substrate and dodecane at t_0 (0% conversion) 400 µL of 0.005 M solution was diluted with 40 µL of AcOEt and analyzed by GC-FID. After 90 minutes 400 µL of reaction mixture was quenched by addition of 4 µL of ethyl vinyl ether and analysed by GC-FID at this concentration.

General procedure for CM.
Solution of substrate and dodecane (5 ml, 0.1 M) and **14** (4 eq) in appropriate solvent was heated to 70 °C for 5 minutes prior to addition of stock solution of catalyst in DCM (50 µL, 0.5 mol%). Reaction mixture was stirred for 1 h without protective atmosphere of inert gas. After that time 400 µL of reaction mixture was quenched with 12 µL of ethyl vinyl ether, dilluted with 400 µL of pure solvent and analysed by GC-FID. To establish the initial ratio between the substrate and dodecane at t_0 (0% conversion) 400 µL of 0.1 M solution was diluted with 412 µL of AcOEt and analyzed by GC-FID.
CM experiments with slow addition of catalysts were carried out by analogy to the macrocyclization. After first 30 min of reaction additional 2 eq of **14** was added in each case (Table 5, Entry 1,2) while **18** was added only at the beginning of the reaction (3 eq).

Characterisation of the metathesis products

Catalyst **E-II'**
^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 16.46 (s, 1H), 7.55-7.50 (m, 7H), 6.89-6.88 (m, 2H), 6.65 (d, 1H *J* = 8.26 Hz), 5.02 (q, 1H, *J* = 6.7 Hz), 4.19 (s, 4H), 3.64-3.58 (m, 7H), 1.64 (d, 3H *J* = 6.83 Hz), 1.28-1.25 (m, 24 H). ^{13}C NMR (75.4 MHz, $CDCl_3$) δ ppm: 292.31, 213.07, 170.67, 151.80, 149.26, 149.12, 144.40, 129.49, 128.85, 124.40, 123.45, 122.49, 112.48, 54.62, 52.89, 28.79, 26.58, 23.57, 23.52, 18.01. IR, ν_{max} (KBr): 3447, 3025, 2966, 2926, 2867, 1941, 1736, 1627, 1575, 1592, 1475, 1453, 1406, 1390, 1345, 1326, 1295, 1262, 1234, 1158, 1116, 1050, 978, 932, 901, 863, 804, 754, 742, 698, 646, 620, 554, 459, 441.

N-Tosyl-2,5-dihydropyrrole (**2**).[3]
^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 7.74-7.68 (m, 2H), 7.33-7.29 (m, 2H), 5.66-5.62 (m, 2H), 4.12-4.08 (m, 4H), 2.41 (s, 3H).

1-Tosyl-2,3-dihydro-1H-pyrrole (**2´**).[4]
^{1}H-NMR (300 MHz, $CDCl_3$) δ ppm: 7.68-7.65 (m, 2H), 7.33-730 (m, 2H), 6.38 (br s, 1H), 5.13 (br s, 1H), 3.47 (t, *J* = 8.7Hz, 2H), 2.51-2.43 (m, 5H).

3-Methyl-4-methylene-1-[(4-methylphenyl)sulfonyl]pyrrolidin (**2´´**).[5]
^{1}H-NMR (300 MHz, $CDCl_3$) δ ppm: 7.71 (d, *J* = 8.2 Hz, 2H), 7.34 (d, *J* = 8.0 Hz, 2H), 4.91 (d, *J* = 2.0 Hz, 1H), 4.85 (d, *J* = 2.2 Hz, 1H), 3.96 (d, *J* = 14.0 Hz, 1H), 3.73 (d, *J* = 15.8 Hz,1H), 3.60-3.58 (m, 1H), 2.72–2.67 (m, 2H), 2.45 (s, 3H), 1.05 (d, *J* = 6.4 Hz, 3H).

N-Tosyl-3-methyl-2,5-dihydropyrrole (**4**).[6]
^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 7.71-7.69 (m, 2H), 7.32-7.29 (m, 2H), 5.24-5.22 (m, 1H), 4.07-4.03 (m, 2H), 3.97-3.95 (m, 2H), 2.41 (s, 3H), 1.64 (s, 3H).

2,2-Diphenyl-3-vinyl-2,5-dihydrofuran (**12**).[7]
Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 7.37–7.28 (m, 10H), 6.28–6.20 (m, 2H), 5.32 (d, *J* = 14.1, 1H), 5.11 (d, *J* = 8.4, 1 H), 4.80–4.79 (m, 2H).

2-(2,5-Dihydropyrrole-1-carbonyl)-pyrrolidine-1-carboxylicacid tert-butyl ester (**6**).[8]
^{1}H NMR (300 MHz, CD_2Cl_2) δ ppm: 5.87-5.69 (m, 2H), 4.54-4.08 (m, 5H), 3.61-3.29 (m, 2H), 2.20-2.04 (m, 2H), 1.92-1.74 (m, 2H), 1.40-1.32 (m, 9H).

(*E,Z*)-Oxacyclotetradec-11-en-2-one (**8**).[9]
E isomer - ^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 5.51-5.30 (m, 2H), 4.14-4.10 (m, 2H), 2.39-2.33 (m, 4H), 2.04-1.98 (m, 2H), 1.63-1.55 (m, 2H), 1.38-1.27 (m, 10H). ^{13}C NMR (75.4 MHz, $CDCl_3$) δ ppm: 174.1, 132.8, 127.8, 64.3, 35.1, 31.9, 31.3, 26.6, 26.1, 25.8, 25.6, 23.88, 23.80.

(*E,Z*)-Oxacyclohexadec-11-en-2-one (**10**).[3]
E isomer - ^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 5.40-5.25 (m, 2H), 4.16-4.04 (m, 2H), 2.35-2.25 (m, 2H), 2.06-1.96 (m, 4H), 1.66-1.56 (m, 4H), 1.41-1.20 (m, 12H). ^{13}C NMR (75.4 MHz, $CDCl_3$) δ ppm: 173.9, 131.8, 130.3, 63.9, 34.7, 32.06, 32.02, 28.37, 28.31, 28.2, 28.0, 27.2, 26.5, 25.5, 25.2.

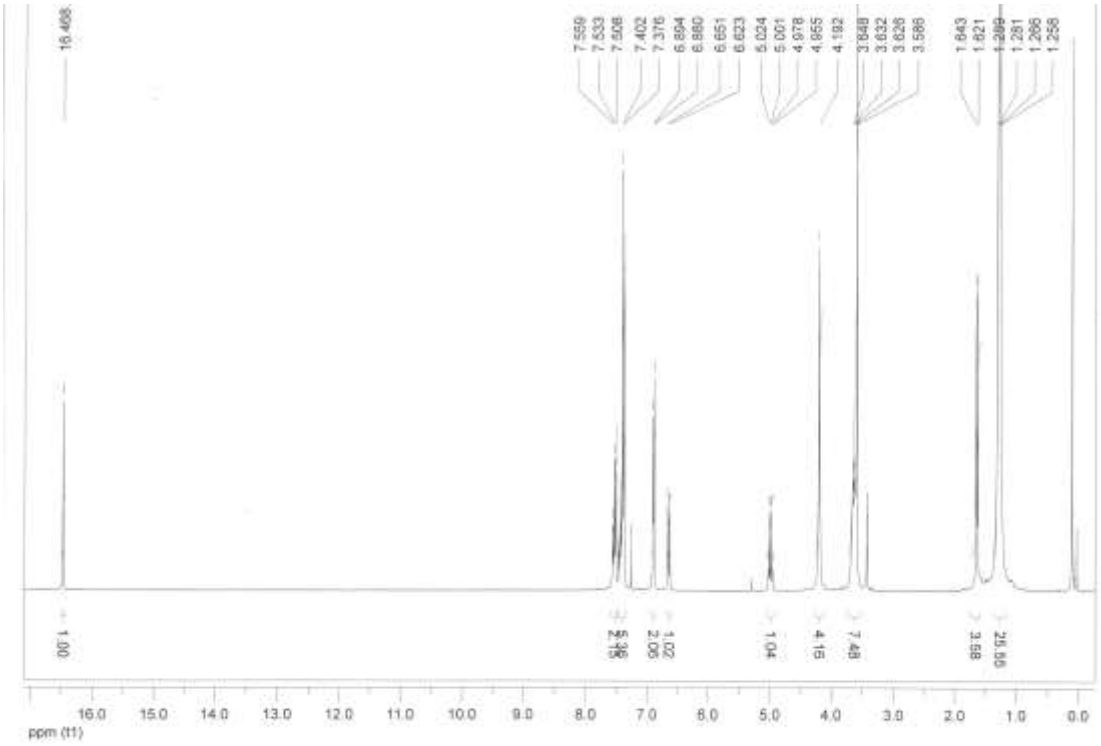
(E,Z)-Dodec-2-enedioic acid dimethyl ester (**15**).[10]
E isomer - ^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 7.01-6.91 (m, 1H), 5.83-5.77 (m, 1H), 3.71 (s, 3H), 3.66 (s, 3H), 2.32-2.27 (m, 2H), 2.21-2.14 (m, 2H), 1.63-1.56 (m, 2H), 1.49-1.39 (m, 2H) 1.28 (s, 8H).

Hex-2-enedioic acid 1-methyl ester 6-(13-methyl-17-oxo-7,8,9,11,12,13,14,15,16,17-decahydro-6H-cyclopenta[a]phenanthren-3-yl) ester (**17**).[11]
E isomer ^{1}H NMR (300 MHz, $CDCl_3$) δ ppm: 7.33-7.27 (m, 1H), 7.01 (dt, *J* = 6.6 Hz, *J* = 15.9 Hz, 1H), 6.86-6.80 (m, 2H), 5.93 (dt, *J* = 1.5 Hz, *J* = 15.9 Hz, 1H), 3.74 (s, 3H), 2.92-2.88 (m, 2H), 2.74-2.60 (m, 4H), 2.55-2.37 (m, 2H), 2.33-2.25 (m, 20 1H), 2.20-1.94 (m, 4H), 1.67-1.42 (m, 6H), 0.90 (s, 3H).

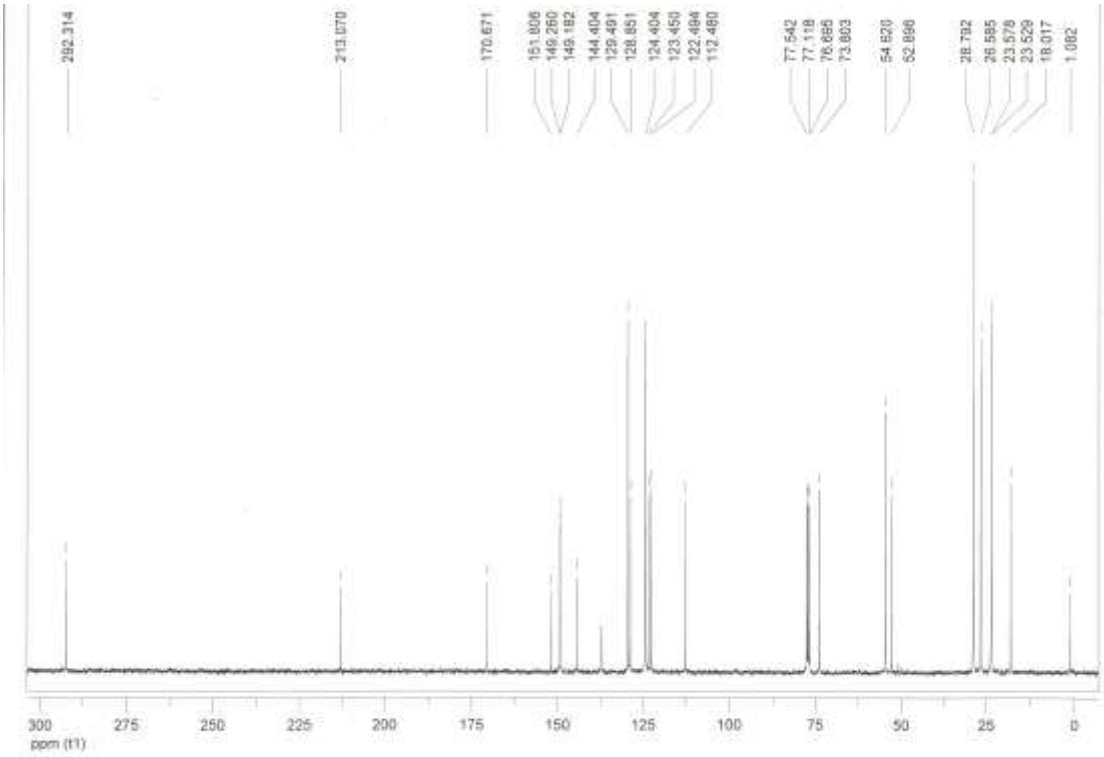
(E/Z)-Methyl 12-acetoxydodec-10-enoate (**19**)[12]
^{1}H NMR (300 MHz, $CDCl_3$,) δ ppm: 5.80–5.75 (m, 1H), 5.59–5.52 (m, 1H), 4.55 (d, *J* = 6.7 Hz, 2H,), 4.52 (d, *J* = 6.4 Hz, 2H), 3.68 (s, 3H), 2.33 (t, *J* = 7,5 Hz, 2H,), 2.07 (s, 3H), 1.64–1.62 (m, 2H), 1.40–1.30 (m, 12H).

Copies of the NMR and IR spectra

Catalyst **E-II'**
^{1}H NMR



^{13}C NMR



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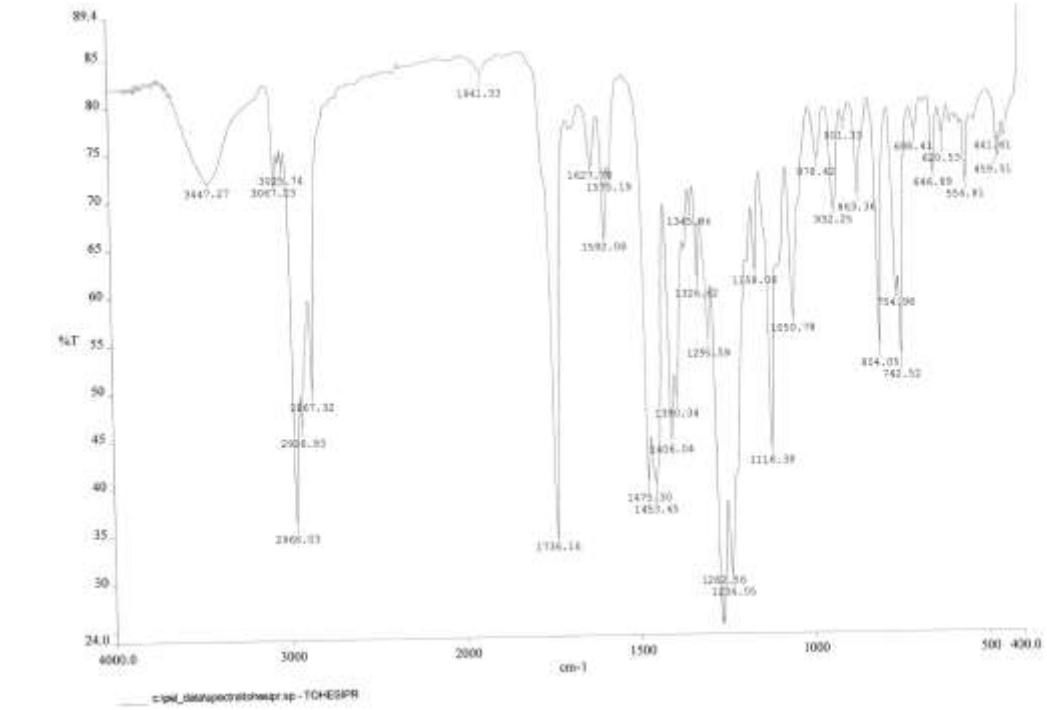
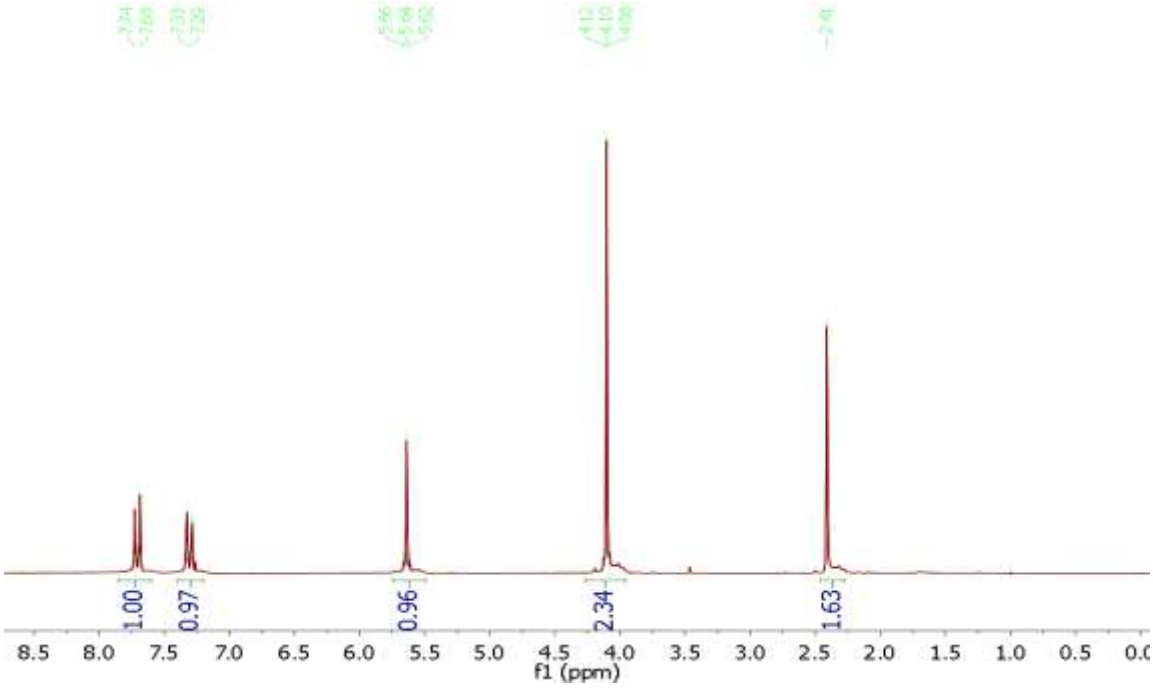
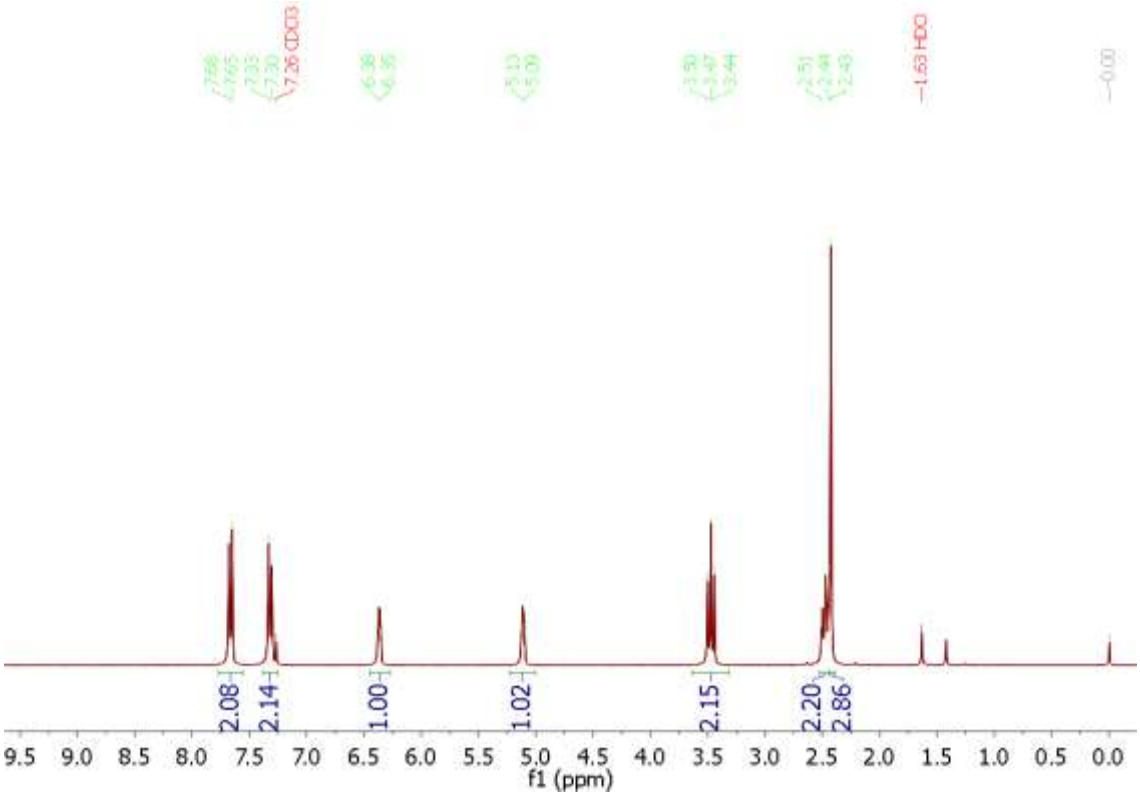


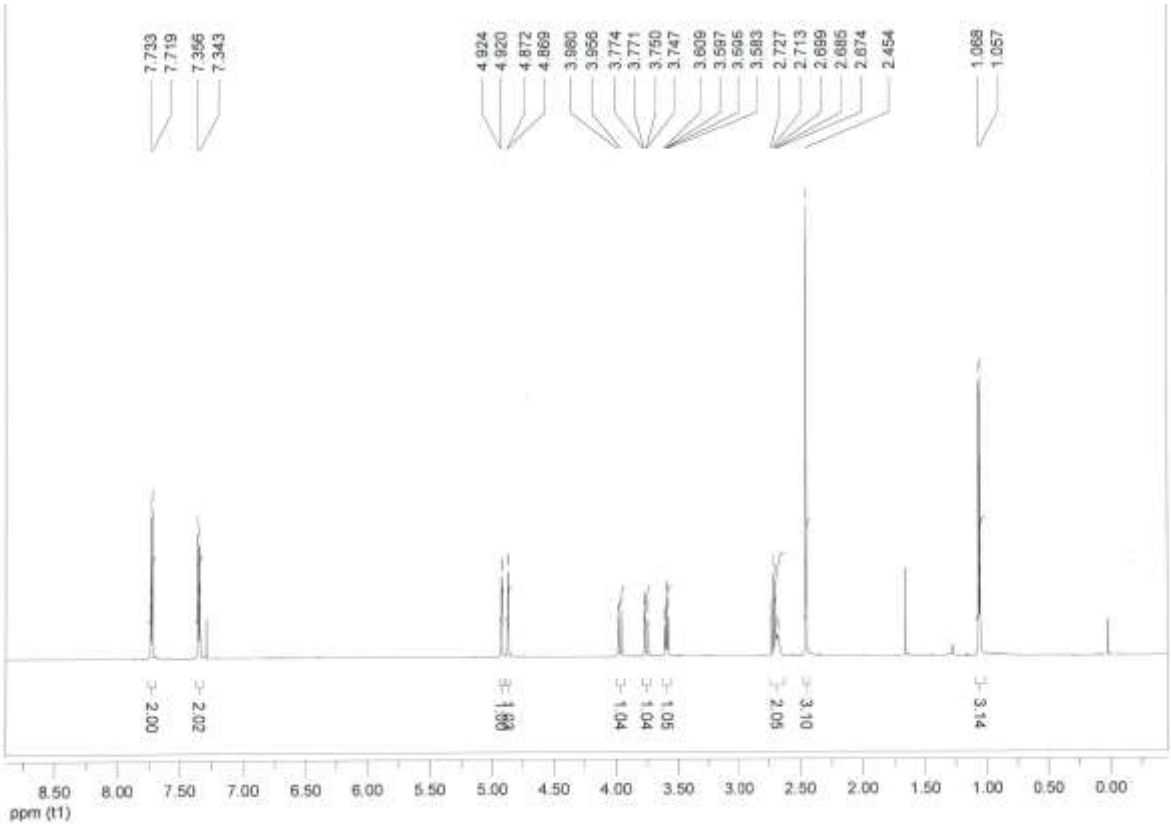
N-Tosyl-2,5-dihydropyrrole (**2**)



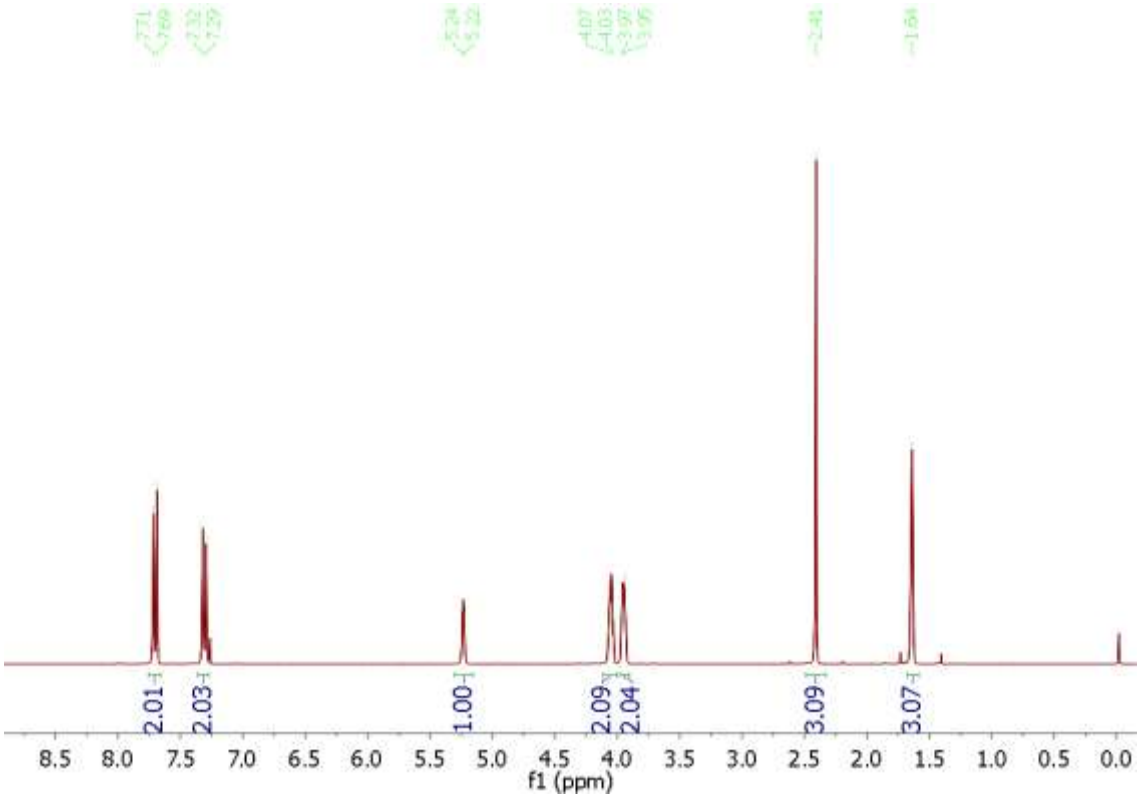
1-Tosyl-2,3-dihydro-1H-pyrrole (**2´**)



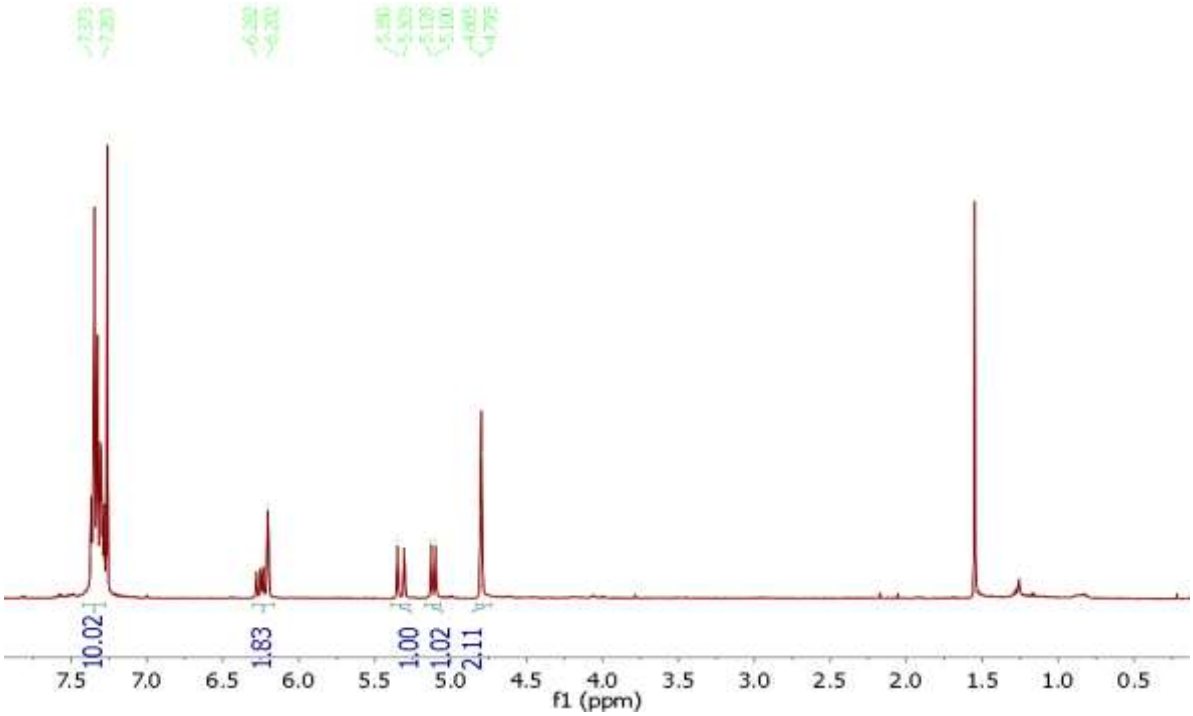
3-Methyl-4-methylene-1-[(4-methylphenyl)sulfonyl]pyrrolidin (**2´´**)



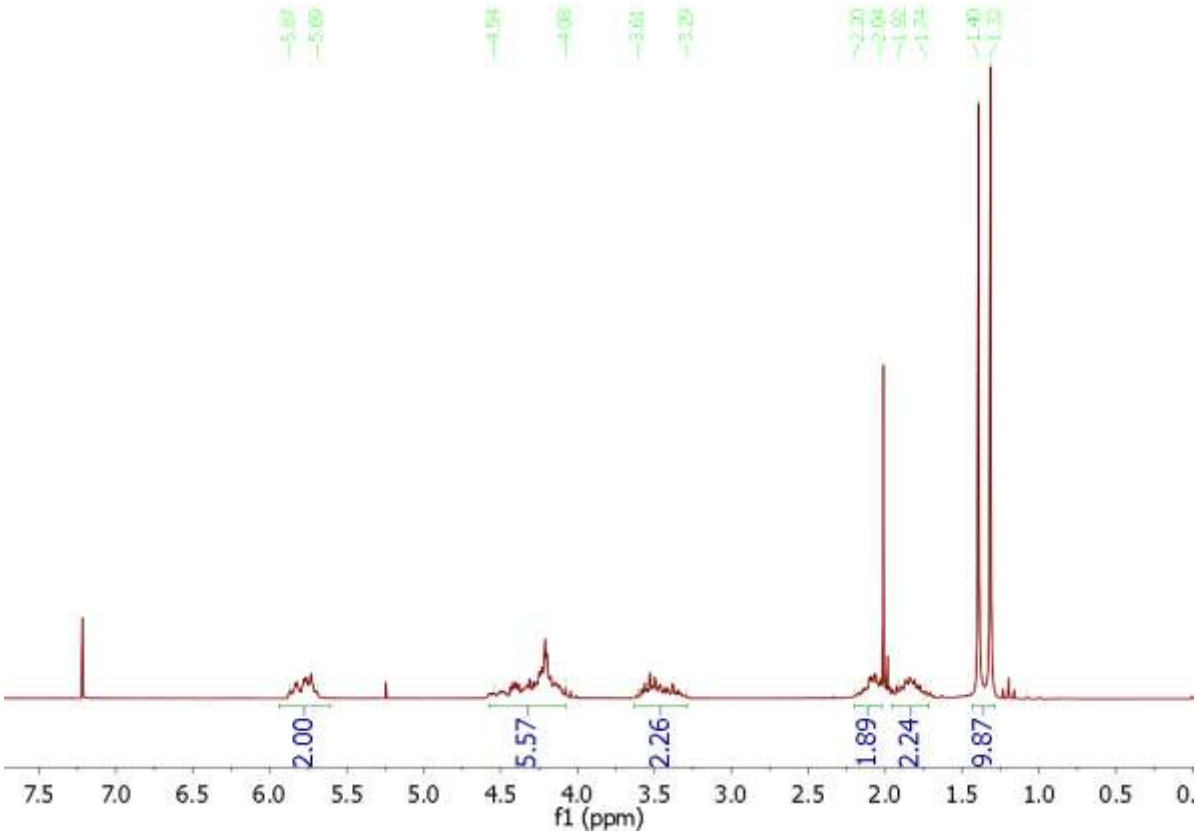
N-Tosyl-3-methyl-2,5-dihydropyrrole (**4**)



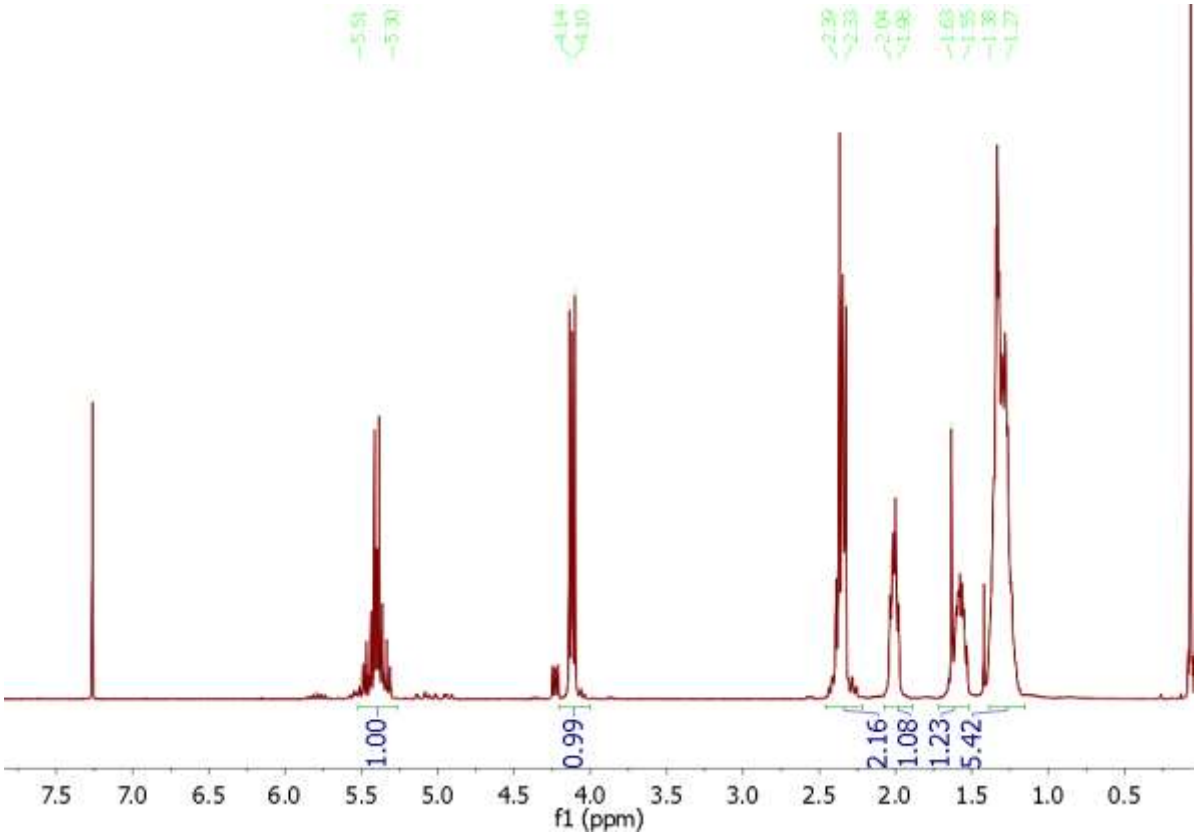
2,2-Diphenyl-3-vinyl-2,5-dihydrofuran (**12**)



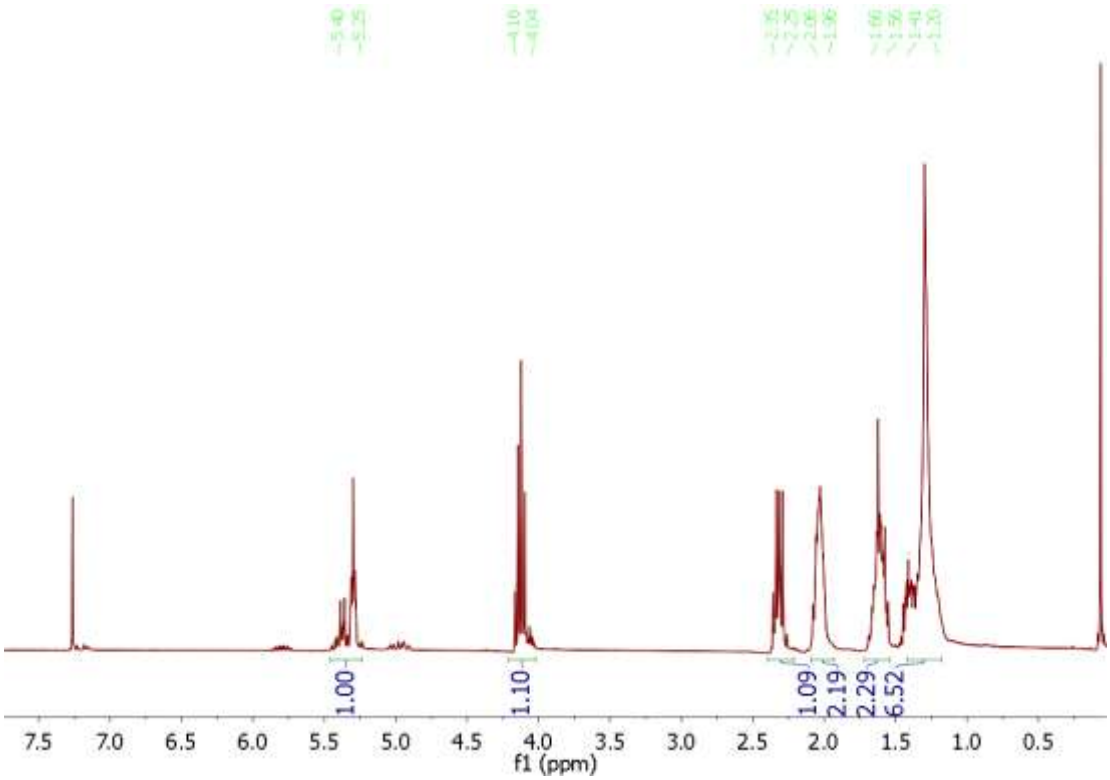
2-(2,5-Dihydropyrrole-1-carbonyl)-pyrrolidine-1-carboxylicacid tert-butyl ester (**6**)



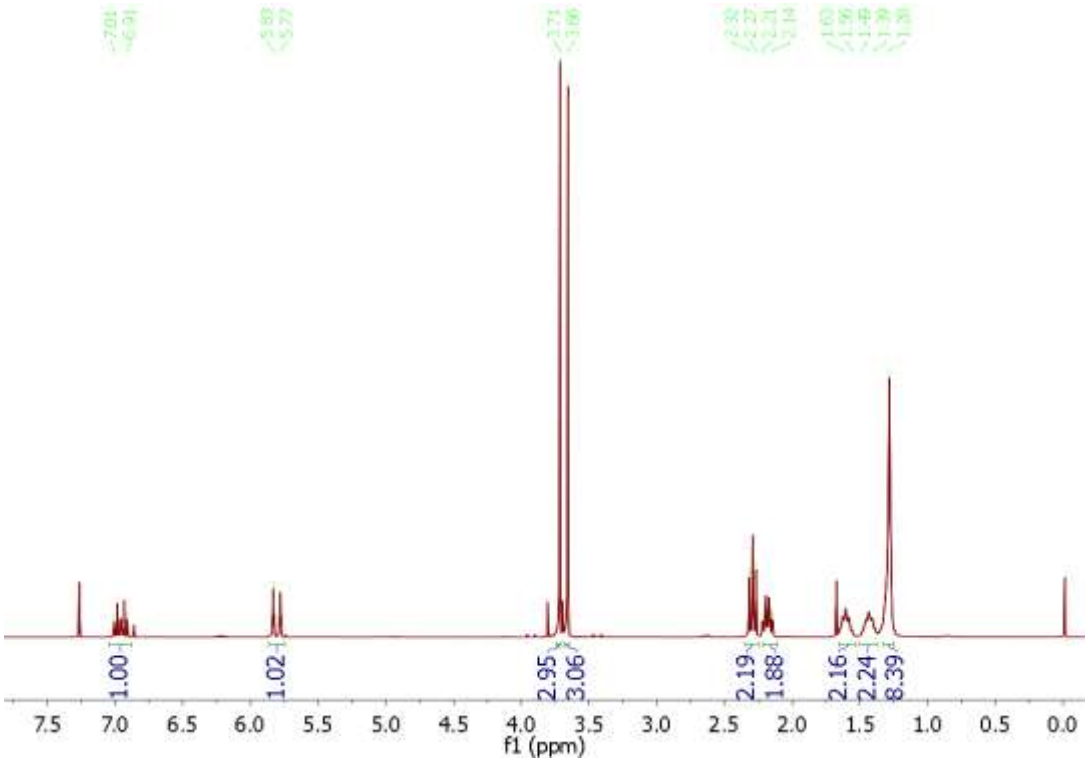
(*E*,*Z*)-Oxacyclotetradec-11-en-2-one (**8**)



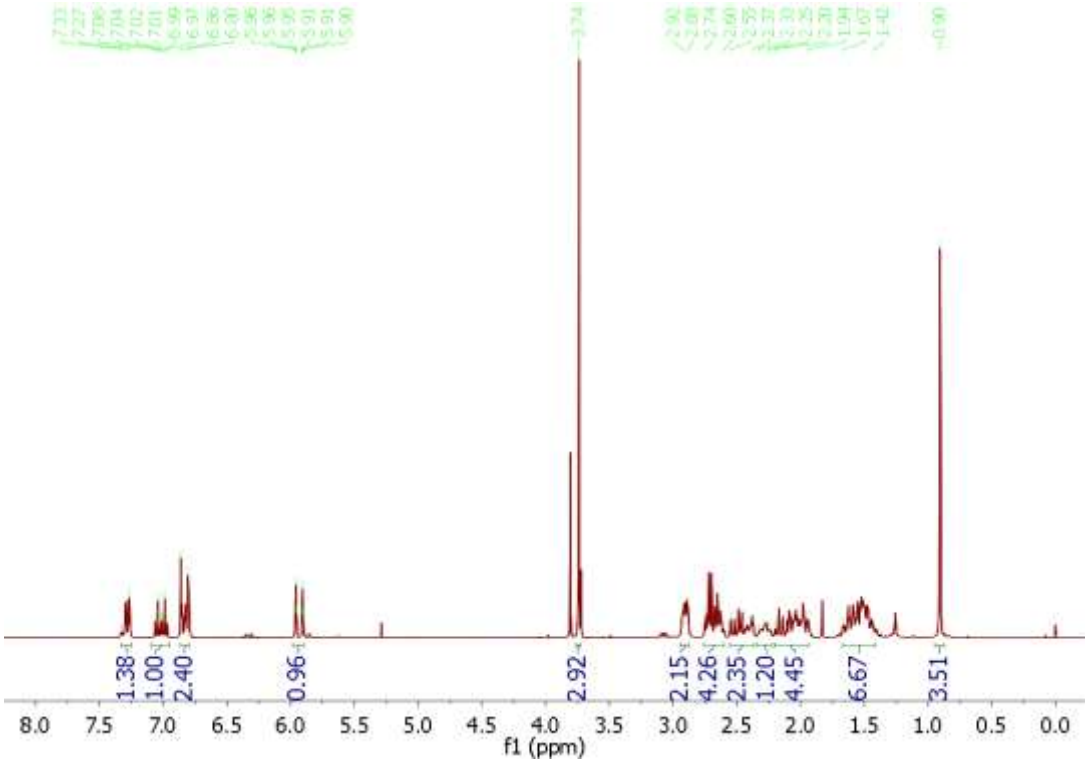
(*E*,*Z*)-Oxacyclohexadec-11-en-2-one (**10**)



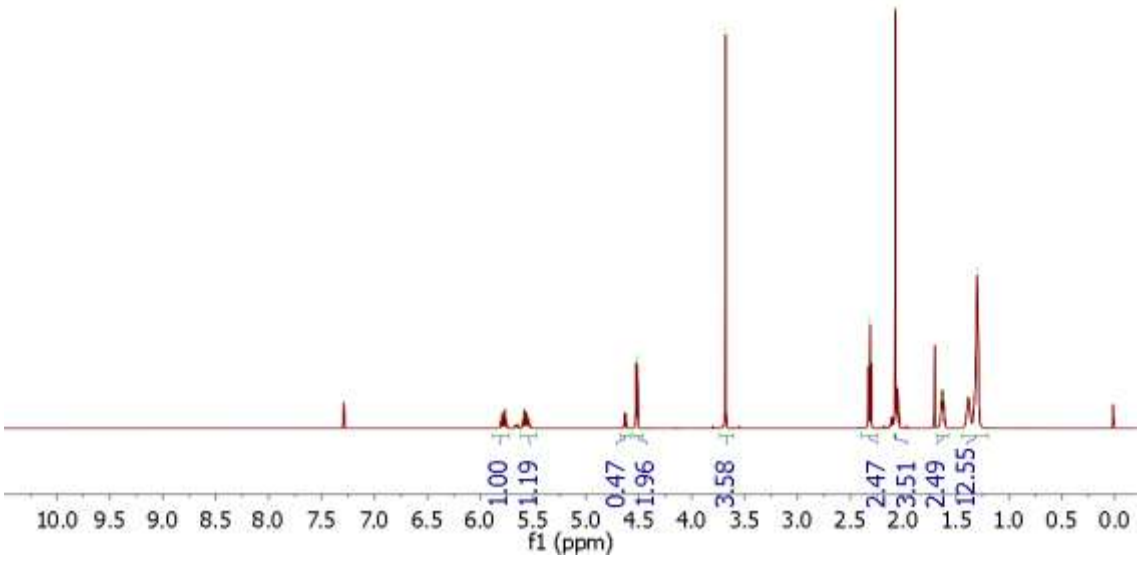
(E,Z)-Dodec-2-enedioic acid dimethyl ester (**15**)



Hex-2-enedioic acid 1-methyl ester 6-(13-methyl-17-oxo-7,8,9,11,12,13,14,15,16,17-decahydro-6H-cyclopenta[a]phenanthren-3-yl) ester (**17**)



Methyl 12-acetoxydodec-10-enoate (**19**)



References

[1] F. C. Courchay, J. C. Sworen, A. Coronado, K. B. Wagener *Journal of Molecular Catalysis A: Chemical* **2006**, 254, 111–117.

[2] Bieniek, M.; Bujok, R.; Cabaj, M.; Lugan, N.; Lavigne, G.; Arlt, D.; Grela, K. *J. Am. Chem. Soc.* **2006**, 128, 13652-13653.

[3] A. Furstner, M. Liebl, C. W. Lehmann, M. Piquet, R. Kunz, C. Bruneau, D. Touchard, P. H. Dixneuf, *Chem. Eur. J.* **2000**, *6*, 1847-1857.

[4] M. Shao, L. Zheng, W. Qiao, J. Wang, and J. Wang *Adv. Synth. Catal*. **2012**, 354, 2743 – 2750.

[5] A. Mallagaray, K. Mohammadiannejad-Abbasabadi, S. Medina, G. Domínguez J. Pérez-Castells *Org. Biomol. Chem.*, **2012**, 10, 6665–6672.

[6] Q. Wu, J. H. X. Ren, J. Zhou, *Chem. Eur. J.* **2011**, *17*, 11553-11558.

[7] A. Furstner, L. Ackermann, B. Gabor, R. Goddard, C. W. Lehmann, R. Mynott, F. Stelzer, O. R. Thiel, *Chem. Eur. J.* **2001**, *7*, 3236-3253.

[8] J. Cabrera, R. Padilla, R. Dehn, S. Deuerlein, Ł. Gułajski, E. Chomiszczak, J. H. Teles, M. Limbach, K. Grela *Adv. Synth. Catal.* **2012**, *354*, 1043–1051.

[9] V. M. Marx, M. B. Herbert, B. K. Keitz, R. H. Grubbs *J. Am. Chem. Soc.* **2013**, *135*, 94−97.

[10] X. Miao, C. Fischmeister, P. H. Dixneuf, C. Bruneau, J.-L. Dubois, J.-L. Couturier *Green Chem.*, **2012**, *14*, 2179–2183.

[11] K. Skowerski, C. Wierzbicka, G. Szczepaniak, Ł. Gułajski, M. Bieniek, K Grela *Green Chem.*, **2012**, 14, 3264–3268.

[12] M. von Czapiewski, O. Kreye, H. Mutlu, M. A. R. Meier *Eur. J. Lipid Sci. Technol*. **2013**, 115, 76–85.