Supporting Information

Asymmetric synthesis of warfarin and its analogs catalyzed by C_2-symmetric squaramide-based primary diamines

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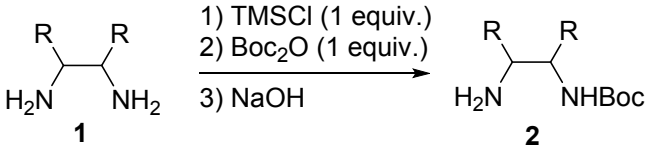
1. General Remarks

The NMR ^{1}H and ^{13}C spectra were recorded by Bruker AM 300 in $CDCI_3$ and DMSO–d_6. The chemical shifts of ^{1}H and ^{13}C were measured relative to Me_4Si or $CDCl_3$, respectively. The high resolution mass spectra (HRMS) were measured by Bruker microTOF II with electrospray ionization (ESI). The optical rotations were measured on a polarimeter and calibrated with a pure solvent as a blank. The HPLC analyses were performed on an HPLC system equipped with chiral stationary phase columns, detection at 220 or 254 nm. Silica gel 0.060 – 0.200 was used for column chromatography. Linalool-derived isoprenoid acids **12b** and **12c** were used as mixtures of isomers with regard to the double bond at C^5 (*E*/*Z* ~4:1).

2. General procedure for selective mono-Boc protetion of diamines 1



TMSCl (0.01 mol, 1.26 mL) was added to MeOH and the resulting solution was stirred for 10 min at 0˚C. Next, diamines **1** (0.01 mol) were added at 0˚C. The mixture was stirred for 15 min at room temperature and the solution of $(Boc)_2O$ (0.01 mol, 2.16 g) in MeOH (15 mL) was added dropwise for 10 min. The resulting solution was stirred for 1.5 h. The mixture was concentrated in *vacuo*. The residue was transferred to a filter and washed by diethyl ether (3 × 30 mL). The resulting pale-yellow solid was successively treated with the 3 N NaOH solution (25 mL) and water (3 × 10 mL). The product was dried in *vacuo* to afford mono-Boc amines **2** as colorless solids.

***Tert*-butyl ((1*R*,2*R*)-2-amino-1,2-diphenylethyl)carbamate (*R,R*-2a)** [1].

Yield 2.65 g (85%) as colorless solid. Mp: 100-101°C. $[\alpha]_D^{22}$ = +29.15 (c 0.5, $CHCl_3$). ^{1}H NMR (300 MHz, DMSO-d_6) δ 7.33 (d, *J* = 8.2 Hz, 1H), 7.27 – 6.90 (m, 10H), 4.63 (t, *J* = 7.2 Hz, 1H), 4.02 (d, *J* = 6.6 Hz, 1H), 1.85 (br s, 2H), 1.44 – 0.95 (m, 9H) ppm.

***Tert*-butyl ((1*S*,2*S*)-2-amino-1,2-diphenylethyl)carbamate (*S,S*-2a).**

Yield 2.69 g (86%) as colorless solid. Mp: 100-101°C. $[\alpha]_D^{22}$ = -28.90 (c 0.5, $CHCl_3$). The ^{1}H NMR spectra was identically (*R,R*-**2a**).

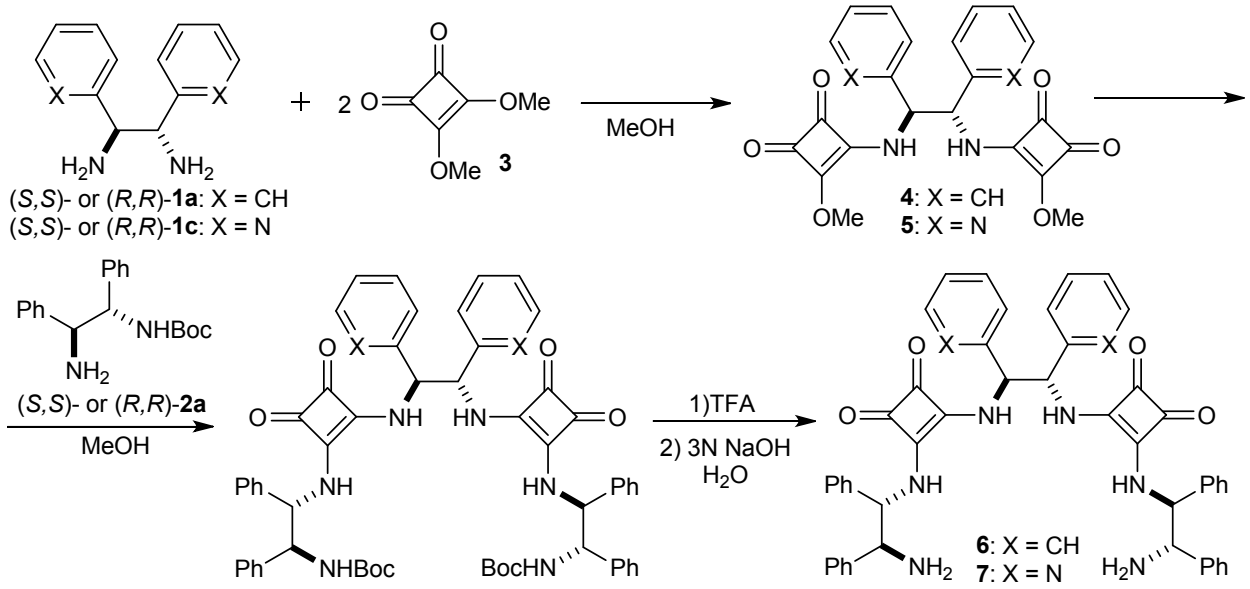
***Tert*-butyl ((1*R*,2*R*)-2-aminocyclohexyl)carbamate (*R*,*R*-2b)** [2].

Yield 1.8 g (85%) as colorless solid. Mp: 113-115°C. $[\alpha]_D^{22}$ = -32.16 (c 0.5, CH_3OH). ^1H NMR (300 MHz, DMSO- d_6) δ 6.62 (d, J = 8.3 Hz, 1H), 2.96 – 2.78 (m, 1H), 2.31 (td, J = 10.3, 4.0 Hz, 1H), 1.82 – 1.68 (m, 2H), 1.65 – 1.52 (m, 2H), 1.38 (br s, 9H), 1.23 – 0.89 (m, 4H) ppm.

***Tert*-butyl ((1*S*,2*S*)-2-amino-1,2-di(pyridin-2-yl)ethyl)carbamate (*R*,*R*-2c).**

Yield 2.45 g (78%) as colorless solid. Mp: 123-125 °C, ^1H NMR (300 MHz, $CDCl_3$): δ 8.56 (d, J = 4.4 Hz, 2H), 7.57 (t, J = 7.6 Hz, 2H), 7.26 – 6.99 (m, 4H), 6.15 (d, J = 6.2 Hz, 1H), 5.22 – 5.03 (m, 1H), 4.58 (d, J = 4.4 Hz, 1H), 2.62 (s, 2H), 1.36 (s, 9H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.4, 159.3, 155.7, 148.9, 148.8, 136.2, 136.1, 122.1, 122.1, 121.9, 79.2, 60.2, 28.2 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{17}H_{22}N_4O_2$: 315.1816; found 315.1809; $[M + Na]^+$ calcd 337.1635; found 337.1631; $[M + K]^+$ calcd 353.1374 found 353.1369.

3. Preparation of the catalysts 6 and 7



4,4'-(((1*S*,2*S*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*S*,*S*-5).

(1*S*,2*S*)-1,2-Di(pyridin-2-yl)ethane-1,2-diamine *S,S*-**1c** (627 mg, 2.93 mmol) and 3,4-dimethoxycyclobut-3-ene-1,2-dione **3** (975 mg, 6.15 mmol) were dissolved in methanol (5 mL) and stirred for 12 hours. The precipitate was filtered off, washed with MeOH (2 × 5 mL) and Et_2O (3 × 10 mL) and dried under reduced pressure (0.5 Torr) at 50 °C for 1 h to afford the amide compound *S,S*-**5** as colorless solid. Yield 826 mg (65%) as colorless solid. Mp: 213-215°C. ^1H NMR (300 MHz, DMSO- d_6) δ = 9.64 – 9.14 (m, 2H), 8.53 (br s, 2H), 7.66 (br s, 2H),

7.21 (br s, 4H), 5.98 (br s, 1H), 5.52 (br s, 1H), 4.25 (s, 6H) ppm. ^{13}C NMR (75 MHz, DMSO-d_6): δ 189.0, 183.0, 177.7, 172.6, 172.3, 157.7, 157.1, 149.6, 137.3, 123.4, 62.2, 61.9, 61.1, 60.7, 60.5, 60.3 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{22}H_{18}N_4O_6$: 435.1299; found 435.1295; $[M + Na]^+$ calcd 457.1119; found 457.1115; $[M + K]^+$ calcd 473.0858 found 473.0848.

4,4'-(((1*R*,2*R*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*R,R*-5).

Compound *R,R*-**5** was prepared similarly to *S,S*-**5** from *R,R*-**1c**. Yield 877 mg (69%) as colorless solid. Spectral data for *R,R*-**5** were identical to those for enantiomer *S,S*-**5**.

4,4'-(((1*S*,2*S*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*S,S*-4).

Compound *S,S*-**4** was prepared similarly to *S,S*-**5** from *S,S*-**1a**. Yield 785 mg (62%) as colorless solid. ^{1}H NMR (300 MHz, DMSO- d_6) δ 9.92 – 9.31 (m, 2H, NH), 7.53 – 6.97 (m, 10H), 5.76 – 5.37 (m, 1H), 5.23 – 4.90 (m, 1H), 4.28 (d, J = 7.4 Hz, 6H) ppm.

4,4'-(((1*R*,2*R*)-1,2-diphenylethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*R,R*-4).

Compound *R,R*-**4** was prepared similarly to *S,S*-**5** from *R,R*-**1a**. Yield 835 mg (66%) as colorless solid. Spectral data for *R,R*-**4** were identical to those for enantiomer *S,S*-**4**.

Di-*tert*-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*S*,2*S*)-1,2-di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl)) dicarbamate (Boc-7a).

The suspension of the compounds *S,S*-**5** (204 mg, 0.47 mmol) and *S,S*-**2a** (320 mg, 1.03 mmol) in methanol (5 mL) was stirred for 12 hours. The precipitate was filtered off, washed with MeOH (3 × 10 mL) and Et_2O (3 × 10 mL) and dried under reduced pressure (0.5 Torr) at 50 °C for 1 h to afford the compound Boc-**7a** as colorless solid. Yield 350 mg (75%) as colorless solid. Mp: 241-245°C. ^{1}H NMR (300 MHz, DMSO- d_6) δ 8.56 (s, 1H), 8.23 – 8.03 (m, 2H), 7.60 (t, J = 7.2 Hz, 1H), 7.32 – 6.92 (m, 12H), 5.86 (d, J = 7.0 Hz, 1H), 5.20 (t, J = 9.2 Hz, 1H), 4.85 (t, J = 9.0 Hz, 1H), 1.10 (s, 9H) ppm. ^{13}C NMR (75 MHz, DMSO-d_6) δ 183.1, 182.9, 168.7, 168.1, 167.7, 157.9, 157.7, 155.5, 149.7, 140.8, 140.4, 137.3, 128.6, 128.5, 128.3, 127.9, 127.6, 127.5, 124.0, 123.5, 78.6, 62.2, 60.9, 60.7, 59.2, 28.6 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{58}H_{58}N_8O_8$: 995.4450; found 995.4431; $[M + Na]^+$ calcd 1017.4270; found 1017.4258.

Di-*tert*-butyl ((1*R*,1'*R*,2*R*,2'*R*)-(((((1*R*,2*R*)-1,2-di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl)) bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl)) dicarbamate (Boc-*ent*-7a).

Compound Boc-*ent*-**7a** was prepared similarly to Boc-**7a** from *R,R*-**5** and *R,R*-**2a** Yield 355 mg (76%) as colorless solid. Spectral data for Boc-*ent*-**7a** were identical to those for enantiomer Boc-**7a**.

Di-*tert*-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*R*,2*R*)-1,2-di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl)) bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl)) dicarbamate (Boc-7b).

Compound Boc-**7b** was prepared similarly to Boc-**7a** from *R,R*-**5** and *S,S*-**2a**. Yield 348 mg (75%) as colorless solid. Mp: 261-263°C. ^{1}H NMR (300 MHz, DMSO- d_6) δ 8.56 (s, 1H), 8.25 – 8.00 (m, 2H), 7.68 – 7.50 (m, 1H), 7.35 – 6.87 (m, 26H), 5.85 (d, J = 6.2 Hz, 1H), 5.20 (t, J = 9.4 Hz, 1H), 4.94 – 4.74 (m, 1H), 1.09 (s, 9H) ppm. ^{13}C NMR (75 MHz, DMSO- d_6) δ 183.1, 182.9, 168.6, 168.1, 167.6, 157.8, 157.6, 155.4, 149.6, 140.7, 140.3, 137.3, 128.6, 128.5, 128.2, 127.9, 127.5, 127.4, 123.9, 123.4, 78.5, 62.1, 60.8, 60.6, 59.1, 28.5 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{58}H_{58}N_8O_8$: 995.4450; found 995.4429; $[M + Na]^+$ calcd 1017.4270; found 1017.4248; $[M + K]^+$ calcd 1033.4009 found 1033.3987.

Di-tert-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*S*,2*S*)-1,2-diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (Boc-6a).

Compound Boc-**6a** was prepared similarly to Boc-**7a** from *S,S*-**4** and *S,S*-**2a**. Yield 340 mg (72%) as colorless solid. Mp: 228-231°C. ^{1}H NMR (300 MHz, DMSO- d_6) δ 8.15 – 7.55 (m, 4H, NH), 7.49 – 6.78 (m, 32H), 5.71 – 5.45 (m, 2H), 5.03 – 4.85 (m, 2H), 4.17 (br s, 2H), 1.43 – 0.95 (m, 18H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{60}H_{60}N_6O_8$: 993.4545; found 993.4540.

Di-tert-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*R*,2*R*)-1,2-diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (Boc-6b).

Compound Boc-**6b** was prepared similarly to Boc-**7a** from *R,R*-**4** and *S,S*-**2a**. Yield 331 mg (70%) as colorless solid. Mp: 230-232°C. ^{1}H NMR (300 MHz, DMSO-d_6) δ 8.15-7.60 (m, 4H, NH), 7.50-6.82 (m, 32H), 5.69-5.47 (m, 2H), 5.01-4.74 (m, 2H), 4.17 (bs s, 2H), 1.1-1.45 (m, 18H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{60}H_{60}N_6O_8$: 993.4545; found 993.4549.

(*S*,*S*)-4,4'-(((1*S*,2*S*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-(((1*S*,2*S*)-2-amino-1,2-diphenylethyl)amino)cyclobut-3-ene-1,2-dione) (7a).

Trifluoroacetic acid (0.5 mL) was added to compound Boc-**7a** (250 mg, 0.25 mmol). The resulting solution was stirred for 1 hour. Then the excess of trifluoroacetic acid was evaporated under reduced pressure (15 Torr). The residue was washed with 4 N NaOH (5mL), then with Et_2O (3 × 10 mL) and dried under reduced pressure (0.5 Torr) for 1 h to afford the compound **7a** as colorless solid, yield 227 mg (89%). Mp: 222-227°C. ^{1}H NMR (300 MHz, DMSO-d_6 + TFA) δ 8.89 – 8.39 (m, 7H), 8.29 (d, J = 5.8 Hz, 2H), 8.10 (d, J = 7.9 Hz, 2H), 7.57 (t, J = 7.4 Hz, 2H), 7.39 – 6.90 (m, 26H), 5.87 (d, J = 6.2 Hz, 2H), 5.49 (t, J = 10.3 Hz, 2H), 4.74 (d, J = 9.8 Hz, 2H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{48}H_{42}N_8O_4$: 795.3402; found 795.3395; $[M + Na]^+$ calcd 817.3221; found 817.3214; $[M + K]^+$ calcd 833.2961 found 833.2950.

(*R*,*R*)-4,4'-(((1*R*,2*R*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-(((1*R*,2*R*)-2-amino-1,2-diphenylethyl)amino)cyclobut-3-ene-1,2-dione) (*ent*-7a).

Compound *ent*-**7a** was prepared similarly to **7a** from Boc-*ent*-**7a**. Yield 225 mg (88%) as colorless solid. Spectral data for *ent*-**7a** were identical to those for enantiomer **7a**.

(*S*,*S*)-4,4'-(((1*R*,2*R*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-(((1*S*,2*S*)-2-amino-1,2-diphenylethyl)amino)cyclobut-3-ene-1,2-dione) (7b).

Compound **7b** was prepared similarly to **7a** from Boc-**7b**. Yield 230 mg (90%) as colorless solid. Mp: 227-230°C ^{1}H NMR (300 MHz, DMSO-d_6 + TFA) δ 9.07 – 8.59 (m, 9H), 8.57 – 8.04 (m, 4H), 7.56 (br s, 2H), 7.45 – 6.64 (m, 26H), 5.93 (br s, 2H), 5.56 (br s, 2H), 4.96 (br s, 2H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{48}H_{42}N_8O_4$: 795.3402; found 795.3393; $[M + Na]^+$ calcd 817.3221; found 817.3218; $[M + K]^+$ calcd 833.2961 found 833.2955.

(*S*,*S*)-4,4'-(((1*S*,2*S*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3-(((1*S*,2*S*)-2-amino-1,2-diphenylethyl)amino)cyclobut-3-ene-1,2-dione) (6a).

Compound **6a** was prepared similarly to **7a** from Boc-**6a**. Yield 230 mg (90%) as light yellow solid. Mp: 280-283°C. ^{1}H NMR (300 MHz, DMSO-d_6 + TFA) δ 8.74 – 8.38 (m, 8H), 8.08 (br s, 2H), 7.41 – 6.83 (m, 40H), 5.62 (d, J = 9.0 Hz, 2H), 5.48 (t, J = 9.8 Hz, 2H), 4.70 (d, J = 8.7 Hz, 2H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{50}H_{44}N_8O_4$: 793.3497; found 793.3495.

(*S*,*S*)-4,4'-(((1*R*,2*R*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3-(((1*S*,2*S*)-2-amino-1,2-diphenylethyl)amino)cyclobut-3-ene-1,2-dione) (6b).

Compound **6b** was prepared similarly to **7a** from Boc-**6b**. Yield 222 mg (89%) as light yellow solid. Mp: 267-270°C. ^{1}H NMR (300 MHz, DMSO-d_6 + TFA) δ 8.87 – 8.42 (m, 8H), 8.16 (br s, 2H), 7.54 – 6.70 (m, 40H), 5.60 (br s, 3H), 5.47 (br s, 2H), 4.73 (br s, 2H) ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{50}H_{44}N_8O_4$: 793.3497; found 793.3493.

4. General procedure for asymmetric Michael addition

The mixture of 4-hydroxycoumarin **8a** or 4-hydroxy-6-methyl-2H-pyran-2-one **8b** (0.126 mmol), *α*,*β*-unsaturated ketone **9** (0.151 mmol), catalyst **7a** or *ent*-**7a** (10 mg, 12.6 μmol), AcOH (70 μL), and CH_2Cl_2 (300 μL) was stirred at ambient temperature for 24 h. The solvent and AcOH were removed under reduced pressure (15 Torr) and the residue was extracted with Et_2O (5 x 3 mL). The combined organic extracts were evaporated under reduced pressure (15 Torr). Corresponding products **10** or **11** were purified via flash-chromatography on silica gel (*n*-hexane/EtOAc 2:1).

4-Hydroxy-3-(3-oxo-1-phenylbutyl)-2H-chromen-2-one (Warfarin) (10a). [3]

Yield 37 mg **10a** (96%) as colorless solid. Mp: 155-158°C. $[\alpha]_D^{20}$ = -10.2 (c 1, MeCN, 96% *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.67 (s, 0.16H), 7.96 – 7.74 (m, 1.42H), 7.59-7.39 (m, 1.67H), 7.39-7.13 (m, 8.47H), 4.77 (d, *J* = 10.1 Hz, 0.16H), 4.30-4.13 (m, 1.23H), 3.90-3.78 (m, 0.36H), 3.37-3.30 (d, 0.19H), 2.53-2.35 (m, 1.50H), 2.29 (s, 0.32H) 2.07-1.95 (m, 0.74), 1.69-1.67 (m, 3H) ppm.

4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-2H-chromen-2-one (10b). [3]

Yield 39 mg **10b** (93%) as colorless solid. Mp: 165-678°C. $[\alpha]_D^{20}$ = +14.64 (c 1, MeCN, 84 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.45 (s, 0.15H), 7.94-7.81 (m, 1.04H), 7.58-7.50 (m, 1.45H), 7.35- 7.14 (m, 4.59H), 6.89-6.83 (m, 2.15H), 4.66 (m, 0.17H), 4.26 (m, 0.50H), 4.13 (m, 0.53H), 3.79-3.78 (m, 3H), 2.57-2.38 (m, 1.83H), 2.29 (s, 0.53H), 1.72 - 1.69 (m, 2.70H) ppm.

3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-2H-chromen-2-one (10c). [3]

Yield 39 mg **10c** (91%) as colorless solid. Mp: 175-176°C. $[\alpha]_D^{20}$ = +22.44 (c 1, MeCN, 88 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.72 (0.18H), 7.90-7.81 (m, 1H), 7.59-7.44 (m, 1.29H), 7.37 – 7.14 (m, 6.64), 4.68 (d, *J* = 8.4 Hz, 0.16H), 4.38 (br s, 0.41H), 4.22-4.05 (m, 1.10H), 3.91-

3.70 (m, 0.55H), 3.32-3.26 (m, 0.20H) 2.48-2.35 (m, 1.28H), 2.28 (s, 0.31H), 2.05 – 1.89 (m, 1.25H), 1.72 (s, 1.43H), 1.69 (s, 0.98H) ppm.

4-Hydroxy-3-(3-oxocyclohexyl)-2H-chromen-2-one (10d). [4]

Yield 29 mg **10c** (89%) as colorless solid. $[\alpha]_D^{20}$ = +15.52 (c 1, MeCN, 50 % *ee*). ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.32 (br s, 0.47H) 7.83-7.74 (d, J = 7.6 Hz, 1.00H), 7.61-7.56 (t, J = 7.8 Hz, 1.00H), 7.36-7.30 (m, 2.00H), 3.19 (s, 0.66H), 2.30-2.19 (m, 1.00H), 2.12-1.99 (m, 2.00H), 1.87-1.79 (m, 2.00H), 1.64-1.57 (m, 2.00H), 1.41-1.35 (m, 1.00H) ppm.

4-Hydroxy-6-methyl-3-(3-oxo-1-phenylbutyl)-2H-pyran-2-one (11a). [3]

Yield 33 mg **11a** (97%) as light yellow oil. $[\alpha]_D^{20}$ = -30.25 (c 1, $CHCl_3$, 94 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68 – 6.83 (m, 5H), 5.88 (s, 0.4H), 5.79 (s, 0.6H), 4.80 – 4.47 (m, 0.4 H), 4.30 – 4.07 (m, 0.6H), 3.82 – 3.58 (m, 0.4H), 3.33 – 3.08 (m, 0.4H), 2.45 – 2.31 (m, 0.6H), 2.27 (s, 1.2H), 2.21 (s, 1.8H), 2.08 (s, 1H), 1.98 – 1.81 (m, 0.6H), 1.58 (s, 1.2H), 1.56 (s, 1.8H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.5, 164.8, 164.3, 161.4, 161.0, 143.2, 141.7, 128.9, 128.47, 128.1, 127.8, 127.0, 126.3, 101.1, 100.8, 100.2, 98.7, 60.4, 45.7, 42.6, 40.3, 34.9, 34.5, 33.9, 27.8, 27.2, 21.0, 19.7, 14.2 ppm. NMR HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{16}H_{16}O_4$: 273.1121; found 273.1124.

4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-6-methyl-2H-pyran-2-one (11b).

Yield 36 mg **11b** (95%) as light yellow oil. $[\alpha]_D^{22}$ = -21.10 (c 0.66, $CHCl_3$, 86 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.43 – 7.19 (m, 2H), 7.19 – 6.98 (m, 2H), 5.87 (s, 0.5H), 5.77 (s, 0.5H), 4.83 – 4.53 (m, 0.5H), 4.09 – 3.91 (m, 0.5H), 3.79 (s, 3H), 3.67 – 3.44 (m, 0.5H), 3.33 – 3.06 (m, 0.5H), 2.48 – 2.09 (m, 3.5H), 2.06 (s, 1H), 1.97 – 1.76 (m, 0.5H), 1.54 (s, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ 210.20, 171.28, 164.58, 164.24, 164.10, 163.62, 161.40, 160.99, 158.51, 158.00, 135.12, 133.25, 128.89, 128.64, 128.01, 114.50, 113.93, 113.51, 101.19, 101.02, 100.78, 100.71, 100.20, 98.78, 98.66, 60.44, 55.18, 45.92, 42.70, 40.11, 34.18, 33.74, 32.87, 30.14, 29.67, 27.92, 27.45, 21.03, 19.81, 19.71, 19.49, 14.17 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{17}H_{18}O_5$: 303.1227; found 303.1231.

3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-6-methyl-2H-pyran-2-one (11c). [5]

Yield 37 mg **11c** (95%) as light yellow oil. $[\alpha]_D^{28}$ = -34.86 (c 1, $CHCl_3$, 89 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44 – 7.09 (m, 4H), 5.88 (s, 0.45H), 5.80 (s, 0.55H), 4.74 – 4.56 (m, 0.45H), 4.21 – 4.06 (m, 0.55H), 3.81 – 3.55 (m, 0.45H), 3.33 – 3.07 (m, 0.45H), 2.48 – 2.29 (m,

0.55H), 2.28 (s, 1.35H), 2.22 (s, 1.65H), 2.09 (s, 1H), 1.97 – 1.80 (m, 0.55H), 1.57 (d, J = 4.0 Hz, 3H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.60, 166.39, 165.57, 164.96, 164.60, 164.43, 163.97, 161.47, 161.05, 160.49, 143.20, 142.60, 141.75, 128.92, 128.46, 128.10, 127.88, 127.02, 126.89, 126.28, 104.11, 101.04, 100.87, 100.31, 98.86, 98.57, 60.49, 45.83, 42.70, 40.39, 35.06, 34.58, 34.06, 30.14, 27.80, 27.18, 19.80, 19.70, 19.55, 14.18 ppm. NMR HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{16}H_{15}ClO_4$: 307.0732; found 307.0728.

4-Hydroxy-6-methyl-3-(3-oxocyclohexyl)-2H-pyran-2-one (**11d**). [6]

Yield 25 mg **11d** (91%) as light yellow oil. $[\alpha]_D^{22}$ = +88.72 (c 0.66, $CHCl_3$, 63 % *ee*). ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.77 (s, 1H), 4.32 (br s, 1H), 3.22 (s, 1H), 2.18 (s, 3H), 2.14 – 1.30 (m, 8H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.5, 164.4, 160.8, 101.8, 100.2, 99.9, 77.5, 77.1, 76.6, 38.4, 35.7, 28.5, 28.2, 19.8, 18.9 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{12}H_{14}O_4$: 223.0965; found 223.0961.

5. Scaling catalytic reaction and catalyst recovery

The mixture of 4-hydroxycoumarin **8a** (1.62 g, 10.0 mmol), *α,β*-unsaturated ketone **9a** (1.75 g, 12.0 mmol), catalyst **7a** (0.79 g, 1.0 mmol), AcOH (0.57 mL), and CH_2Cl_2 (5 mL) was stirred at ambient temperature for 24 h. The solvent and AcOH were removed under reduced pressure (15 Torr) and the residue was extracted with Et_2O (5 x 30 mL). The combined organic extracts were evaporated under reduced pressure (15 Torr) to afford the product **10a**. After extraction of product **10a** with Et_2O, remained catalyst **7a** was dried under reduced pressure (1.0 Torr, 30 min). Fresh portions of **8a**, **9a**, AcOH and CH_2Cl_2 were added to the recovered catalyst and the reaction was re-performed.

6. General procedure for warfarin esterification

Warfarin **10a** (0.154 g, 0.5 mmol), acid **12** (0.5 mmol), DCC (0.11 g, 0.5 mmol), DMAP (*cat.*) and DCM (0.5 mL) were stirred for 24 h. The precipitate was filtered off and washed with DCM (3×5 mL). The combined organic washings were evaporated and the residue was purified by column chromatography on silica gel (eluent: *n*-hexane/EtOAc, 4:1-2:1) to afford ester **13**.

2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 2-acetoxybenzoate (13a).

Yield 0.2 g (85%) as colorless oil. $[\alpha]_D^{22}$ = +4.67 (c, 0.2, $CHCl_3$, 96 % *ee*). ^{1}H NMR (300 MHz, DMSO-d_6) δ 7.85 (d, J = 7.9 Hz, 1H), 7.67 (t, J = 7.8 Hz, 1H), 7.54 – 7.05 (m, 11H), 4.06

– 3.82 (m, 1H), 3.00 – 2.69 (m, 1H), 2.16-2.06 (m, 1H), 2.05 (s, 3H), 1.94 (s, 3H) ppm. ^{13}C NMR (75 MHz, DMSO-d_6) δ 168.9, 160.1, 157.7, 152.8, 143.3, 132.8, 128.8, 127.6, 126.7, 124.7, 123.1, 116.7, 115.1, 104.8, 103.0, 41.0, 34.9, 24.3, 22.1 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{28}H_{22}O_7$: 471.1438; found 471.1435; $[M + NH_4]^+$ calcd 488.1704, found 488.1703.

2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 5,9-dimethyldeca-4,8-dienoate (13b).

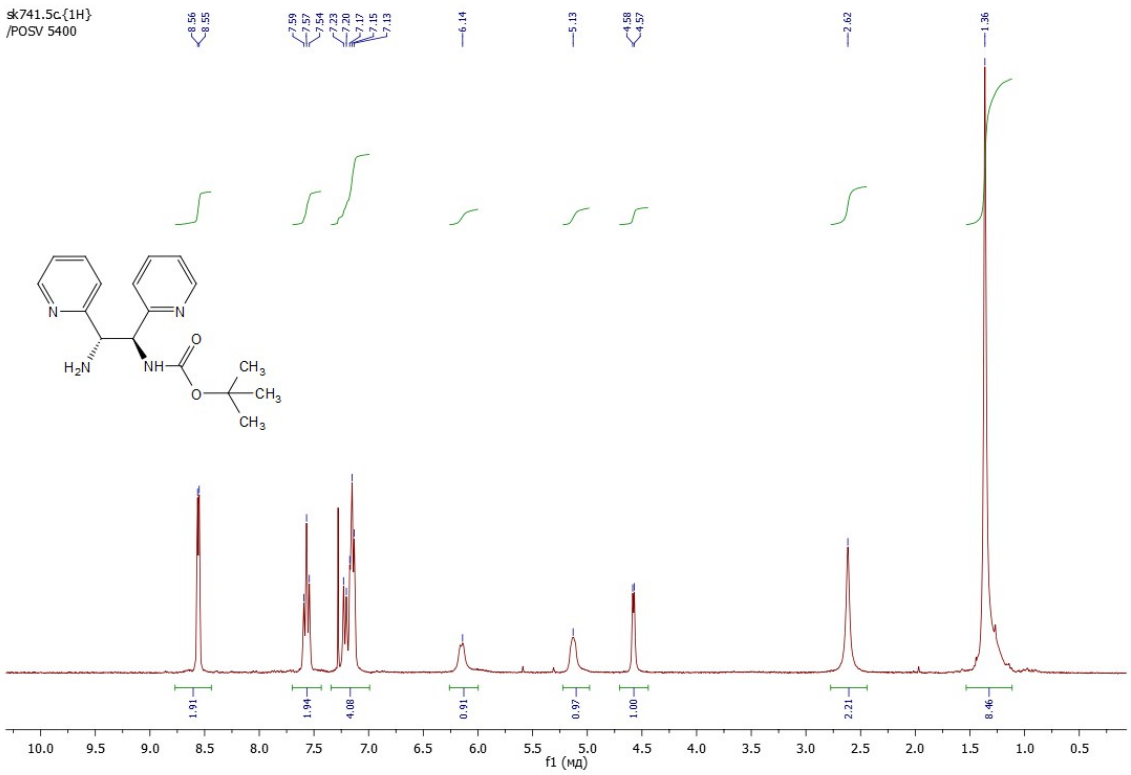
Yield 0.21 g (86%) as colorless oil. ^{1}H NMR (300 MHz, DMSO-d_6) δ 7.84 (d, J = 7.5 Hz, 1H), 7.66 (t, J = 7.8 Hz, 1H), 7.49 – 7.07 (m, 7H), 5.05 – 4.84 (m, 2H), 3.98 – 3.80 (m, 1H), 2.83 (m, 1H), 2.33 (m, 2H), 2.13 (m, 2H), 2.05 – 1.83 (m, 6H), 1.78 (m, 2H), 1.66 – 1.39 (m, 9H) ppm. ^{13}C NMR (75 MHz, DMSO-d_6) δ 170.9, 160.0, 157.7, 152.7, 143.2, 136.5, 136.4, 132.8, 131.3, 131.1, 128.8, 127.5, 126.7, 124.6, 124.4, 123.2, 123.0, 122.4, 116.7, 115.1, 104.8, 102.9, 102.9, 41.2, 35.2, 35.1, 31.8, 26.5, 26.3, 25.9, 25.8, 24.2, 23.5, 23.4, 17.9, 17.8, 16.2 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{31}H_{34}O_5$: 487.2479; found 487.2469; $[M + NH_4]^+$ calcd 504.2744, found 504.2734; $[M + Na]^+$ calcd 509.2298, found 509.2288.

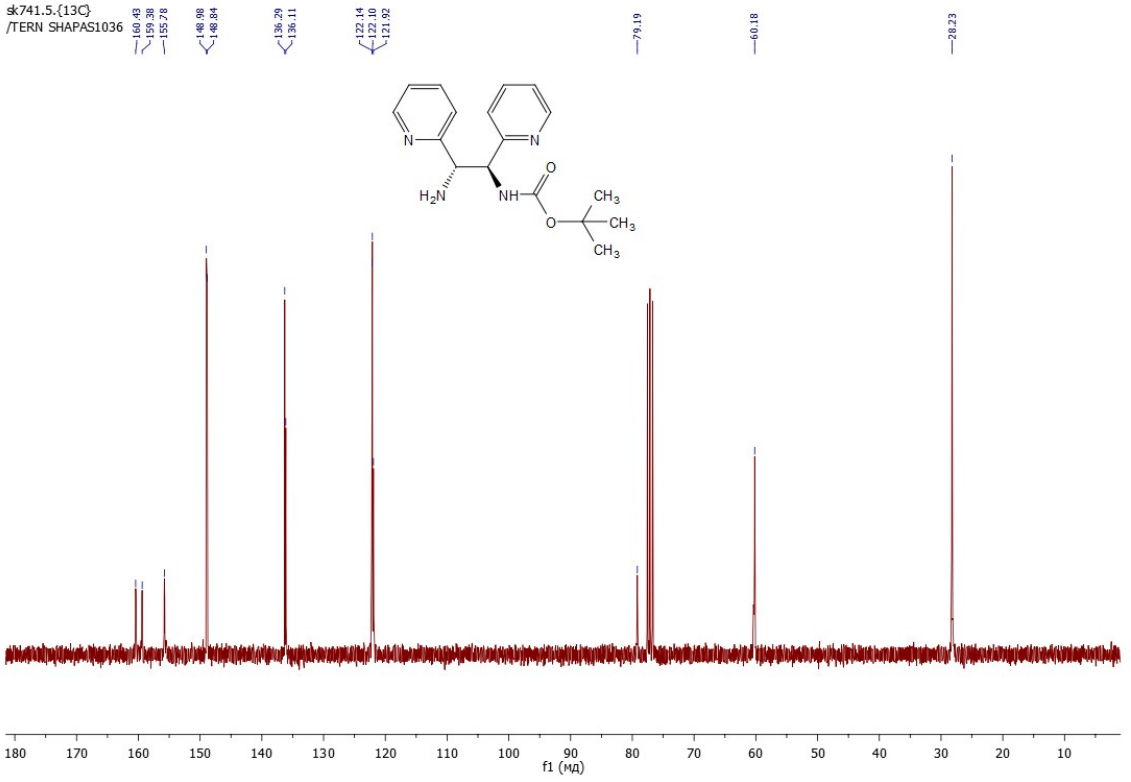
2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 2-cyclohexyl-5,9-dimethyldeca-4,8-dienoate (13c).

Yield 0.21 g (75%) as colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.69 – 7.07 (m, 9H), 5.43 – 5.24 (m, 1H), 5.21 – 5.02 (m, 1H), 4.90 – 4.76 (m, 1H), 3.93 – 3.51 (m, 1H), 3.50 – 3.11 (m, 1H), 2.90 – 2.70 (m, 1H), 2.69 – 2.54 (m, 1H), 2.53 – 2.30 (m, 1H), 2.28 – 1.43 (m, 21H), 1.26 (m, 6H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ 206.1, 171.8, 171.8, 160.9, 152.5, 140.0, 138.2, 131.7, 131.6, 128.3, 127.8, 127.7, 126.7, 124.1, 124.0, 123.7, 121.2, 121.1, 116.6, 116.1, 109.9, 77.5, 77.1, 76.7, 52.0, 45.2, 40.0, 39.9, 39.8, 37.5, 36.5, 36.5, 31.4, 31.2, 30.3, 29.9, 27.0, 26.6, 26.4, 26.3, 26.2, 25.7, 23.5, 22.4, 17.8, 17.7, 16.3 ppm. HRMS (ESI): *m/z* $[M]^+$ calcd for $C_{37}H_{44}O_5$: 569.3262, found 569.3257; $[M + NH_4]^+$ calcd 586.3527, found 586.3524; $[M + Na]^+$ calcd 591.3081, found 591.3076; $[M + K]^+$ calcd 607.2820, found 607.2821.

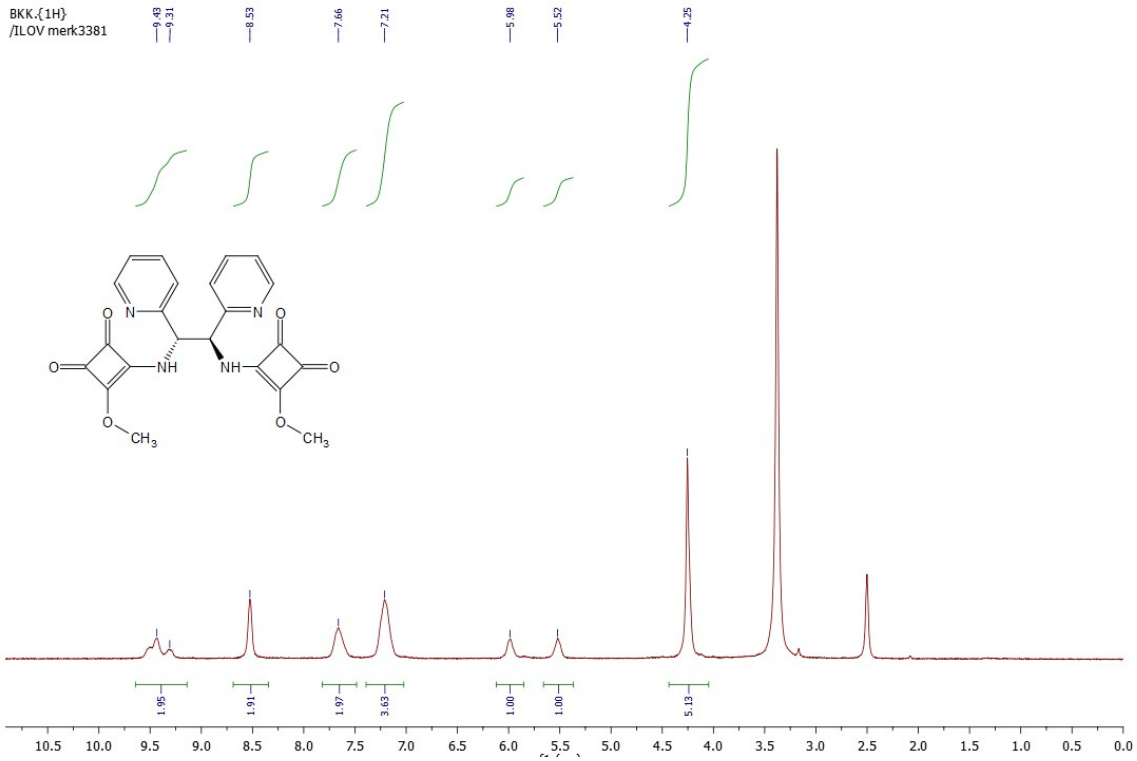
7. Pictures of ^{1}H and ^{13}C NMR spectra for novel compounds

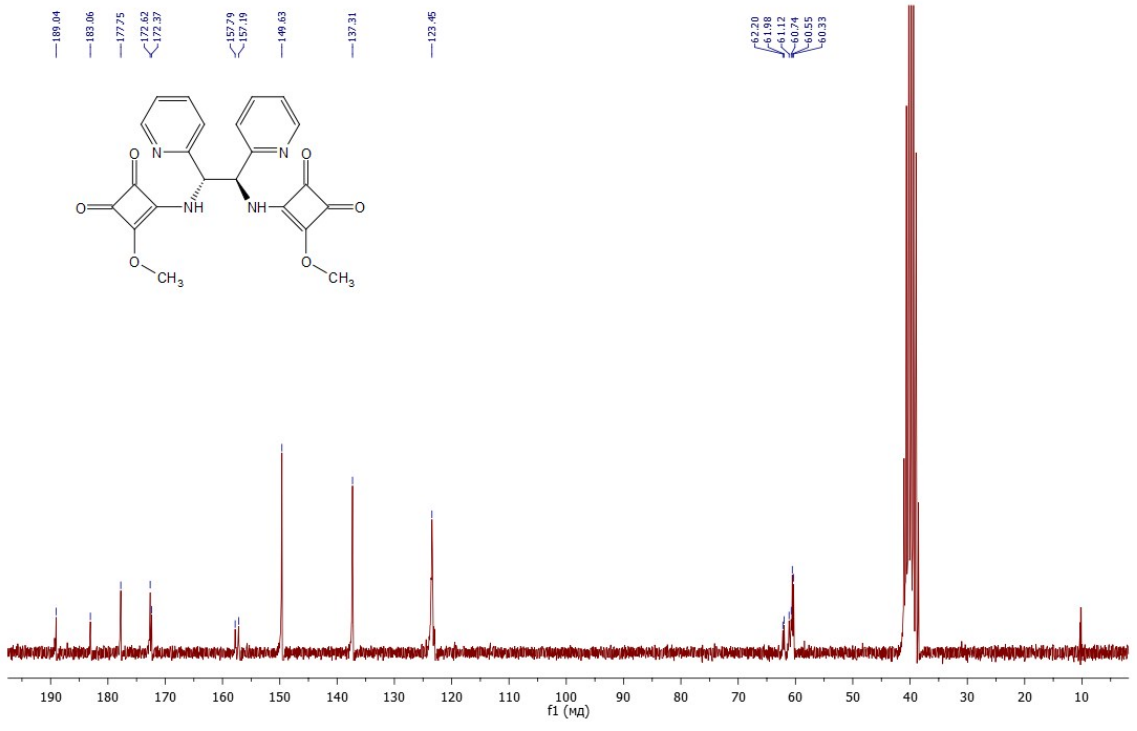
***Tert*-butyl ((1*S*,2*S*)-2-amino-1,2-di(pyridin-2-yl)ethyl)carbamate (2c).**



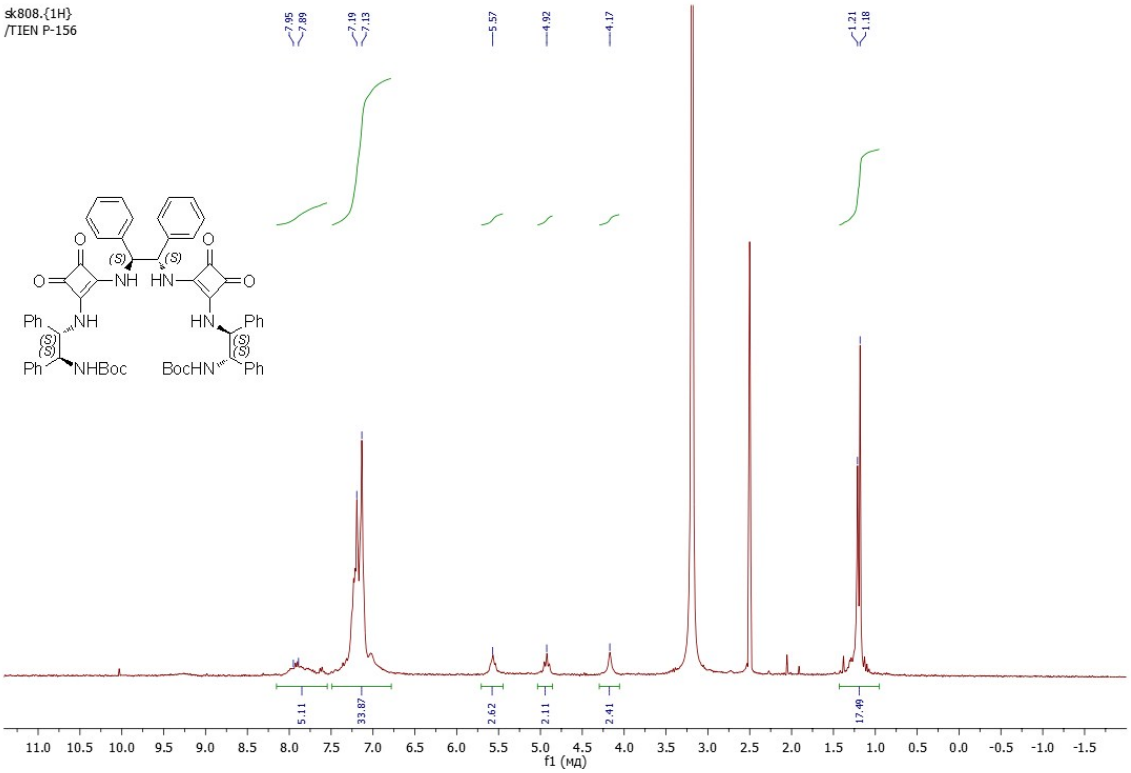


4,4'-(((1*S*,2*S*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*S*,*S*-5).

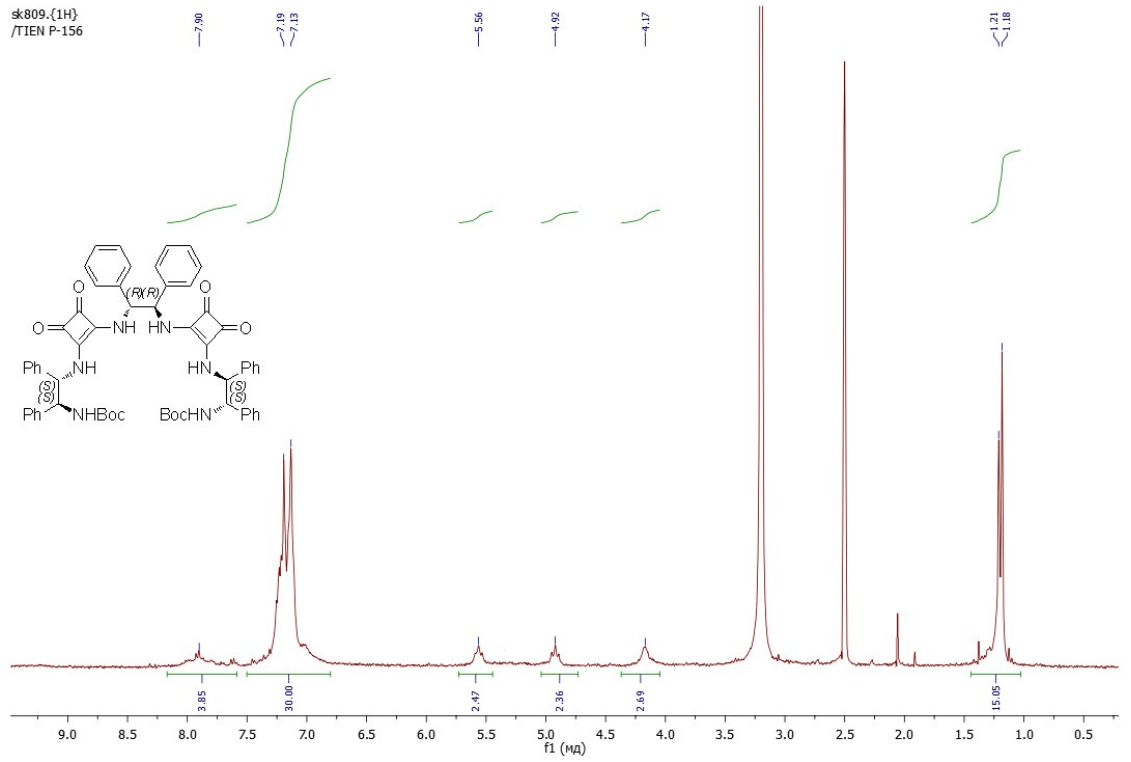




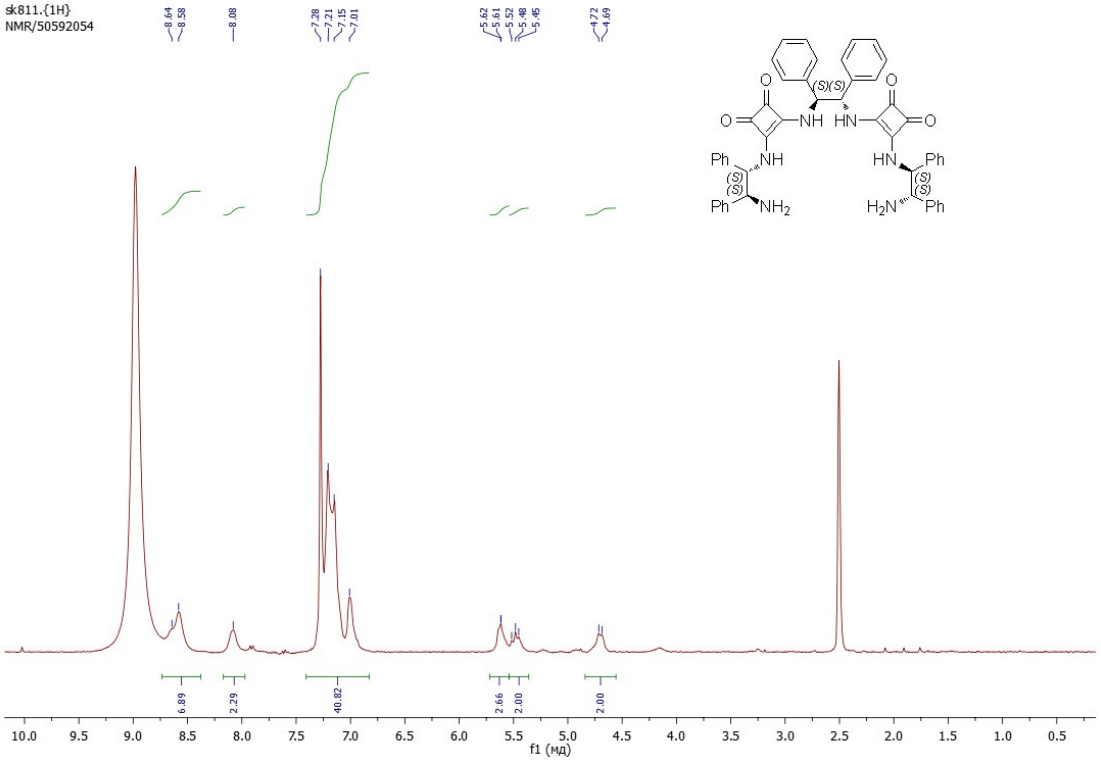
Di-*tert*-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*S*,2*S*)-1,2-diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (Boc-6a).



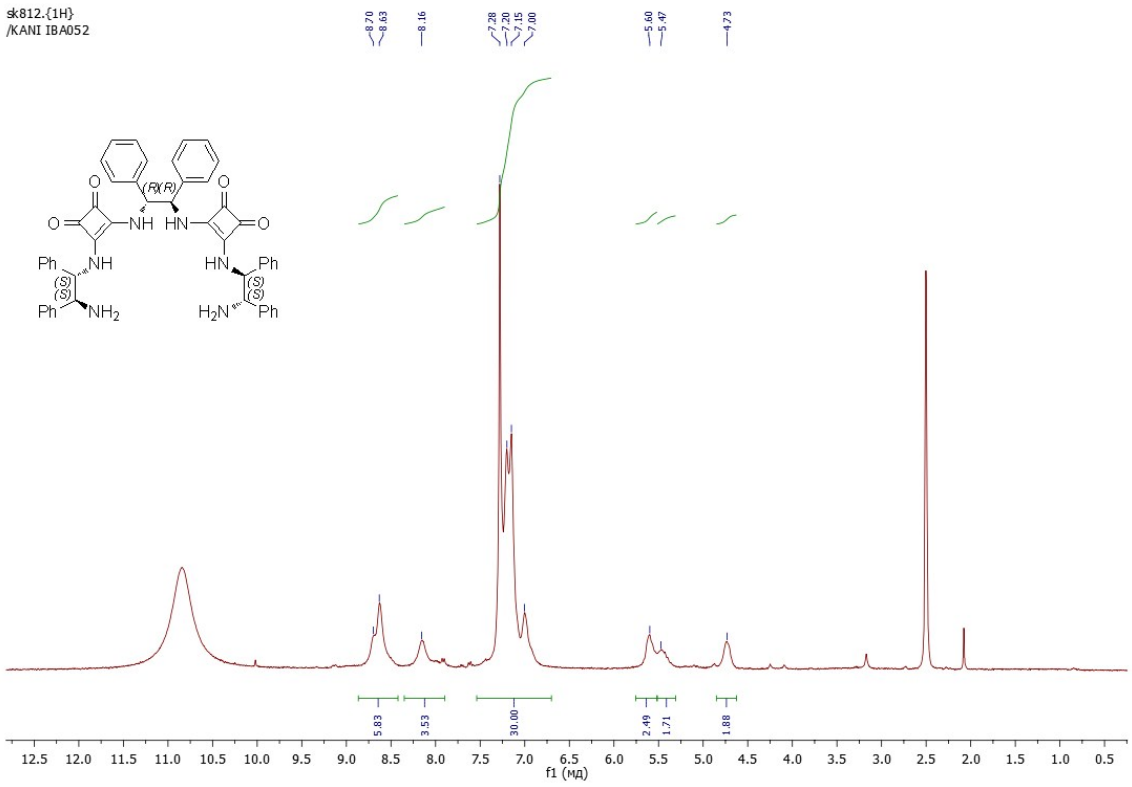
Di-*tert*-butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*R*,2*R*)-1,2-diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (Boc-6b).



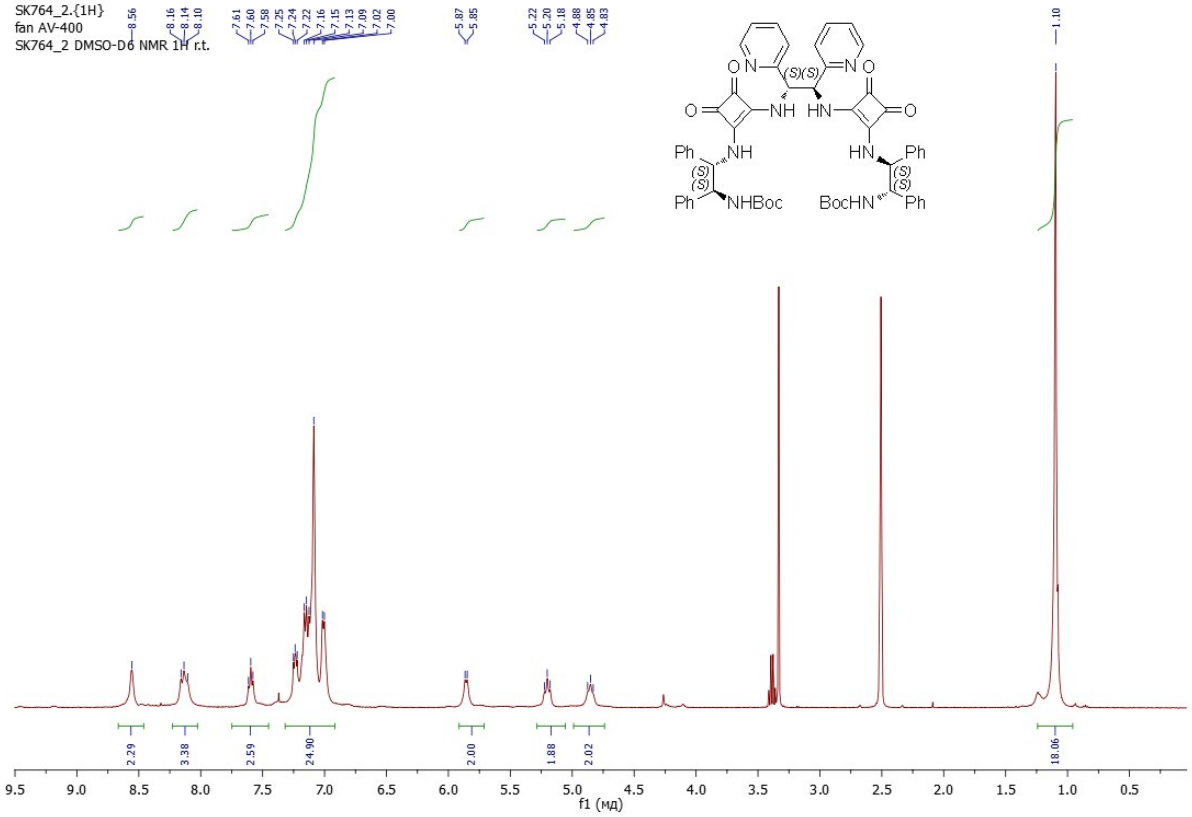
(1*S*,1'*S*,2*S*,2'*S*)-2,2'-(((((1*S*,2*S*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethanaminium) trifluoroacetate (**6a**).

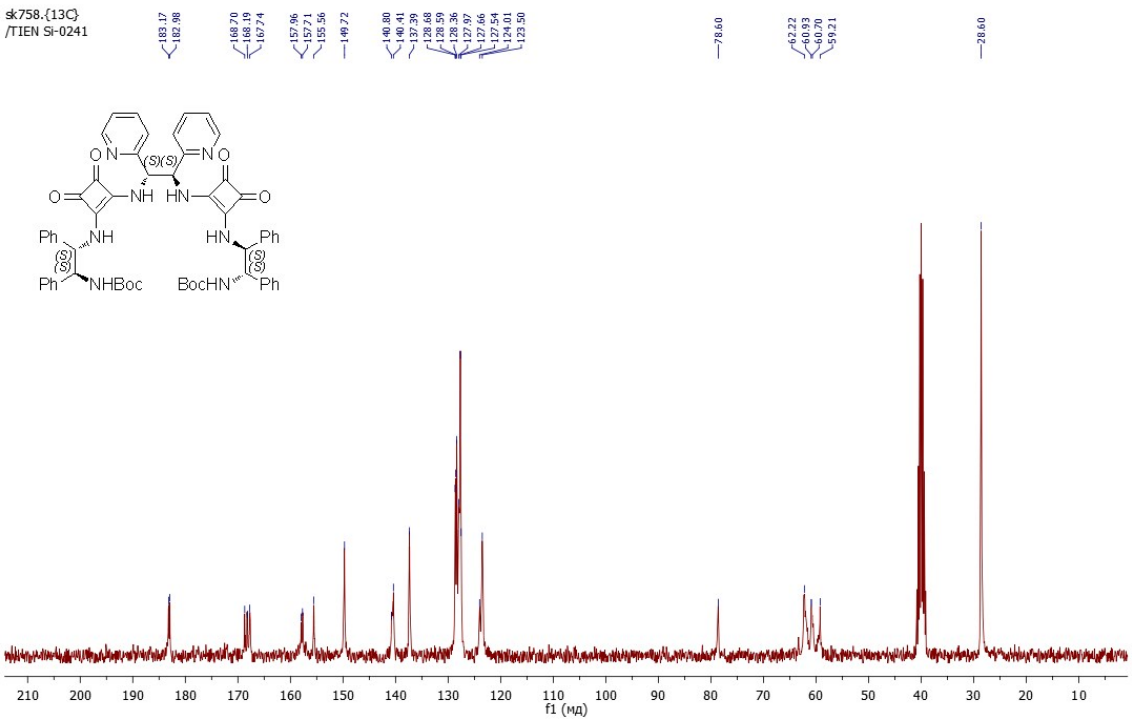


(1*S*,1'*S*,2*S*,2'*S*)-2,2'-(((((1*R*,2*R*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethanaminium) trifluoroacetate (**6b**).

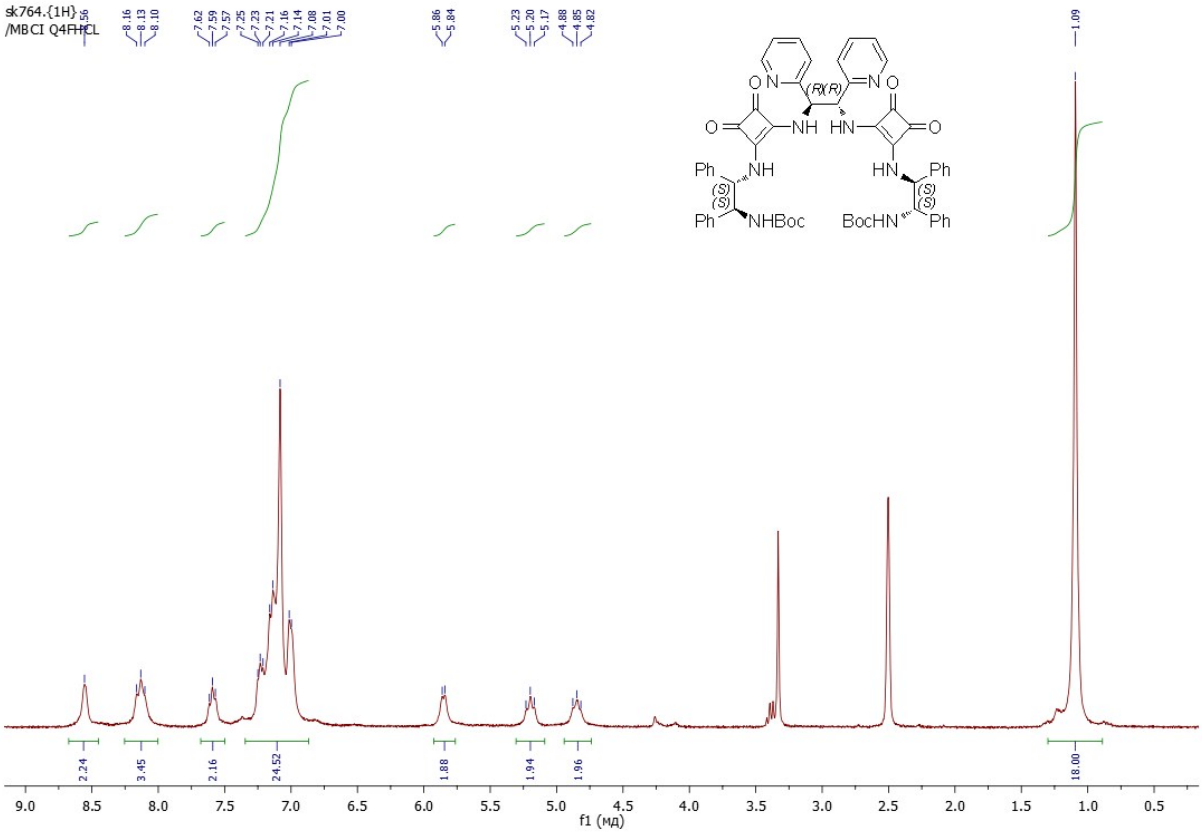


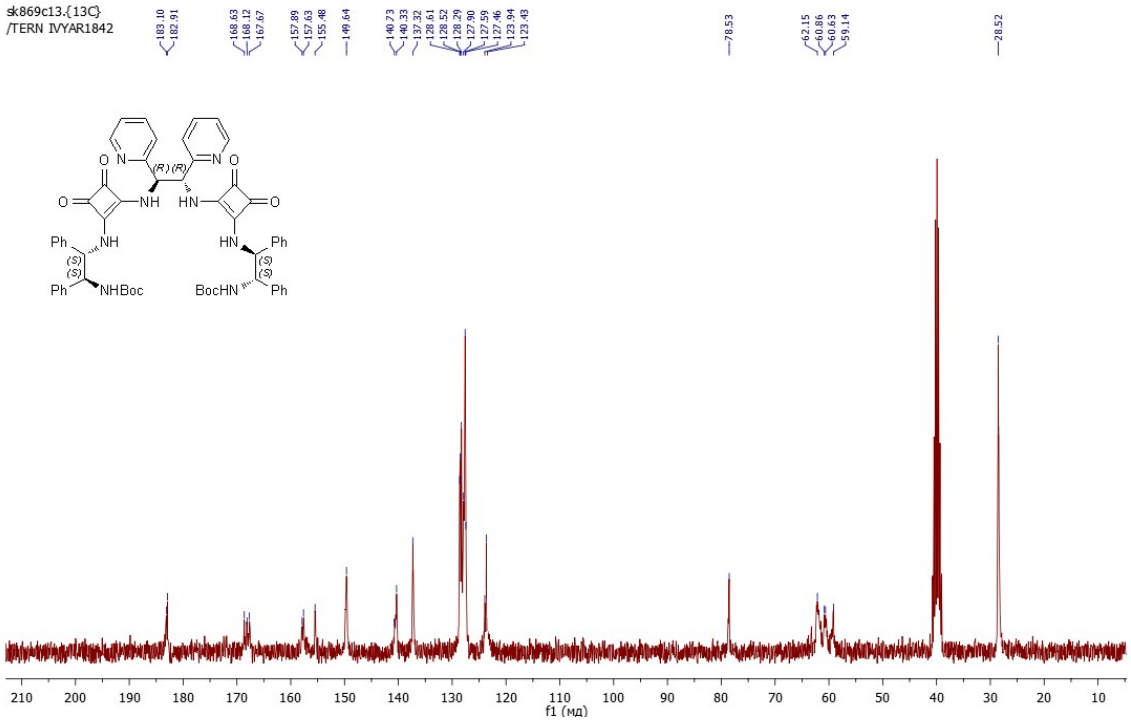
Di-*tert*-Butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*S*,2*S*)-1,2-di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (**Boc-7a**).



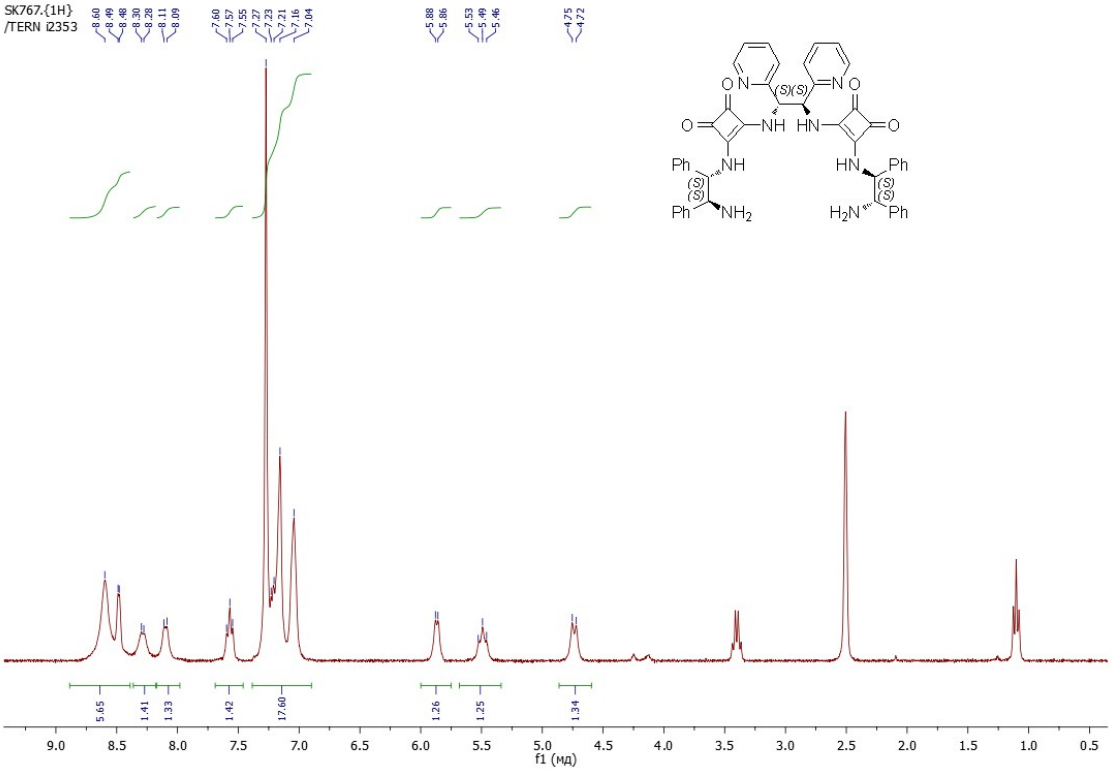


Di-*tert*-Butyl ((1*S*,1'*S*,2*S*,2'*S*)-(((((1*R*,2*R*)-1,2-di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethane-2,1-diyl))dicarbamate (Boc-7b).

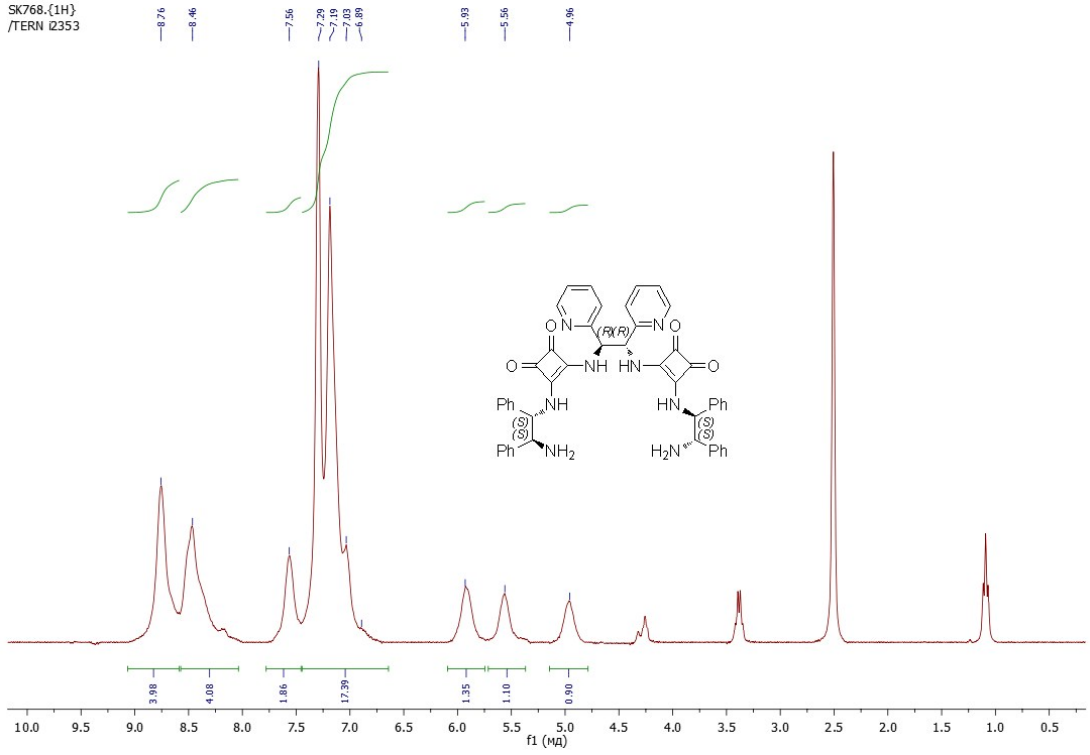




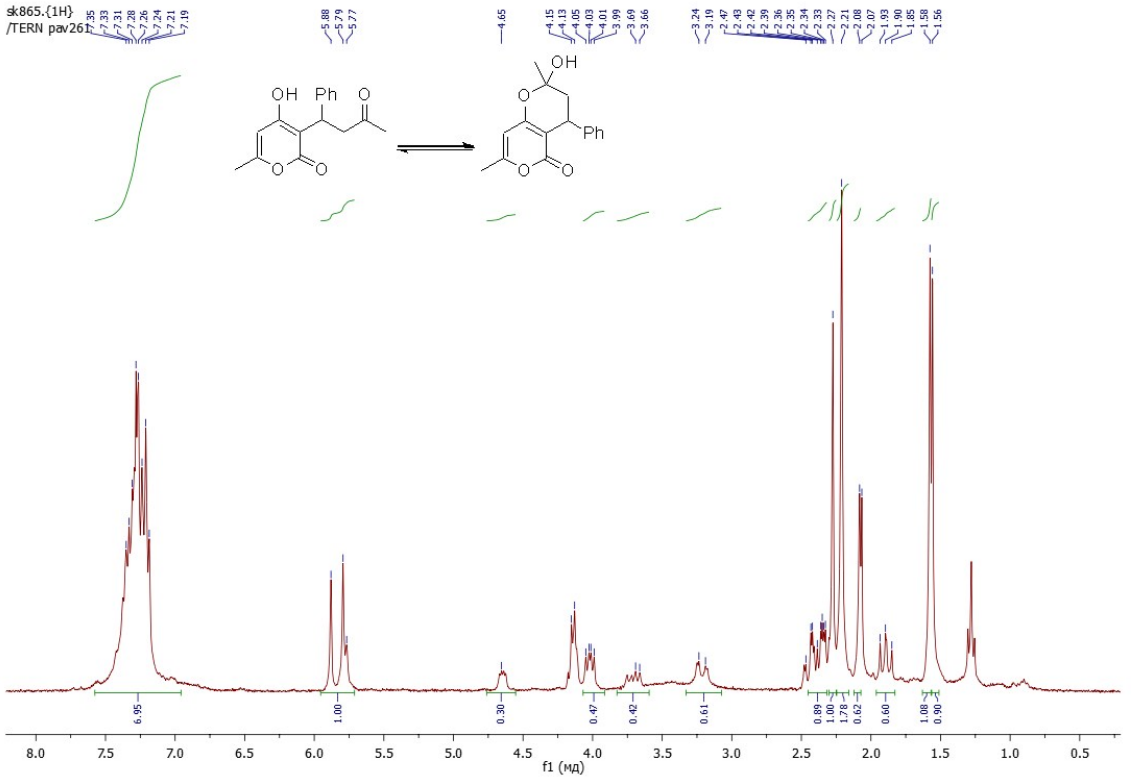
(1*S*,1'*S*,2*S*,2'*S*)-2,2'-(((((1*S*,2*S*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethanaminium) trifluoroacetate (**7a**).

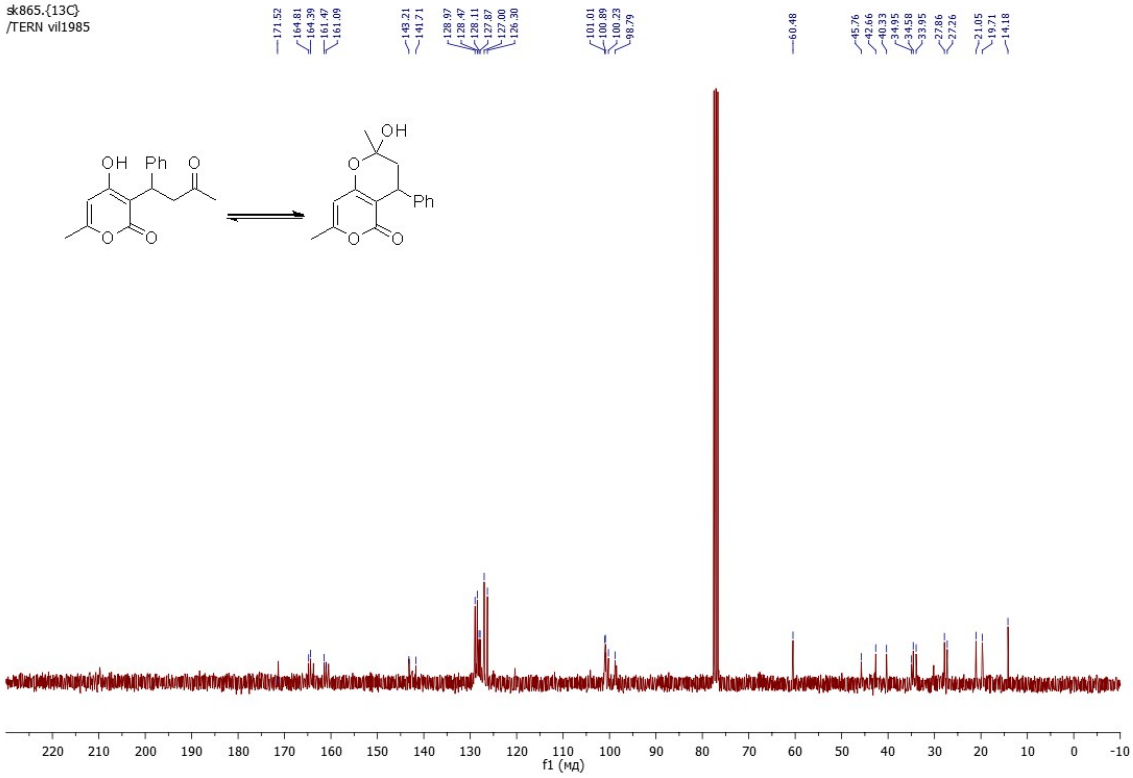


(1*S*,1'*S*,2*S*,2'*S*)-2,2'-(((((1*R*,2*R*)-1,2-Di(pyridin-2-yl)ethane-1,2-diyl)bis(azanediyl))bis(3,4-dioxocyclobut-1-ene-2,1-diyl))bis(azanediyl))bis(1,2-diphenylethanaminium) trifluoroacetate (**7b**).

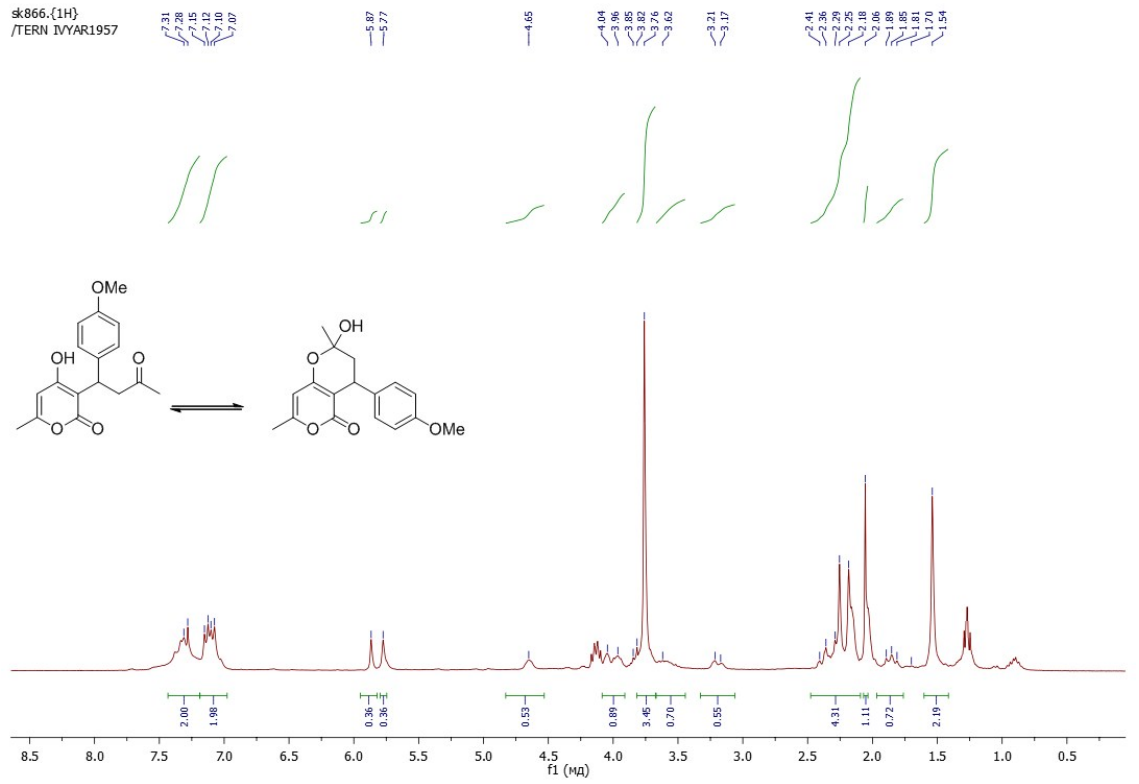


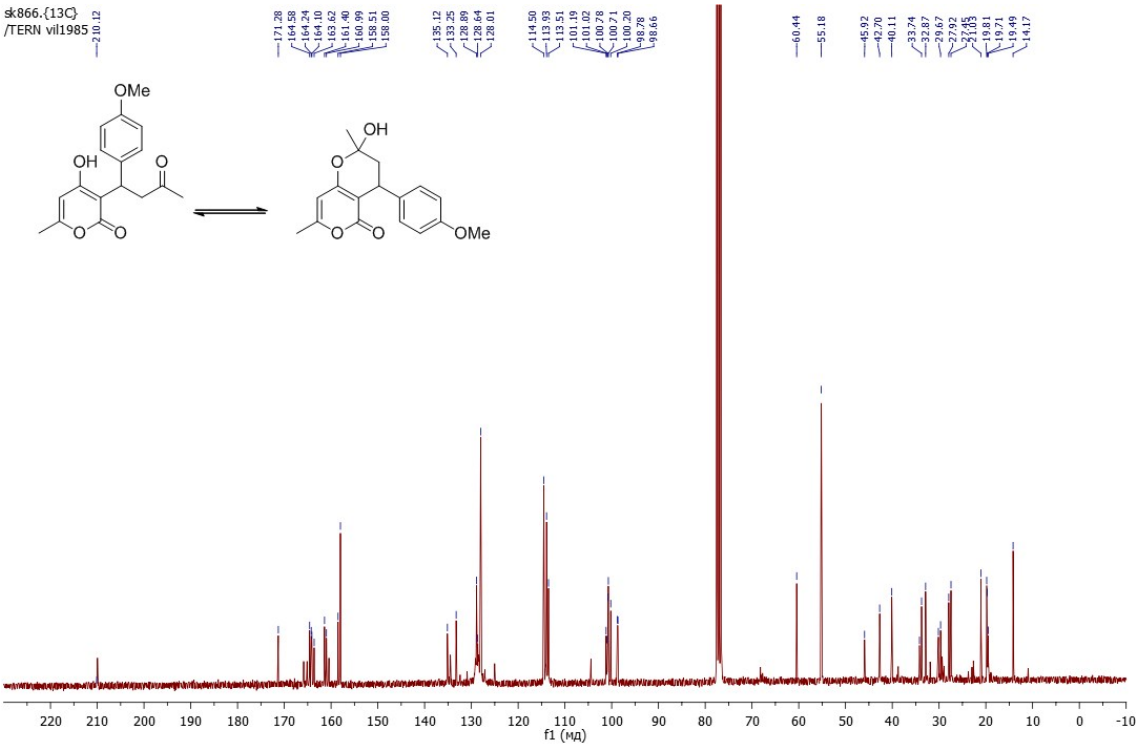
4-Hydroxy-6-methyl-3-(3-oxo-1-phenylbutyl)-2H-pyran-2-one (**11a**).



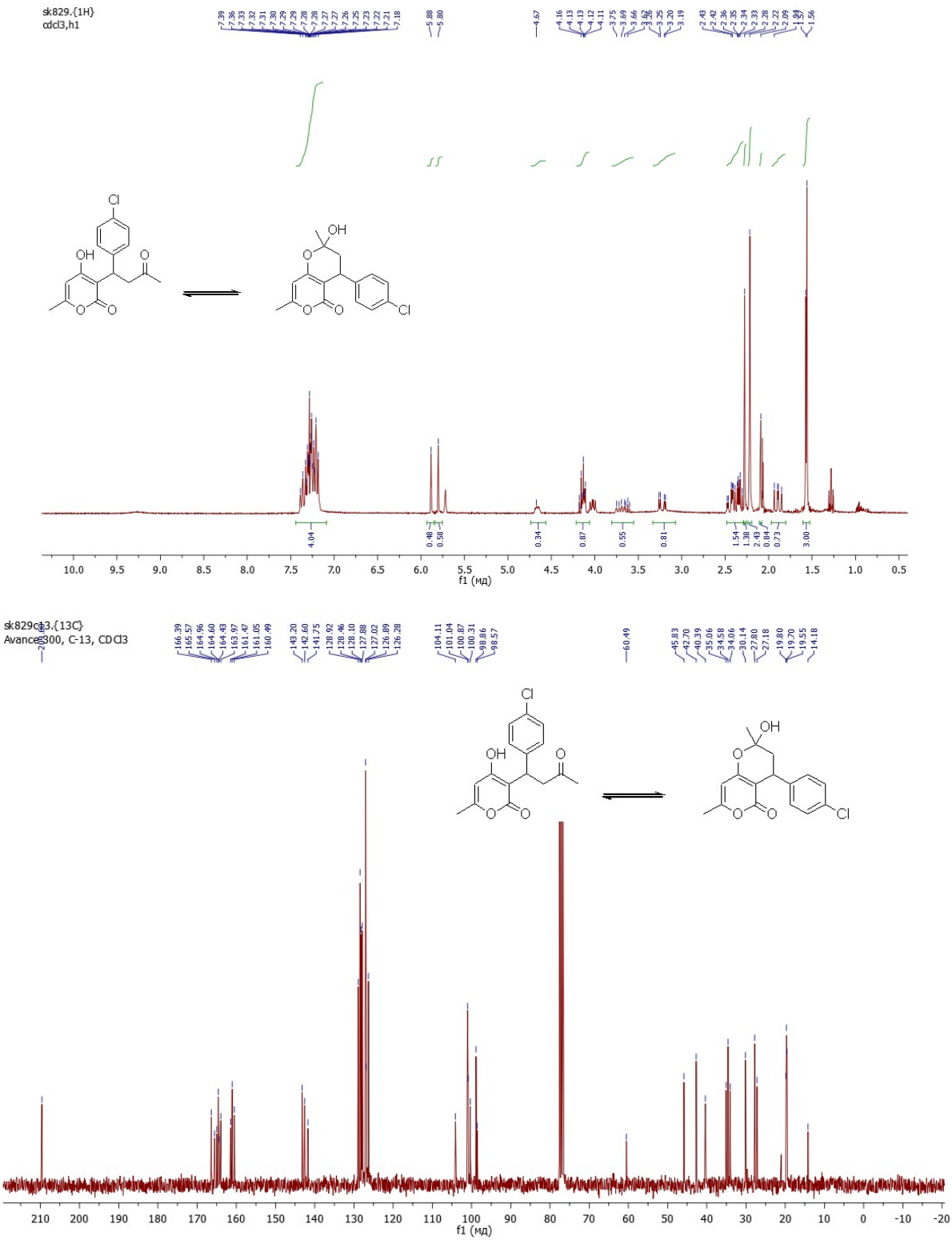


4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-6-methyl-2H-pyran-2-one (11b).

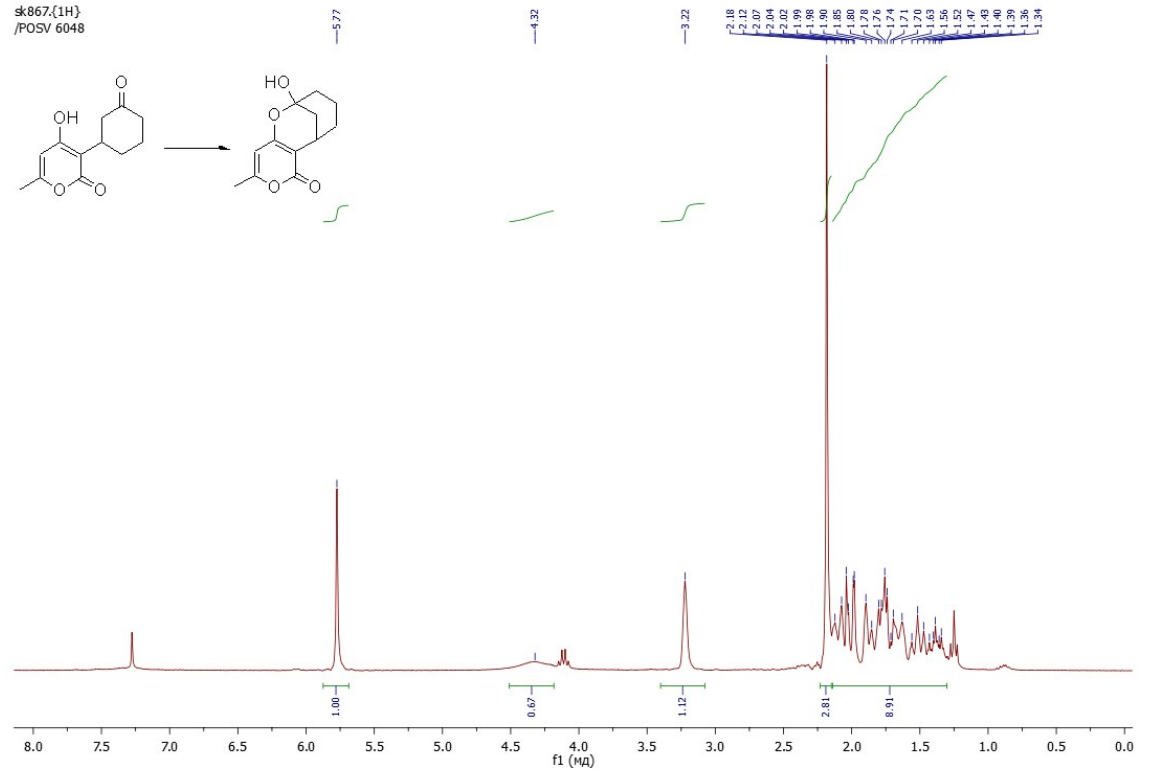


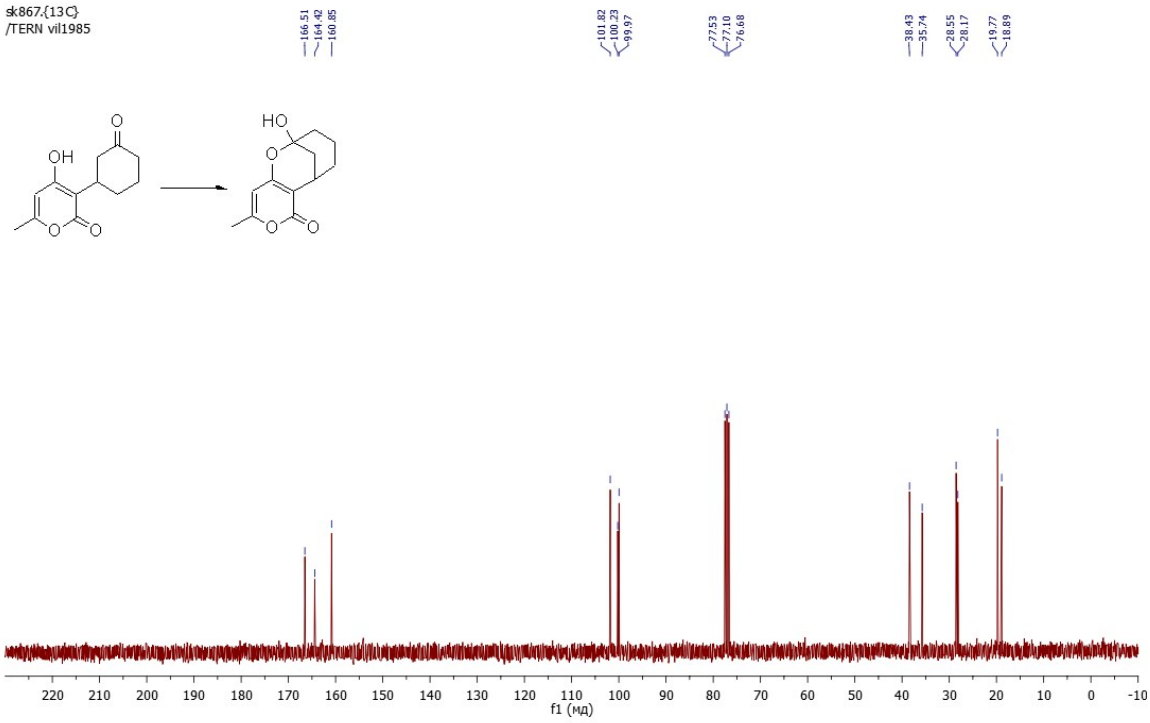


3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-6-methyl-2H-pyran-2-one (11c).

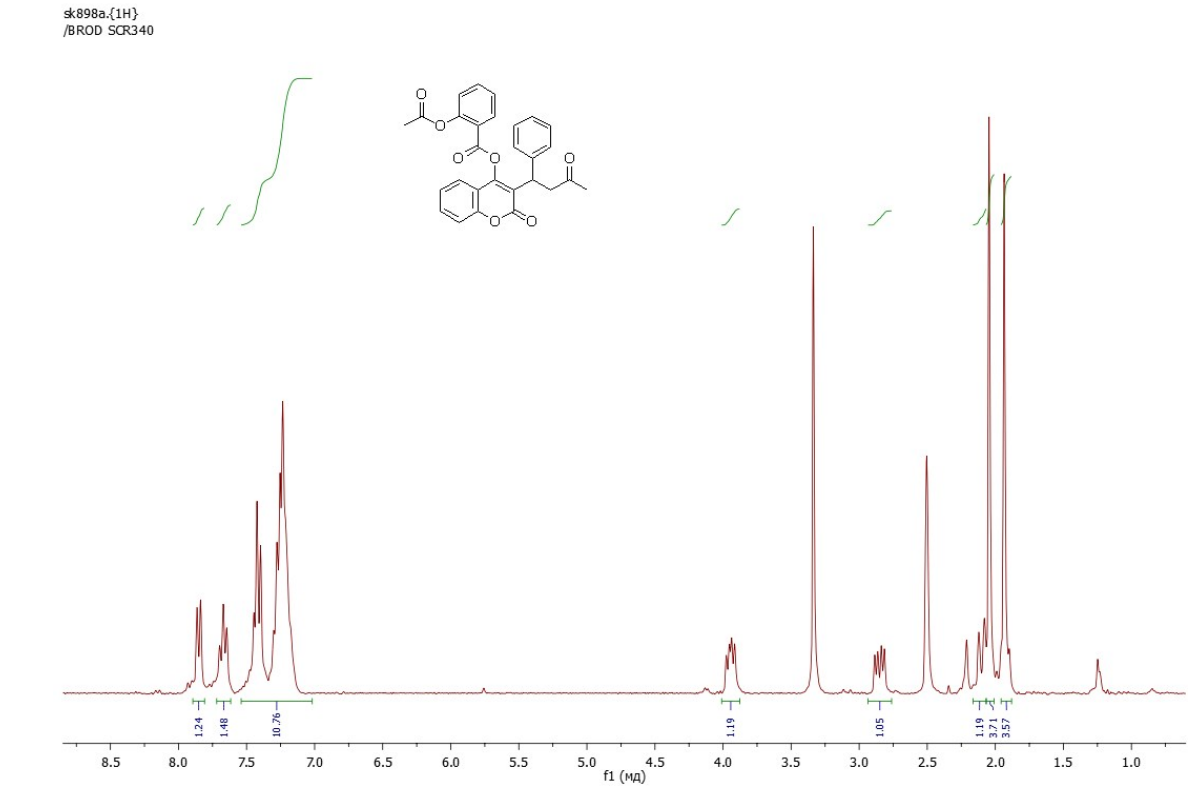


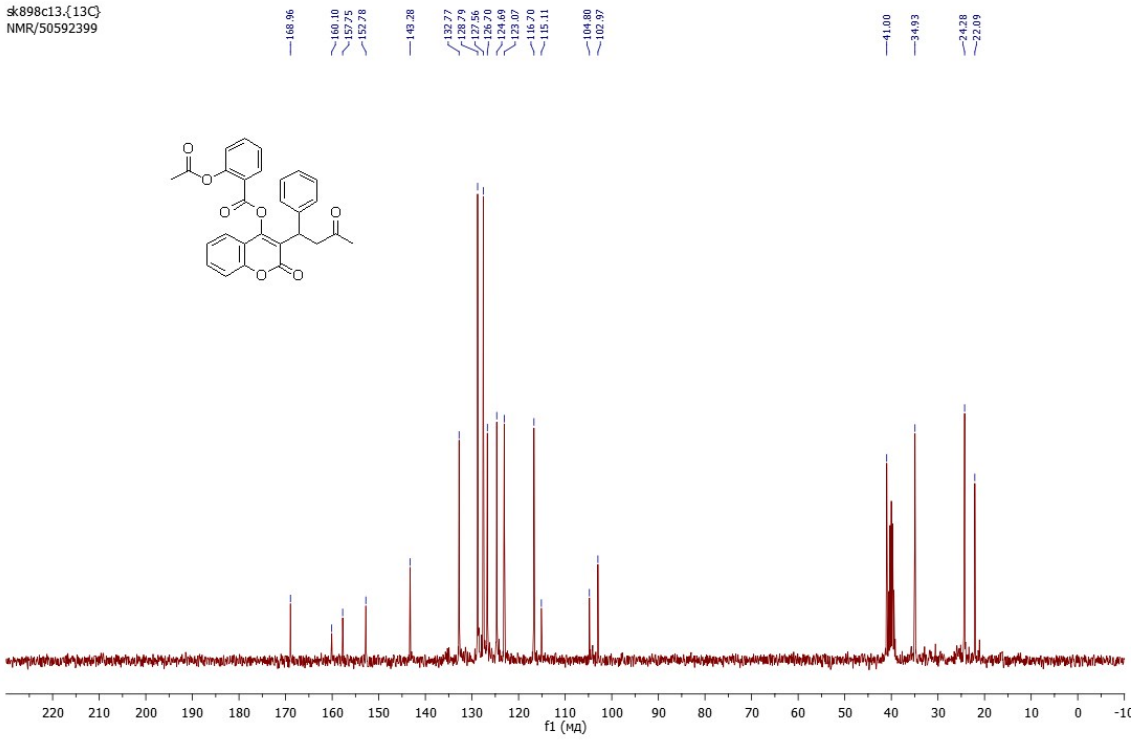
4-Hydroxy-6-methyl-3-(3-oxocyclohexyl)-2H-pyran-2-one (**11d**).



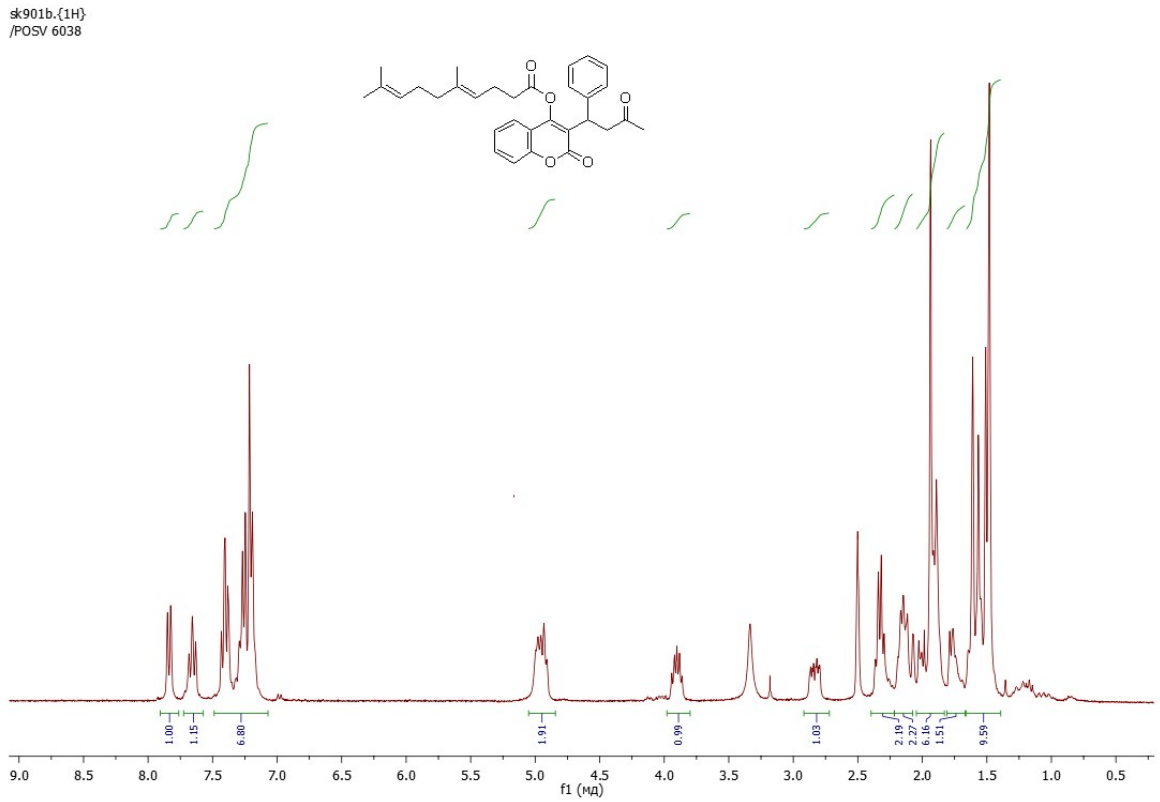


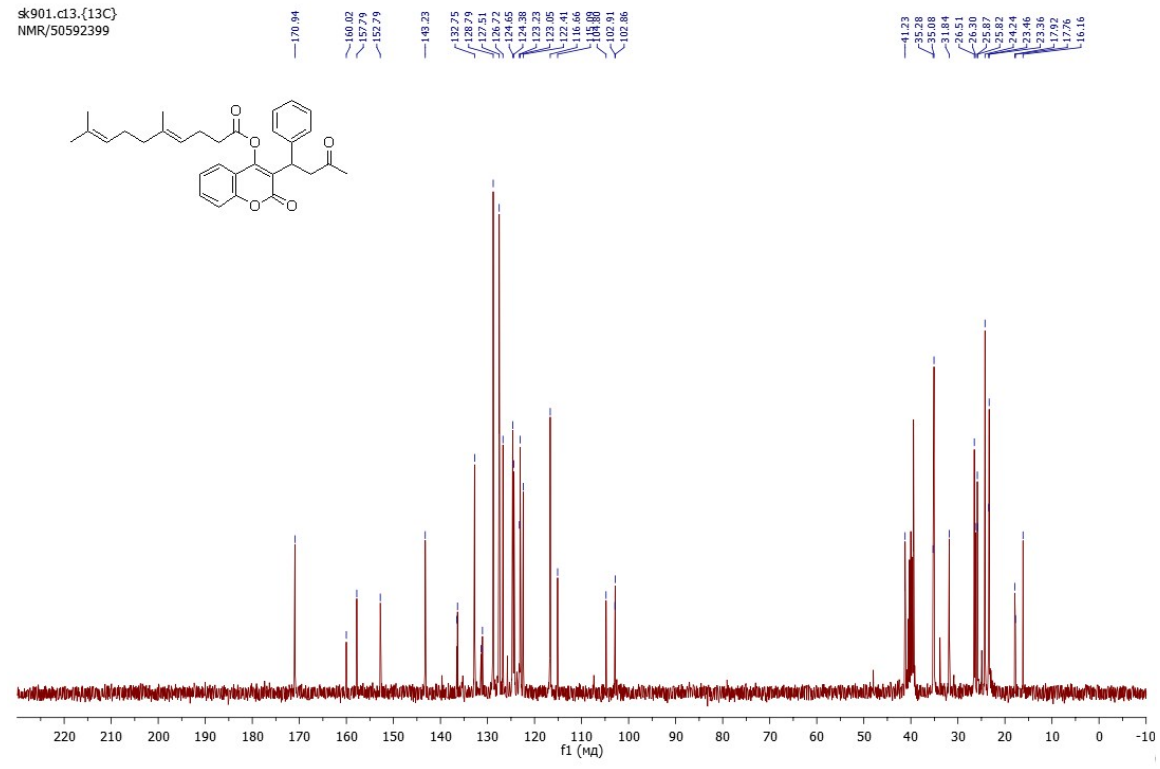
2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 2-acetoxybenzoate (13a).



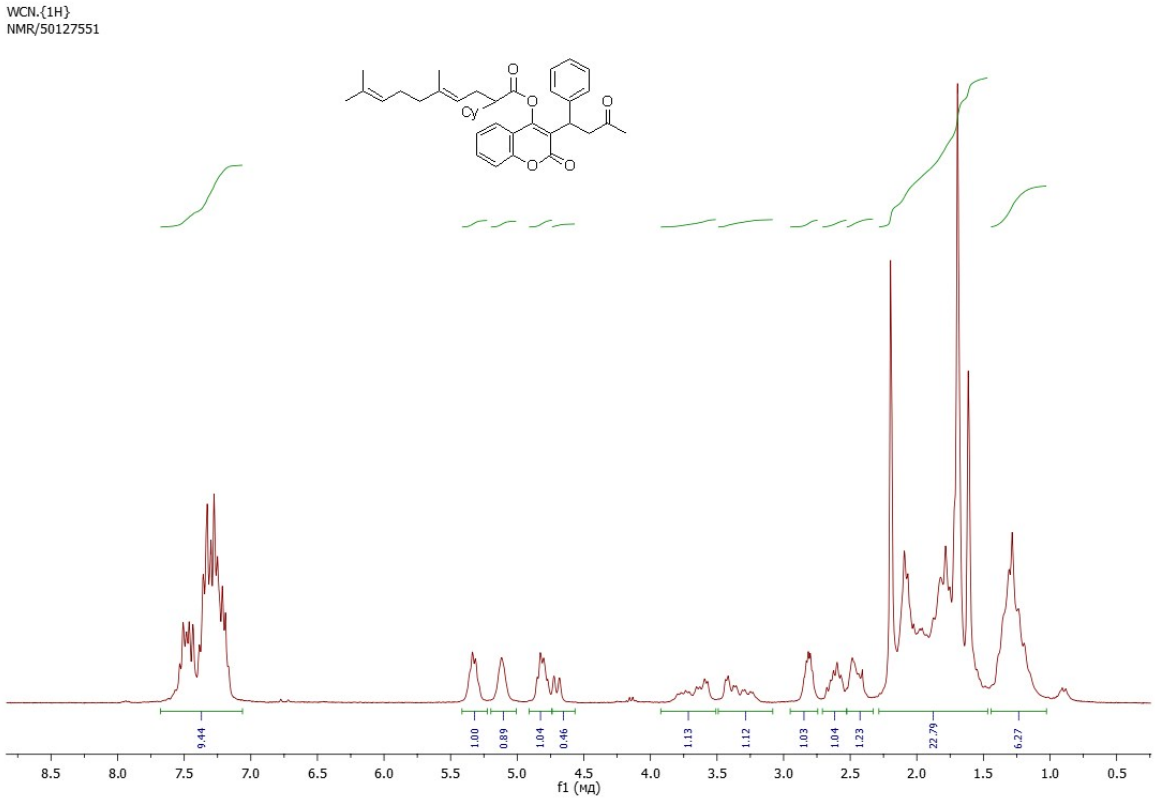


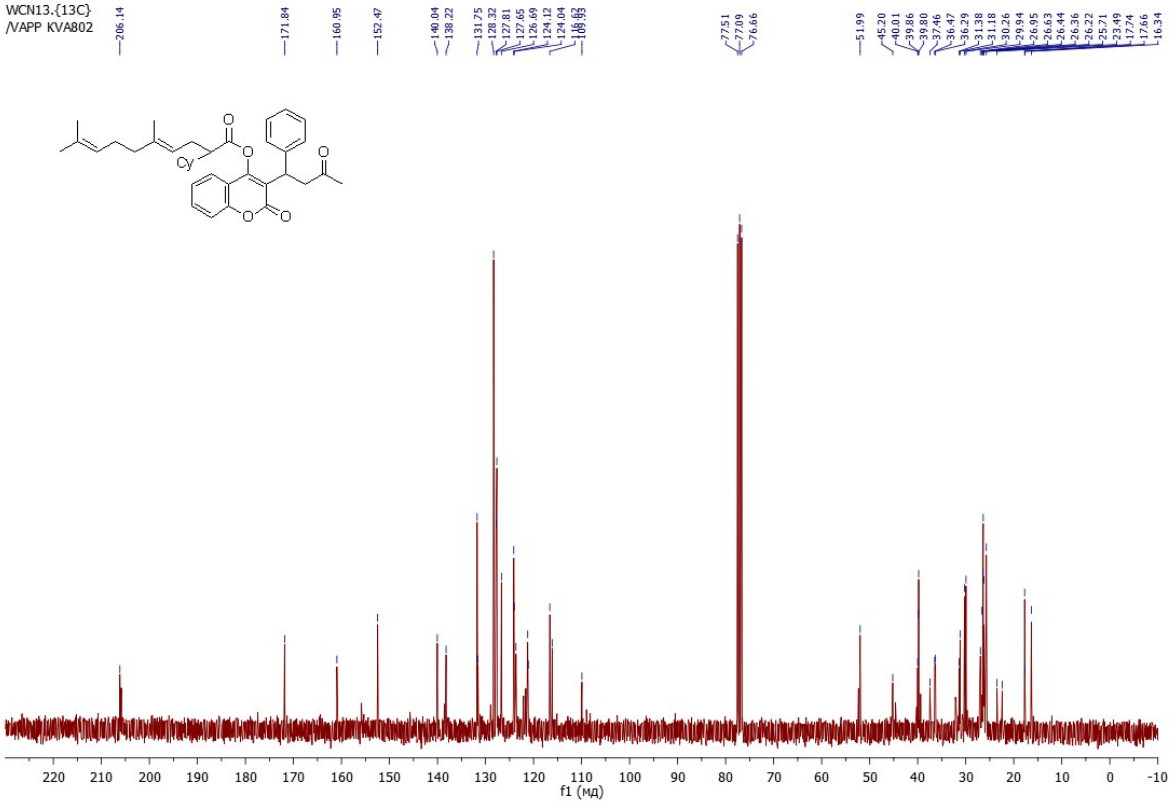
2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 5,9-dimethyldeca-4,8-dienoate (13b).





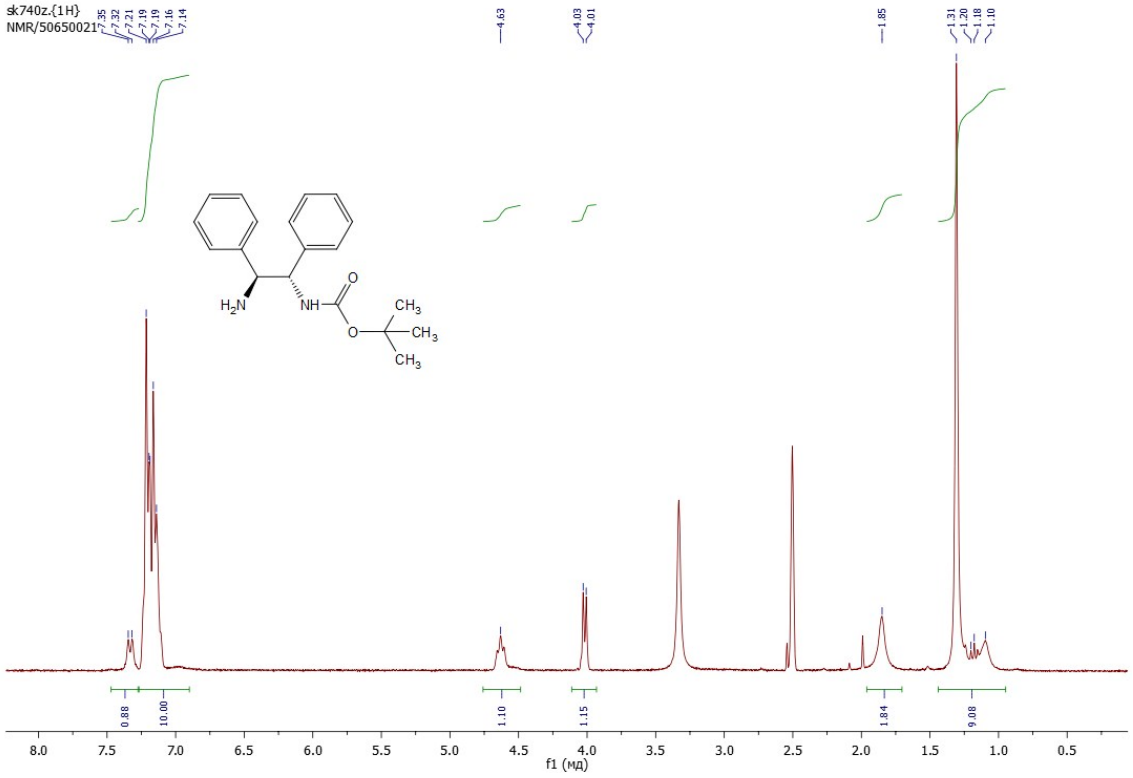
2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl 2-cyclohexyl-5,9-dimethyldeca-4,8-dienoate (13c).



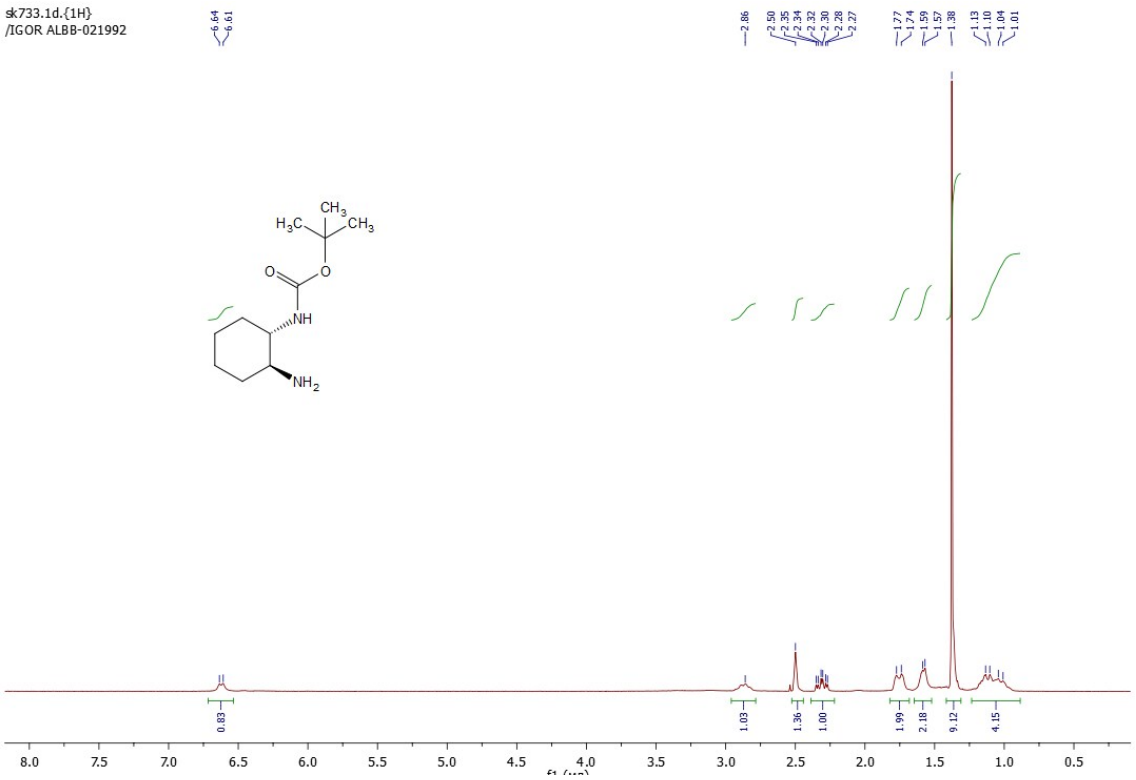


8. Pictures of ^{1}H NMR spectra for known compounds

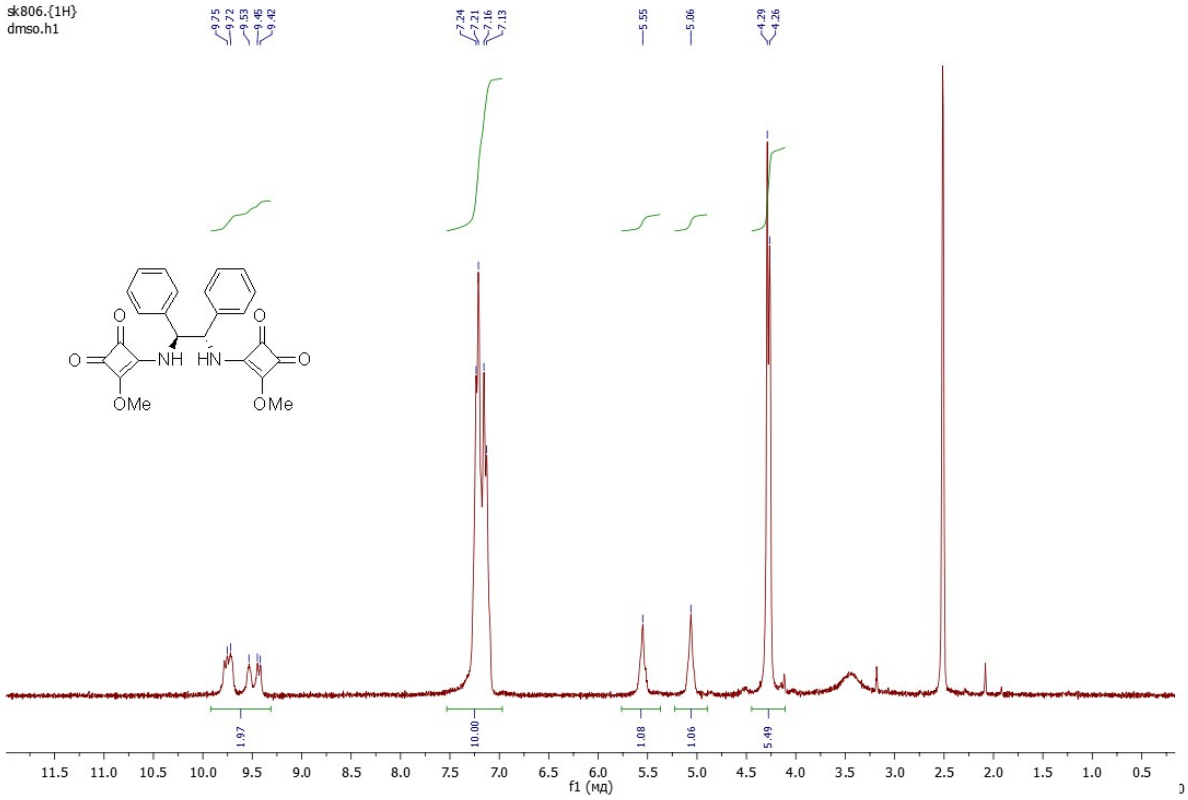
(1*S*,2*S*)-*N*-(*tert*-Butoxycarbonyl)-1,2-diphenylethylenediamine (*S*,*S*-2a).



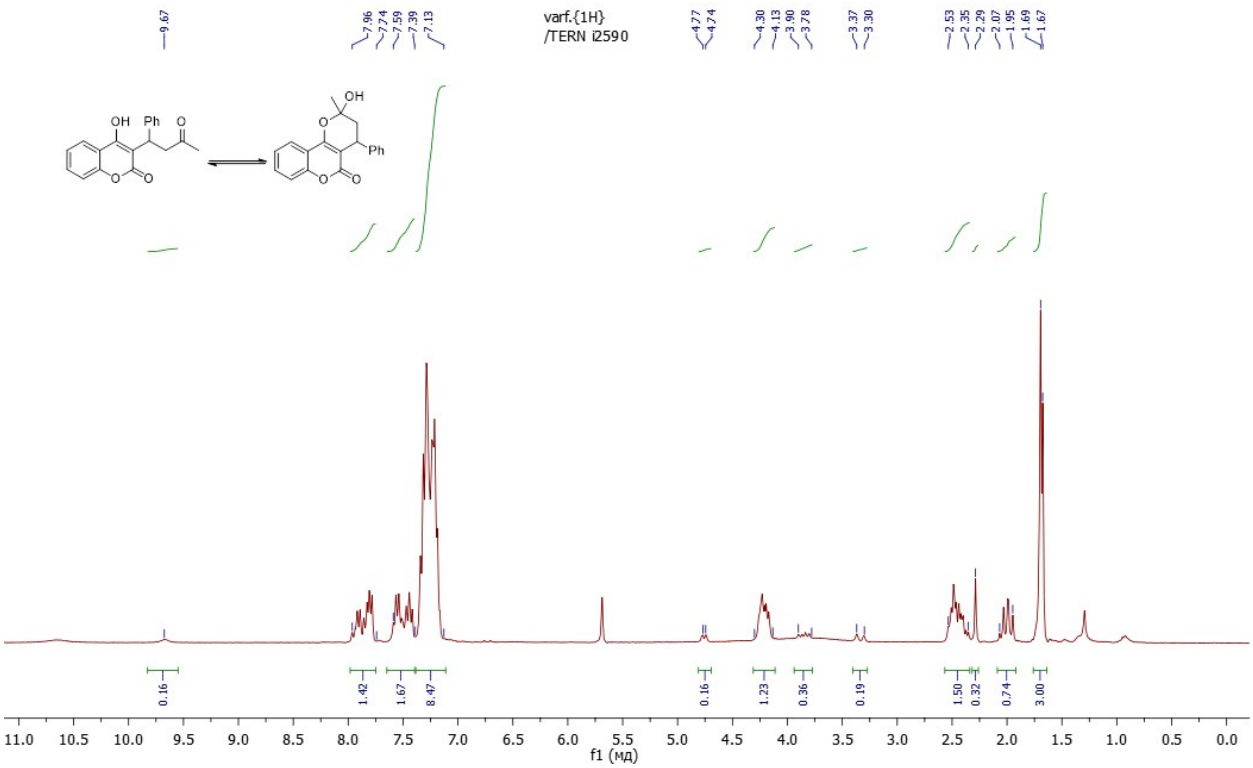
(1*S*,2*S*)-*N*-(*tert*-Butoxycarbonyl)-1,2-cyclohexanediamine (2b).



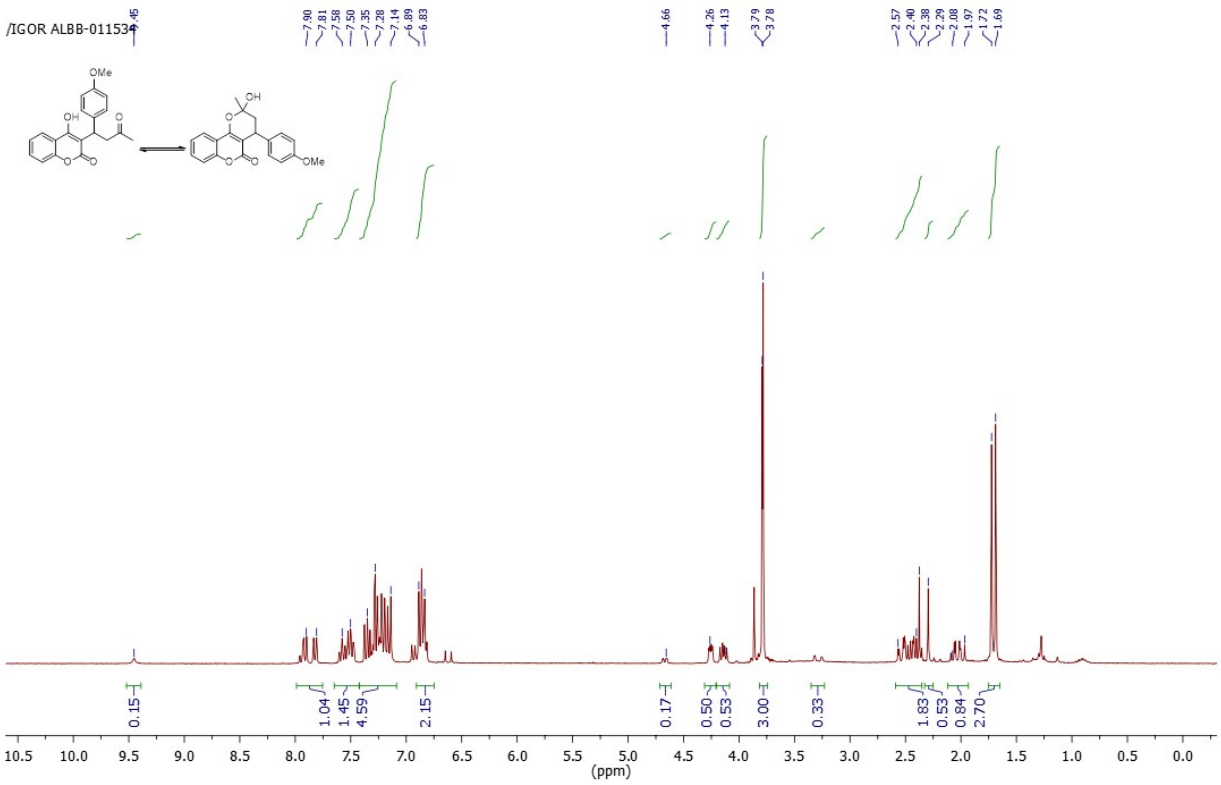
4,4'-(((1*S*,2*S*)-1,2-Diphenylethane-1,2-diyl)bis(azanediyl))bis(3-methoxycyclobut-3-ene-1,2-dione) (*S*,*S*-4).



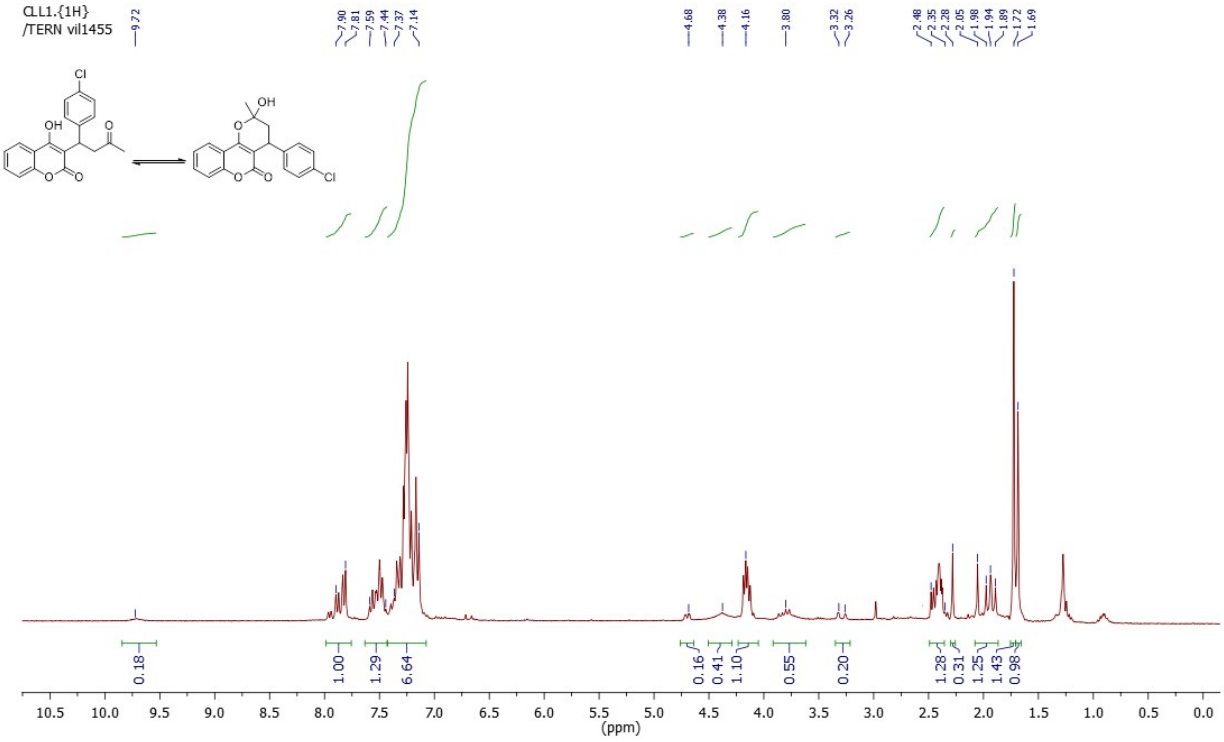
4-Hydroxy-3-(3-oxo-1-phenylbutyl)-2H-chromen-2-one (Warfarin) (10a).



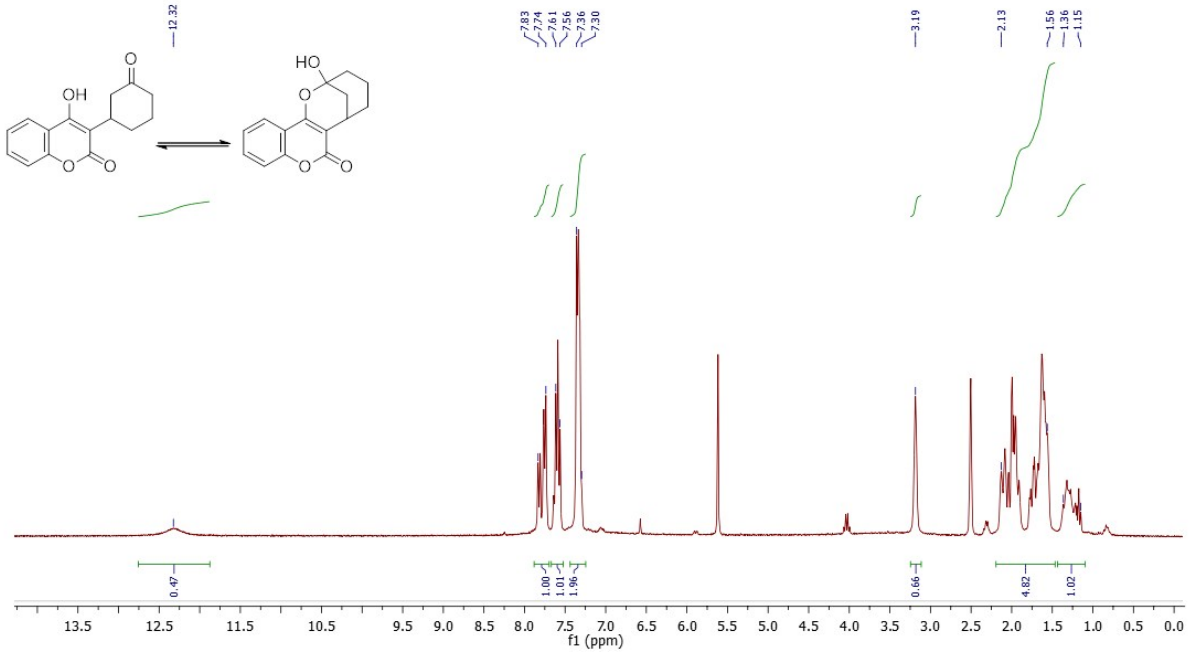
4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-2H-chromen-2-one (10b).



3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-2H-chromen-2-one (Coumachlor) (10c).



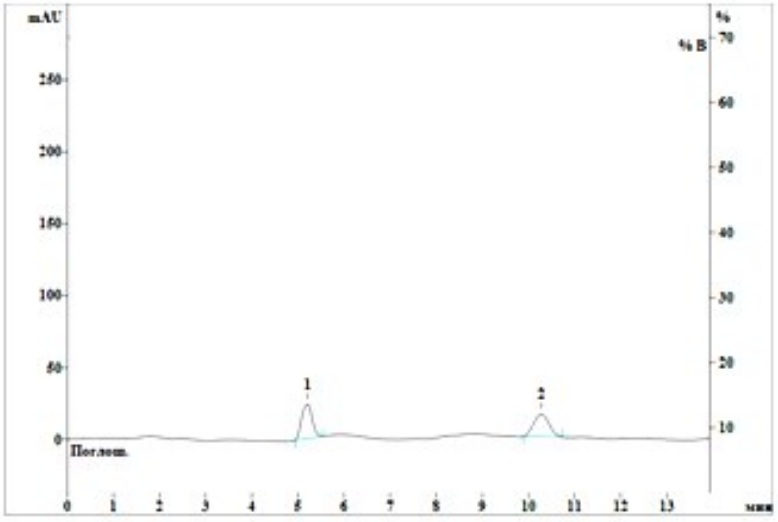
4-Hydroxy-3-(3-oxocyclohexyl)-2H-chromen-2-one (**10d**).



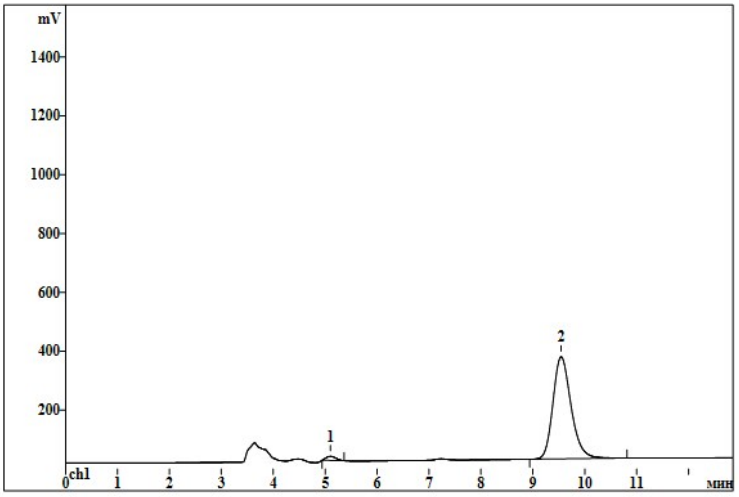
9. HPLC data

4-Hydroxy-3-(3-oxo-1-phenylbutyl)-2H-chromen-2-one (Warfarin) (**10a**).

HPLC (Daicel Chiralcel AD-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 5.2 min., t_2 = 10.3 min.



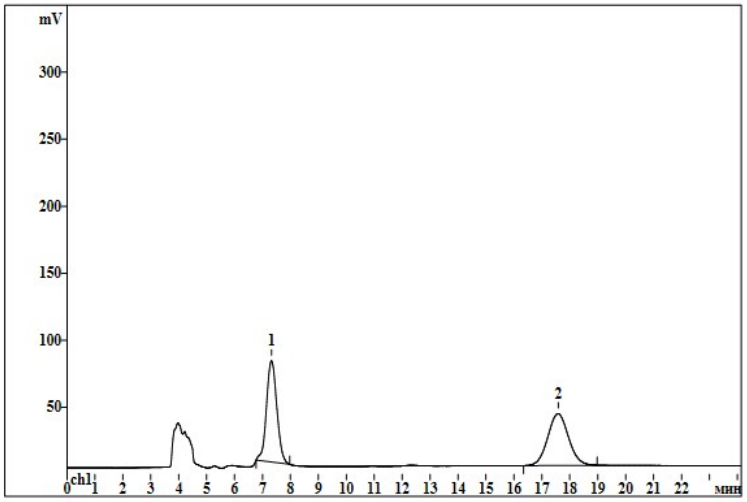
Пик	Время мин	Площадь mAU*сек	Площадь %
1	5.203	375.46	50.75
2	10.28	364.41	49.25
2	13.93	739.87	100.00



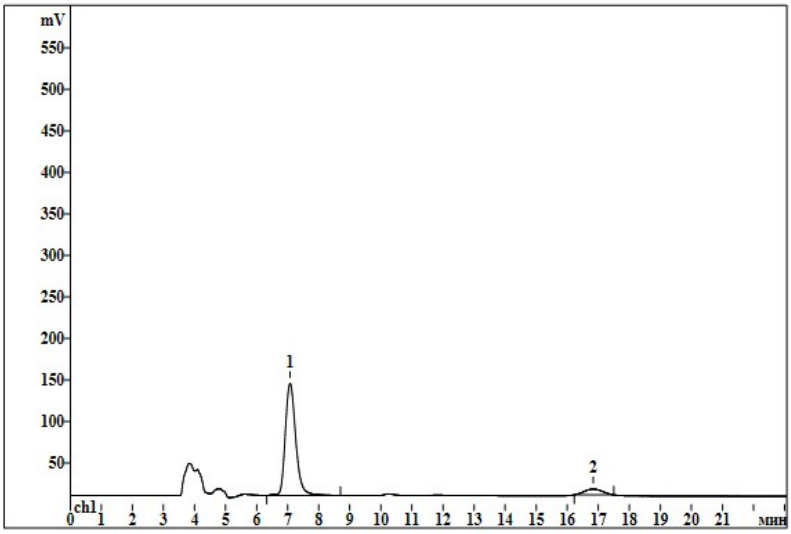
No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	5.107	0.224	13.76	3.81	184.28	2.14
2	9.545	0.366	346.91	96.19	8420.91	97.86
2	12.86	0.295	360.66	100.00	8605.20	100.00

4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-2H-chromen-2-one (**10b**).

HPLC (Daicel Chiralcel AD-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 7.07 min., t_2 = 18.84 min.



No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	7.318	0.398	75.45	66.18	1943.64	49.38
2	17.58	0.797	38.56	33.82	1992.15	50.62
2	24.14	0.598	114.01	100.00	3935.79	100.00

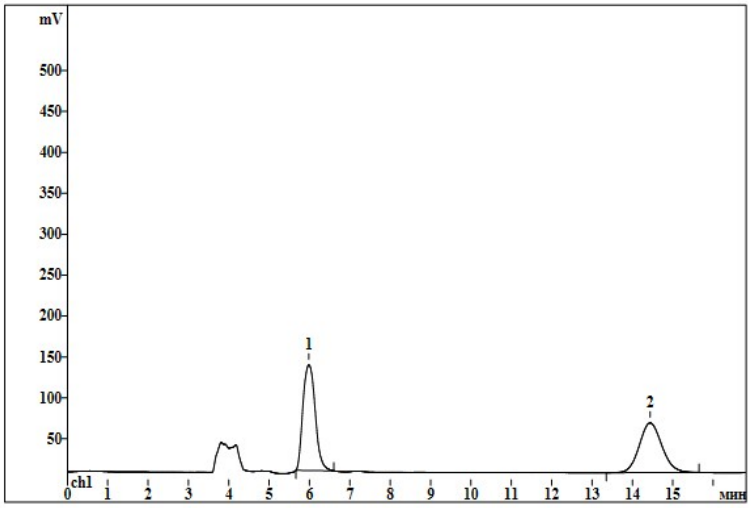


RESULTS
Quantitation method: Заказной
Standard component: Нет

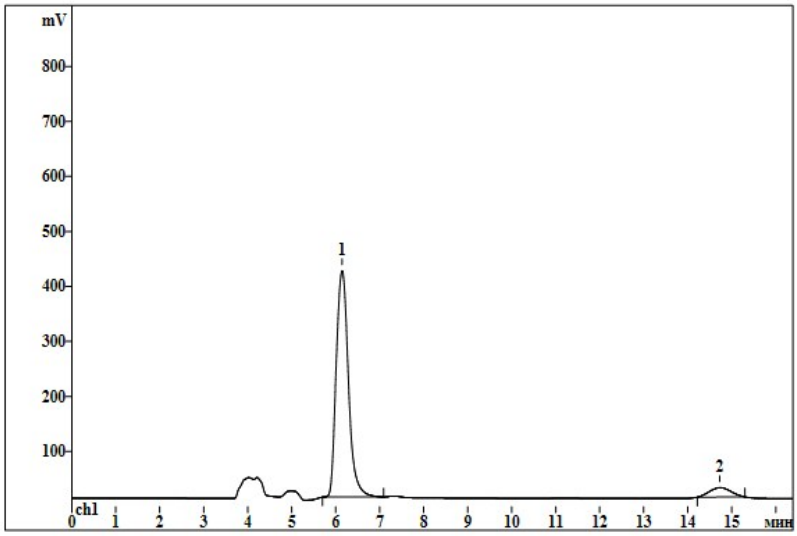
No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	7.074	0.351	134.84	95.06	3150.07	91.73
2	16.84	0.667	7.01	4.94	283.95	8.27
2	23.07	0.509	141.84	100.00	3434.01	100.00

3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-2H-chromen-2-one (Coumachlor) (**10c**).

HPLC (Daicel Chiralcel OD-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 6.14 min., t_2 = 14.74 min.



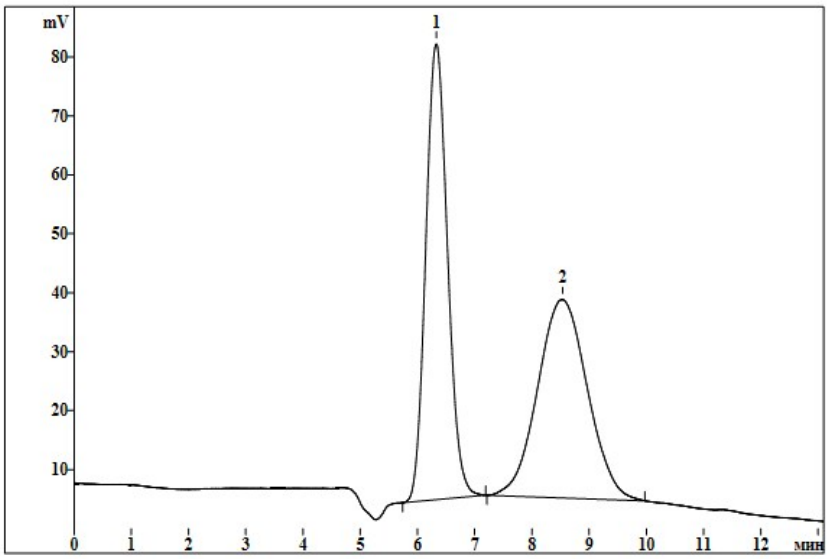
No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	5.98	0.340	128.83	67.97	2733.95	53.63
2	14.44	0.598	60.70	32.03	2363.75	46.37
2	16.82	0.469	189.53	100.00	5097.70	100.00



No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	6.144	0.297	411.50	96.03	7945.75	93.22
2	14.74	0.558	17.02	3.97	577.50	6.78
2	16.39	0.427	428.52	100.00	8523.25	100.00

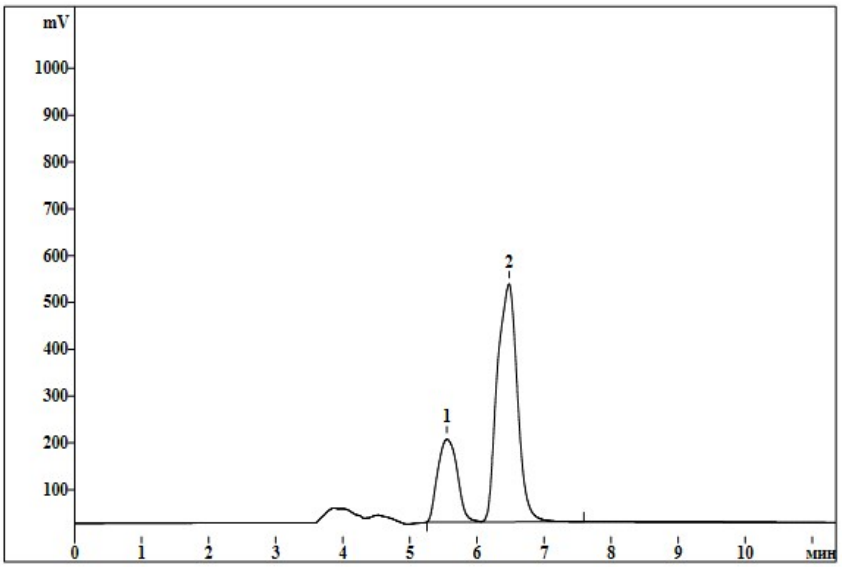
4-Hydroxy-3-(3-oxocyclohexyl)-2H-chromen-2-one (**10d**).

HPLC (Daicel Chiralcel OJ-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 220 nm): t_1 = 5.55 min., t_2 = 6.48 min.



RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	6.328	0.412	77.28	69.68	2037.76	50.09
2	8.53	0.942	33.63	30.32	2030.56	49.91
2	13.1	0.677	110.90	100.00	4068.32	100.00

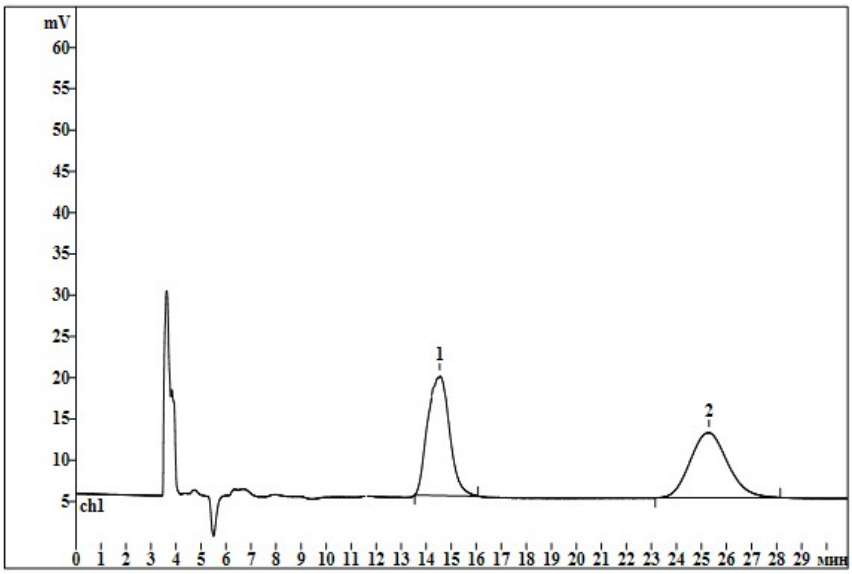


RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	5.552	0.336	176.88	25.84	3594.86	25.39
2	6.476	0.339	507.64	74.16	10565.40	74.61
2	11.36	0.338	684.53	100.00	14160.26	100.00

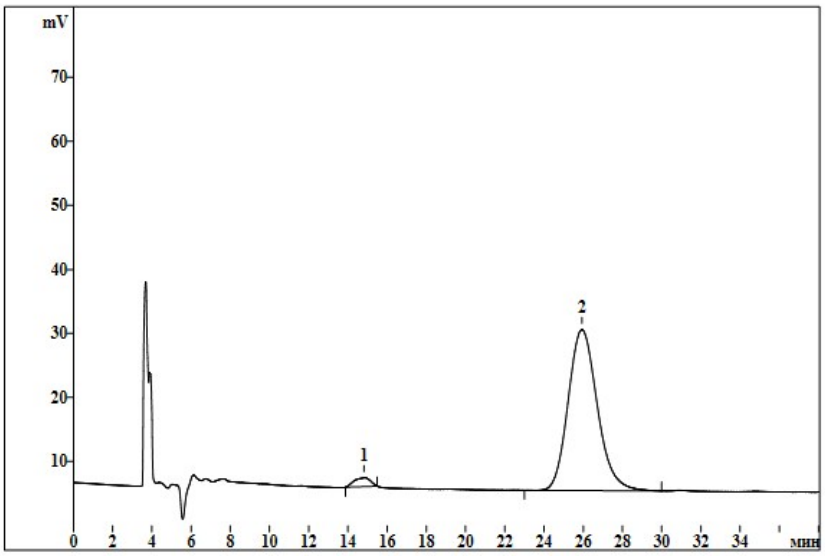
4-Hydroxy-6-methyl-3-(3-oxo-1-phenylbutyl)-2H-pyran-2-one (11a).

HPLC (Daicel Chiralcel AD-H; *n*-hexane/2-propanol, 90:10; flow rate = 0.8 mL/min; λ = 220 nm): t_1 = 14.8 min., t_2 = 25.9 min.



RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	14.55	1.152	14.58	64.91	1010.23	55.13
2	25.3	1.616	7.88	35.09	822.22	44.87
2	30.85	1.384	22.46	100.00	1832.46	100.00

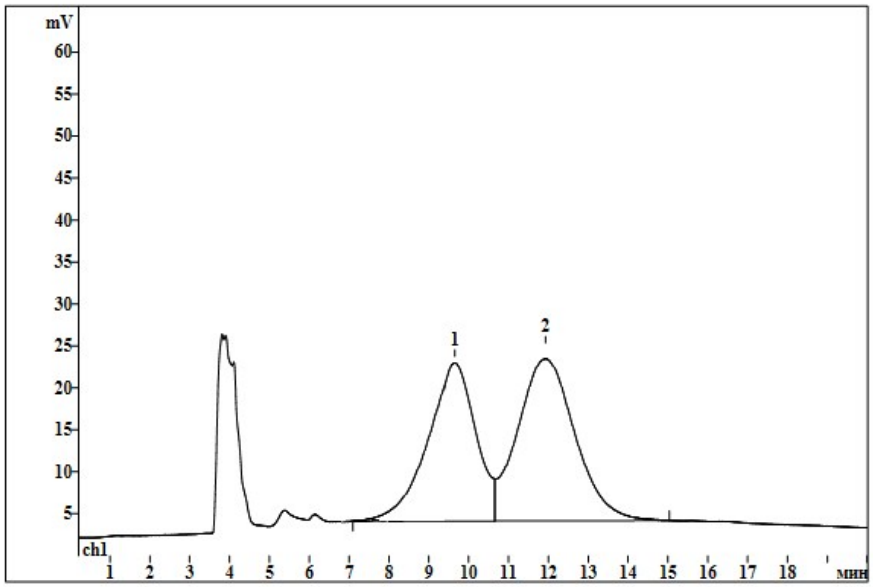


RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	14.81	1.004	1.34	5.07	78.61	2.94
2	25.93	1.582	25.12	94.93	2596.03	97.06
2	38.06	1.293	26.46	100.00	2674.64	100.00

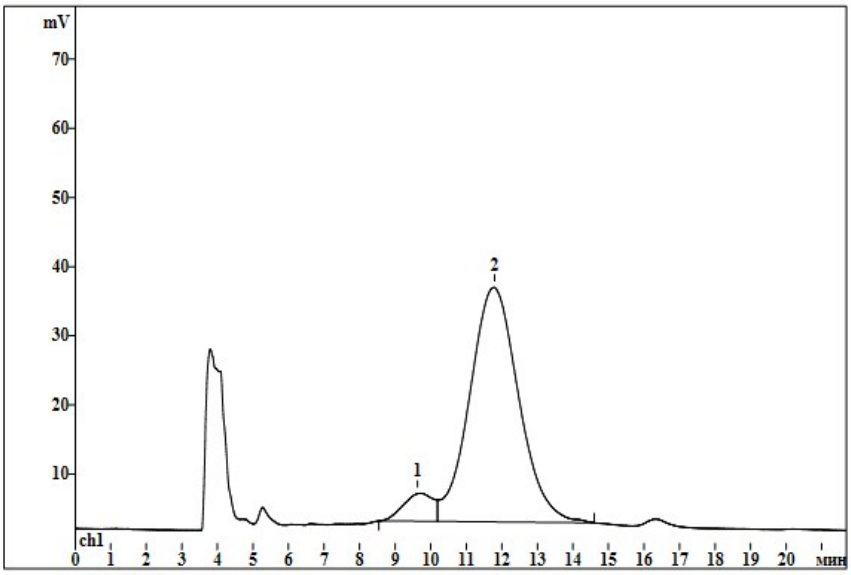
4-Hydroxy-3-(1-(4-methoxyphenyl)-3-oxobutyl)-6-methyl-2H-pyran-2-one (11b).

HPLC (Daicel Chiralpak AS-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 9.63 min., t_2 = 11.78 min.



RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	9.656	1.096	18.83	48.01	1300.82	48.98
2	11.93	1.525	20.39	51.99	2010.24	51.02
2	28.41	1.310	39.23	100.00	3311.06	100.00

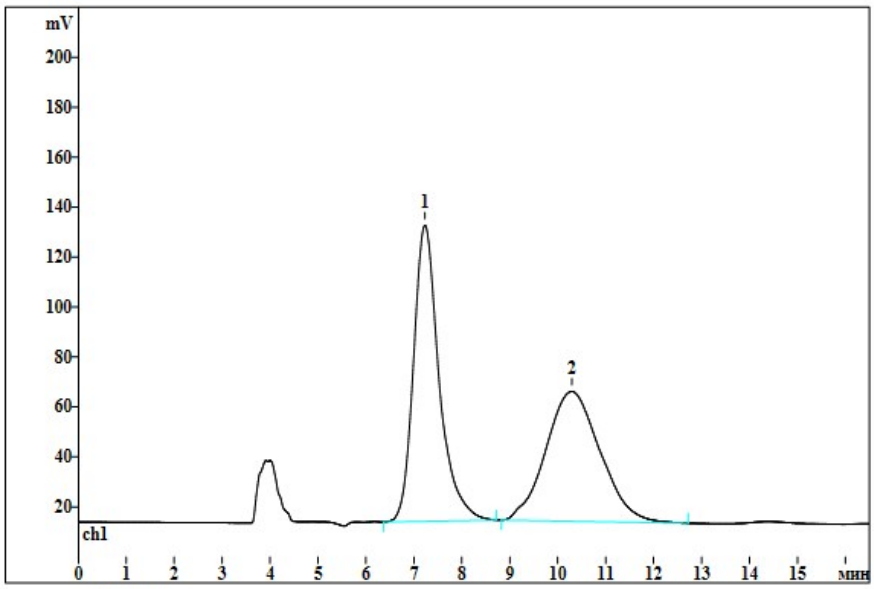


RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	9.631	1.028	3.99	10.53	236.91	6.79
2	11.78	1.460	33.92	89.47	3251.07	93.21
2	21.7	1.244	37.91	100.00	3487.98	100.00

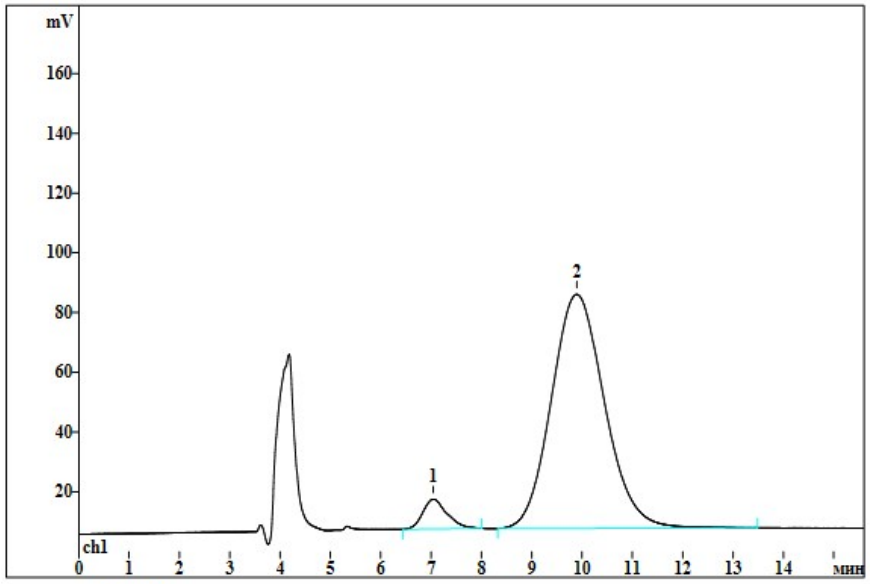
3-(1-(4-Chlorophenyl)-3-oxobutyl)-4-hydroxy-6-methyl-2H-pyran-2-one (**11c**).

HPLC (Daicel Chiralpak AS-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 7.22 min., t_2 = 10.29 min.



RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	7.227	0.536	118.52	69.52	4388.19	51.80
2	10.29	1.218	51.97	30.48	4083.77	48.20
2	29.98	0.877	170.49	100.00	8471.96	100.00

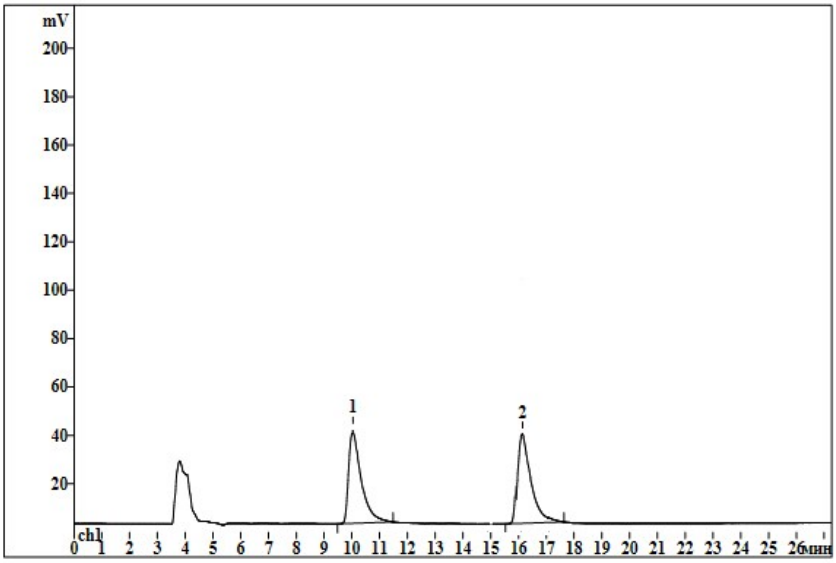


RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	7.045	0.510	9.91	11.23	332.04	5.45
2	9.894	1.130	78.30	88.77	5755.34	94.55
2	15.61	0.820	88.21	100.00	6087.38	100.00

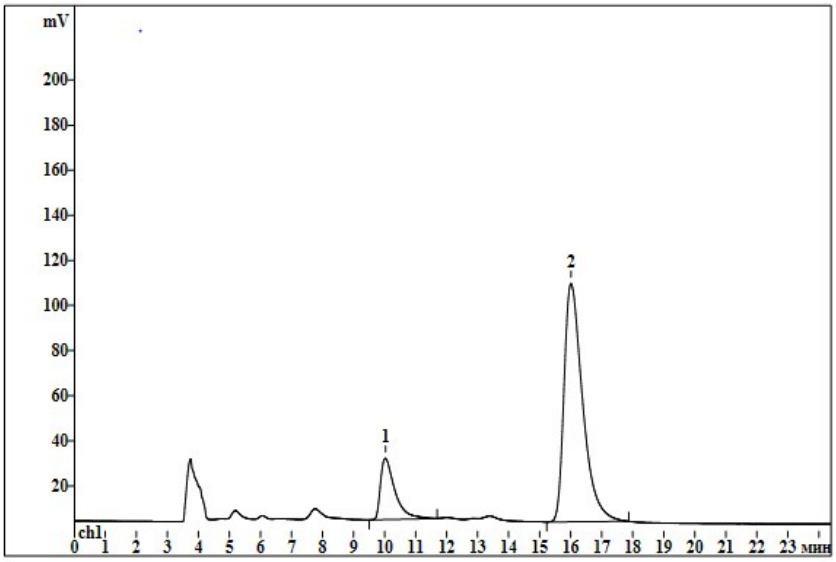
4-Hydroxy-6-methyl-3-(3-oxocyclohexyl)-2H-pyran-2-one (**11d**).

HPLC (Daicel Chiralpak AS-H; *n*-hexane/2-propanol, 70:30; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 10.03 min., t_2 = 16.14 min.



RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	10.03	0.470	37.47	42.14	1211.94	49.95
2	16.14	0.407	36.45	57.86	1214.16	50.05
2	27.28	0.438	73.92	100.00	2426.10	100.00

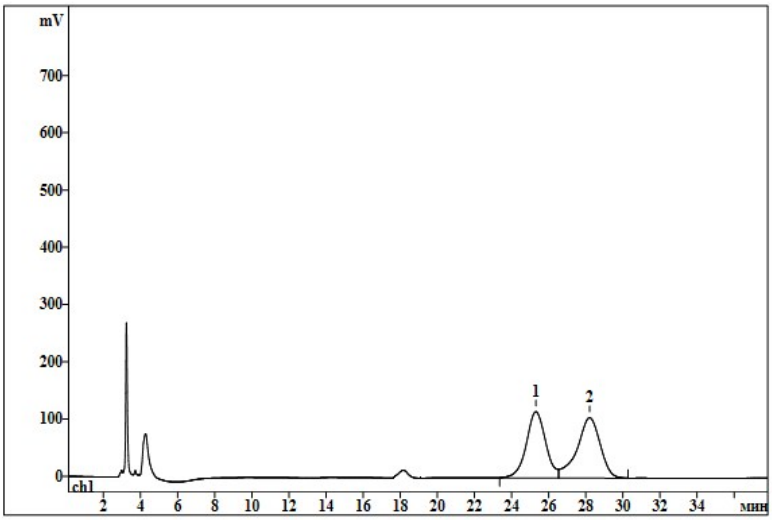


RESULTS
Quantitation method: Заказной
Standard component: Нет

No	Retention мин	Width/2 мин	Height mV	Height %	Area mV*сек	Area %
1	10.02	0.468	27.10	20.41	878.84	16.63
2	16.01	0.624	105.65	79.59	4405.09	83.37
2	24.4	0.546	132.74	100.00	5283.93	100.00

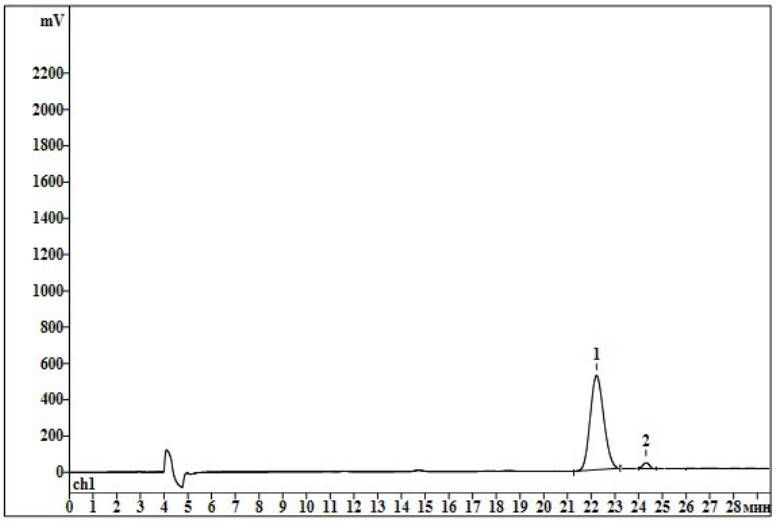
2-Oxo-3-(3-oxo-1-phenylbutyl)-2H-chromen-4-yl -2-acetoxybenzoate (13a).

HPLC (Daicel Chiralpak AS-H; *n*-hexane/2-propanol, 99:1; flow rate = 0.8 mL/min; λ = 254 nm): t_1 = 22.22 min., t_2 = 24.19 min.



RESULTS
Quantitation method: Нормировка отклика
Standard component: Нет

No	Retention мин	Area mV*сек	Area %	Name
1	25.31	8348.33	47.72	
2	28.21	9147.07	52.28	
2	41.74	17495.40	100.00	



RESULTS
Quantitation method: Нормировка отклика
Standard component: Нет

No	Retention мин	Area mV*сек	Area %	Name
1	22.22	20602.28	97.88	
2	24.19	445.48	2.12	
2	29.57	21047.75	100.00	

10. References

1. J. Flores-Ferrándiz, B. Fiser, E. Gómez-Bengoa, R. Chinchilla, *Eur. J. Org. Chem.,* 2015, 1218.

2. T. Takeda, M. Terada, *J. Am. Chem. Soc.*, 2013, **135**, 41, 15306.

3. N. Halland, T. Hansen, K. A. Jorgensen, *Angew. Chem. Int. Ed.,* 2003, **42**, 4955.

4. J. W. Xie, L. Yue, W. Chen, W. Du, J, Zhu, J. G. Deng, Y. C. Chen, *Org. Lett.*, 2007, **9**, 3, 413.

5. K. Rehse, W. Schinkel, *Arch. Pharm.,* 1983, **316**, 12, 988.

6. X. Zhu, A. Lin, Y. Shi, J. Guo, Ch. Zhu, Y. Cheng, *Org. Lett*., 2011, **13**, 16, 4382.