Supporting Information

1. Critical Assessment of the Efficiency of Chitosan Biohydrogel Beads as Recyclable and Heterogeneous Organocatalyst for C-C Bond Formation

Table of Contents

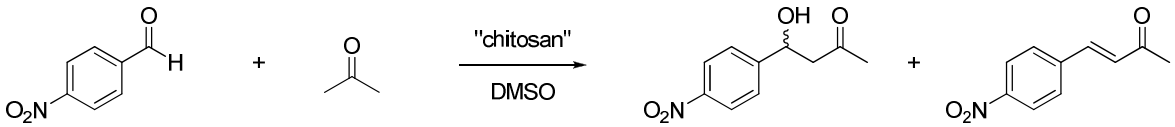
1. Additional tables

Table S1. Representative set of various CSHB batches submitted to different number of washings.

Entry	Batch number	Water used in each washing (mL)	Number of washings	pH[a]
1	1	250	12	7.34
2	1	250	18	6.57
3	2	250	12	7.62
4	2	250	15	7.00
5	2	250	21	6.61
6	3	250	< 20	7.87
7	3	250	20	7.32
8	3	250	28	6.87

[a] Slight variations in the pH values of washings could be observed depending on the suction capacity of the filter pump.

Table S2. Aldol model reaction I between 4-nitrobenzaldehyde (**1**) and acetone (**2**) performed in DMSO under different conditions.[a]

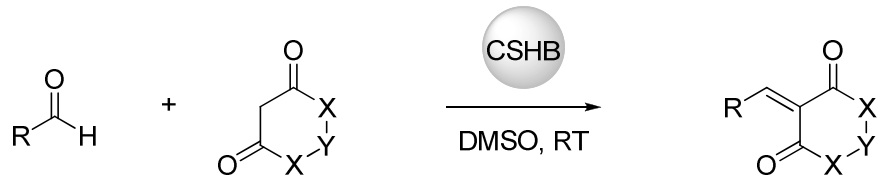


1a **2** **3a** **4a**

Entry	Catalyst	Catalyst Loading (mol%)	T (± 2 °C)	Conversion (%)[b]	Selectivity 3a:4a[c]
1	-	-	23	0	-
2	DGB[d]	17	23	0	-
3	PCS	17	23	0	-
4	CSHB	17	23	4	99:1
5	CSHB	51	23	2	99:1
6	CSHB	51	40	5	99:1

[a] Reaction conditions: 1a (1.0 mmol), 2 (1 mL, 13.6 mmol), DMSO (3 mL), 24 h, mean pH = 6.8; Beads number: Entry 4 = 20; entry 5 = entry 6 = 60 (corresponding to 17 and 51 mol%, respectively, of free amino groups with respect to the aldehyde); [b] Determined by ^{1}H NMR analysis of the crude product based on the aldehyde proton; Batch-to-batch estimated relative error for for entries 3-5 = ± 0.5%; [c] Based on ^{1}H NMR analysis; [d] Dried gel beads (DGB) were used instead CSHB.

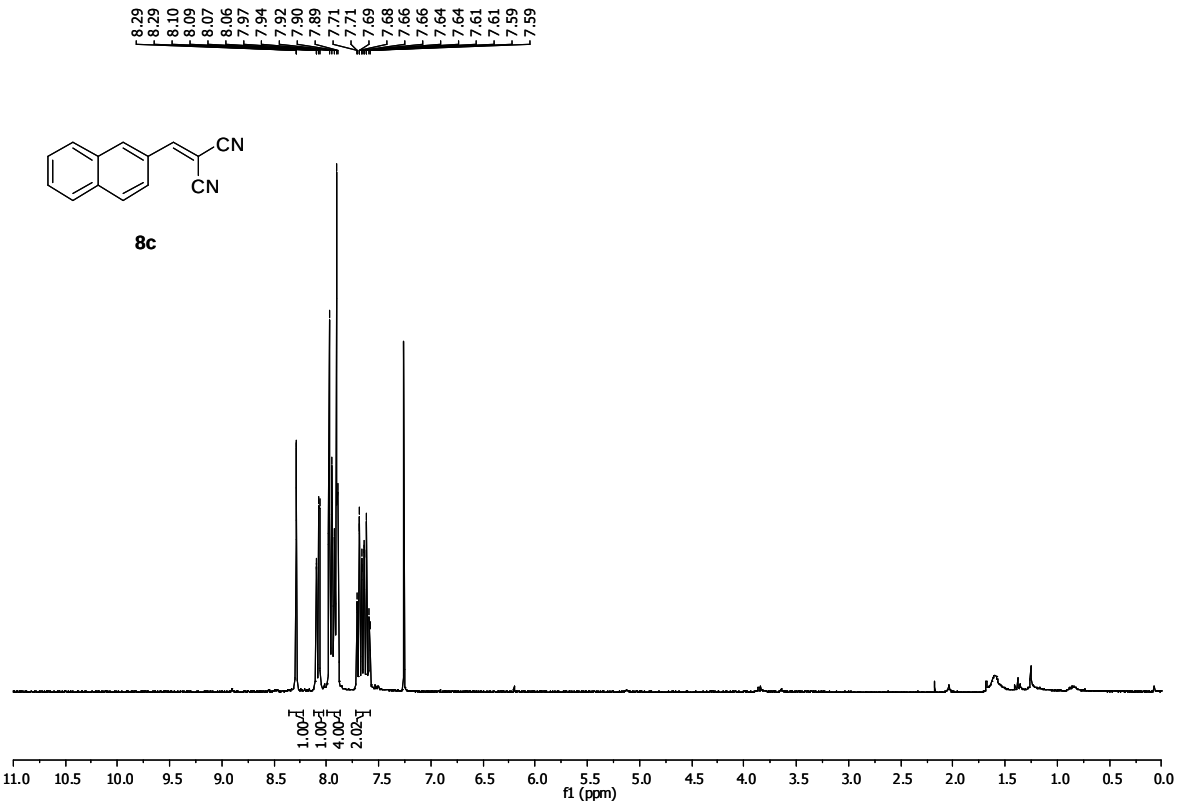
Table S3. Knoevenagel condensation reaction of barbituric acid and Meldrum's salt catalyzed by CSHB in DMSO at RT.[a]



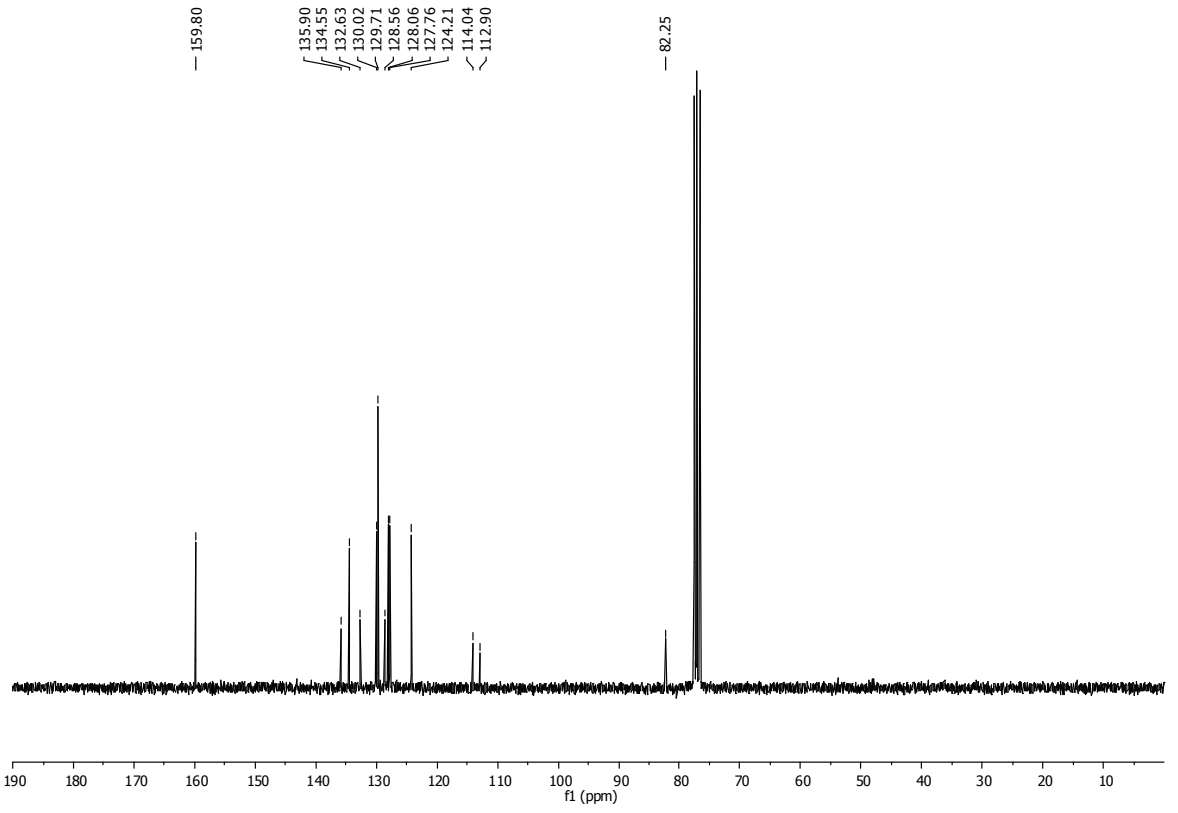
Entry	RCHO	Product	Time (min)	Conversion (%)[b]
1	**1l**	**10l**	5	2
2	**1m**	**10m**	5	30

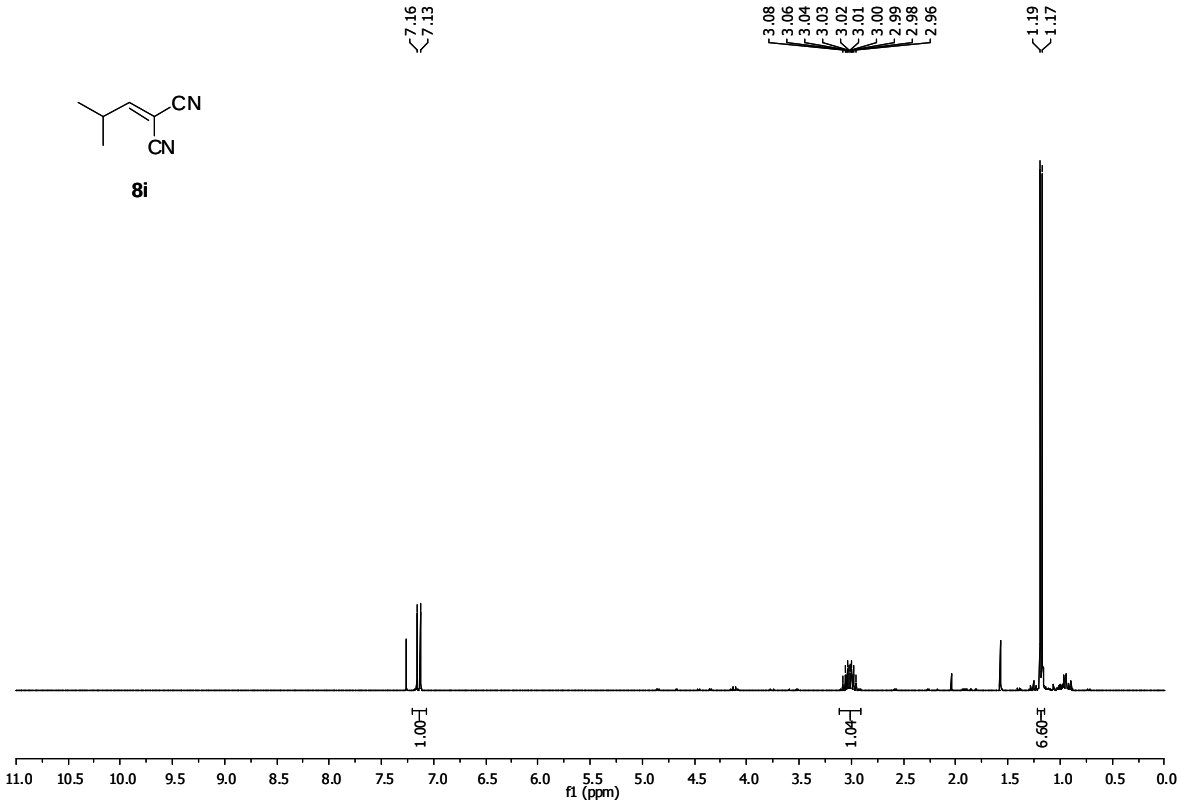
[a] Reaction conditions: **1** (1.0 mmol), **donor** (1.1 mmol), DMSO (3 mL), mean pH = 6.9, beads number = 20 (corresponding to 17 mol% of free amine groups with respect to the aldehyde), RT; [b] Determined by ^{1}H NMR spectroscopy of the crude product based on the aldehyde proton.

2. ^{1}H NMR and ^{13}C NMR spectra of new compounds



8c

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7.13
3.08
3.06
3.04
3.03
3.02
3.01
3.00
2.99
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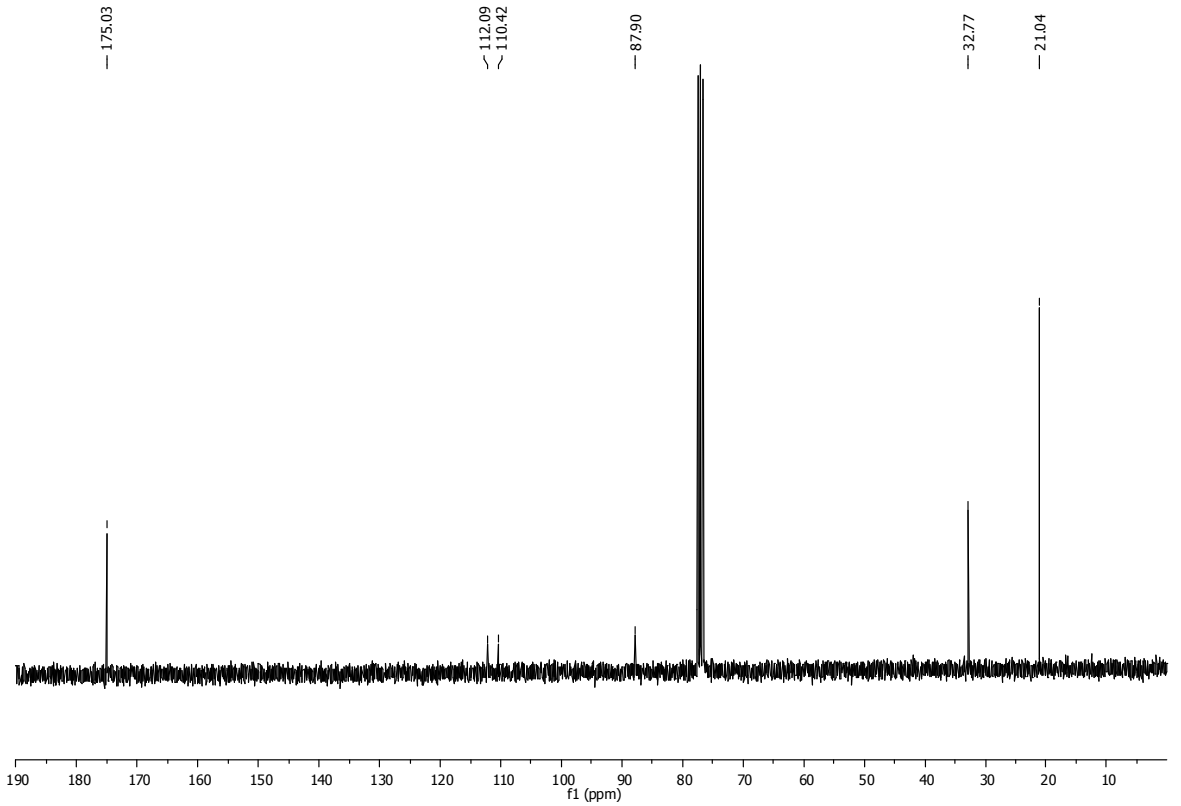
2.96
1.19
1.17
CN
CN
8i
1.00
1.04
6.60
f1 (ppm)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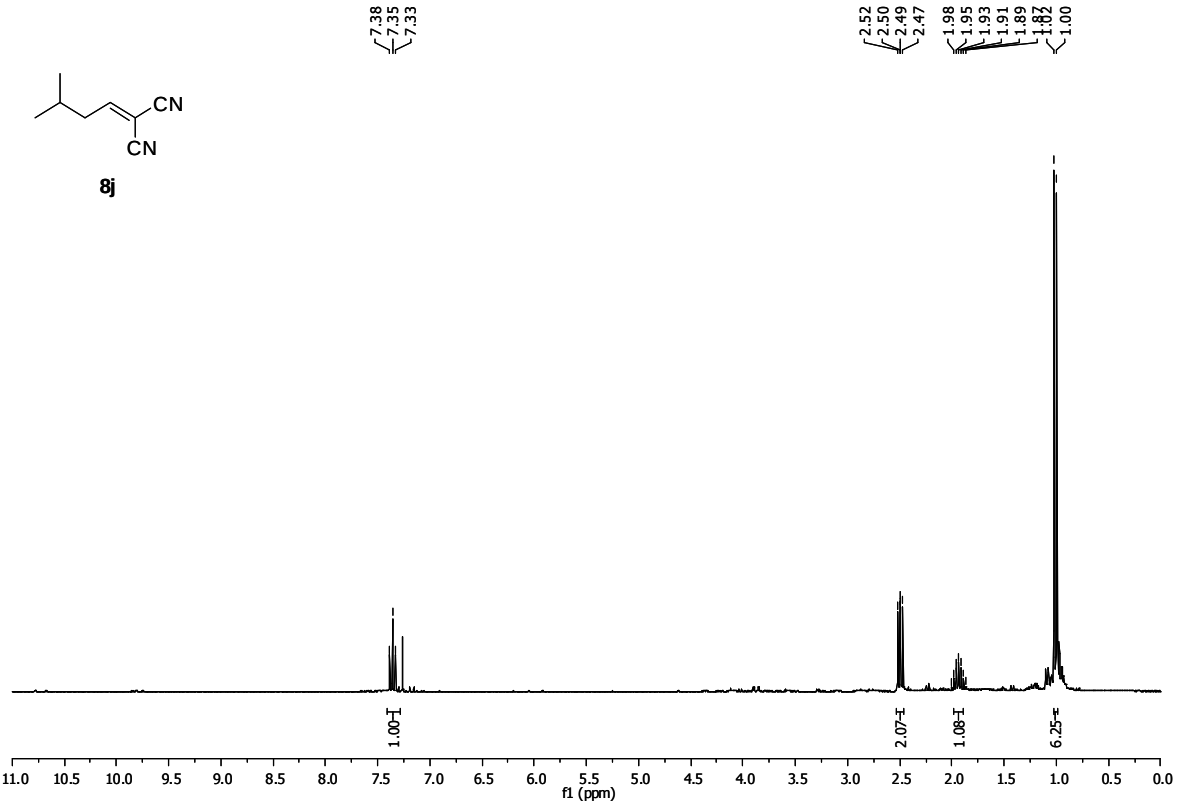
112.09
110.42
87.90
32.77
21.04
f1 (ppm)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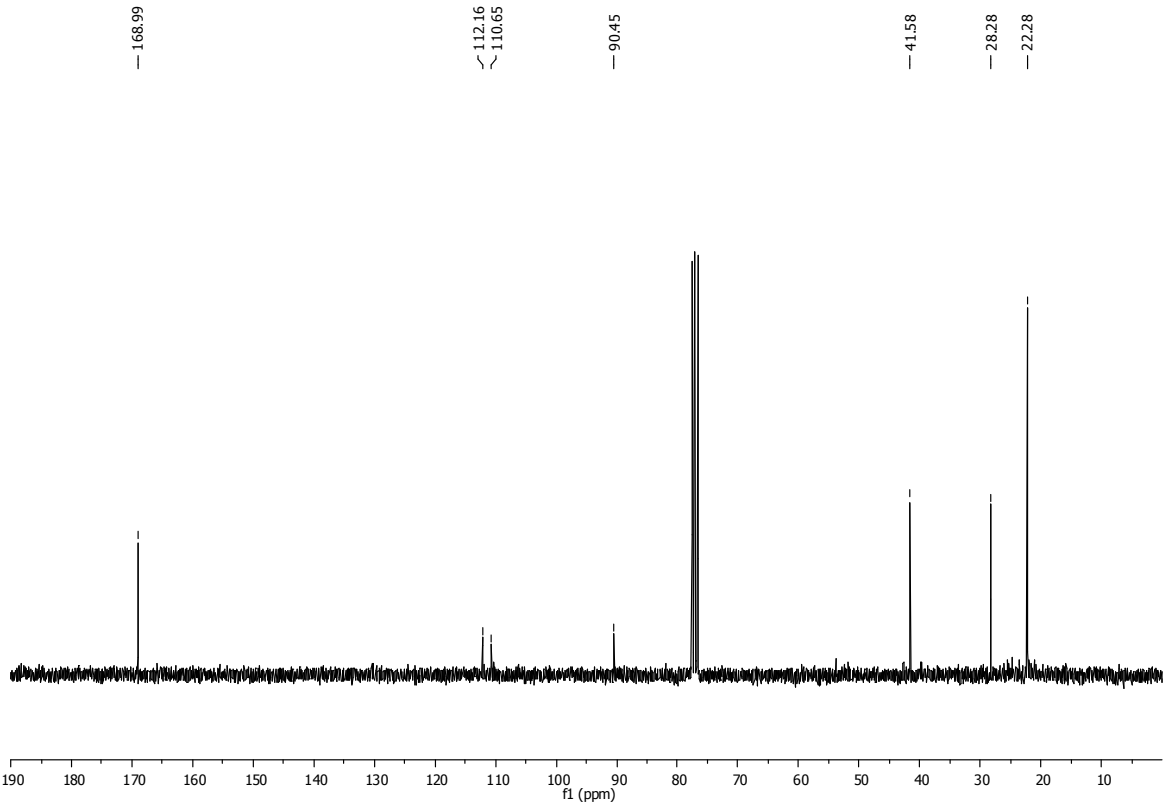
7.35
7.33
2.52
2.50
2.49
2.47
1.98
1.95
1.93
1.91
1.89
1.87
1.02
1.00
CN
CN
8j
1.00
2.07
1.08
6.25
f1 (ppm)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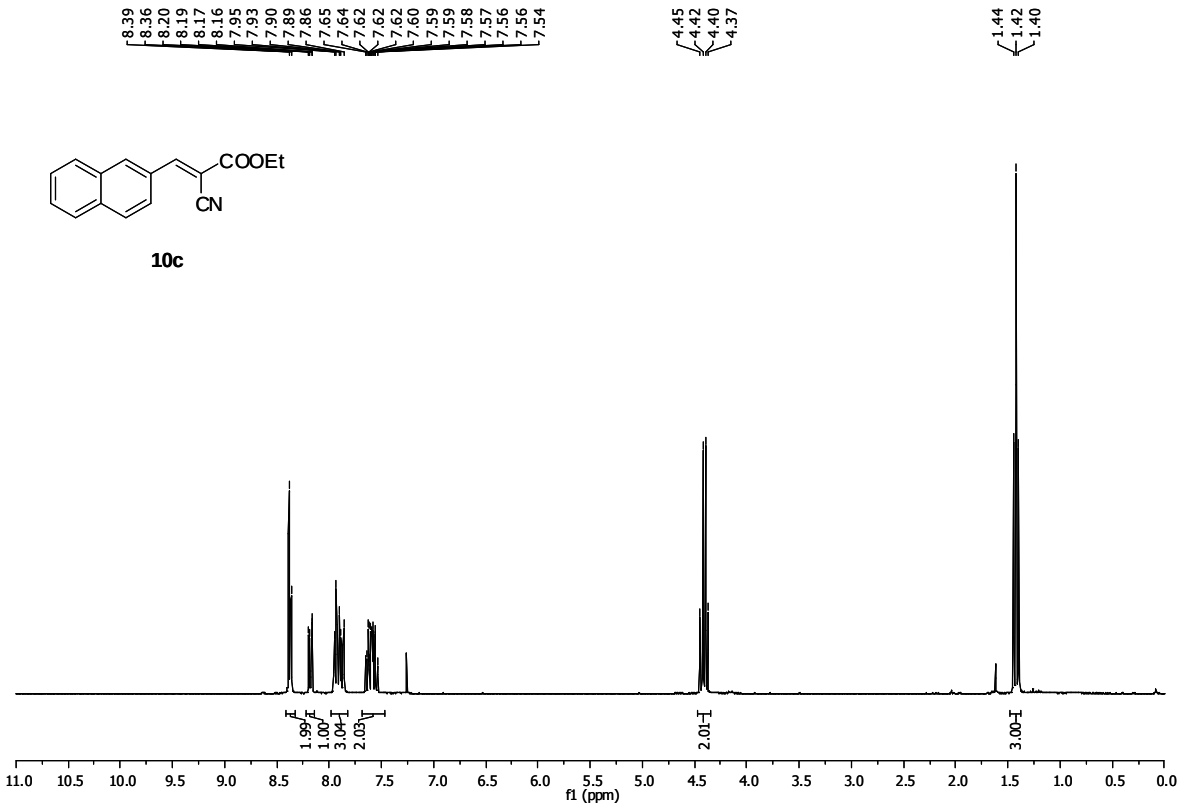
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7.95
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7.89
7.86
7.65
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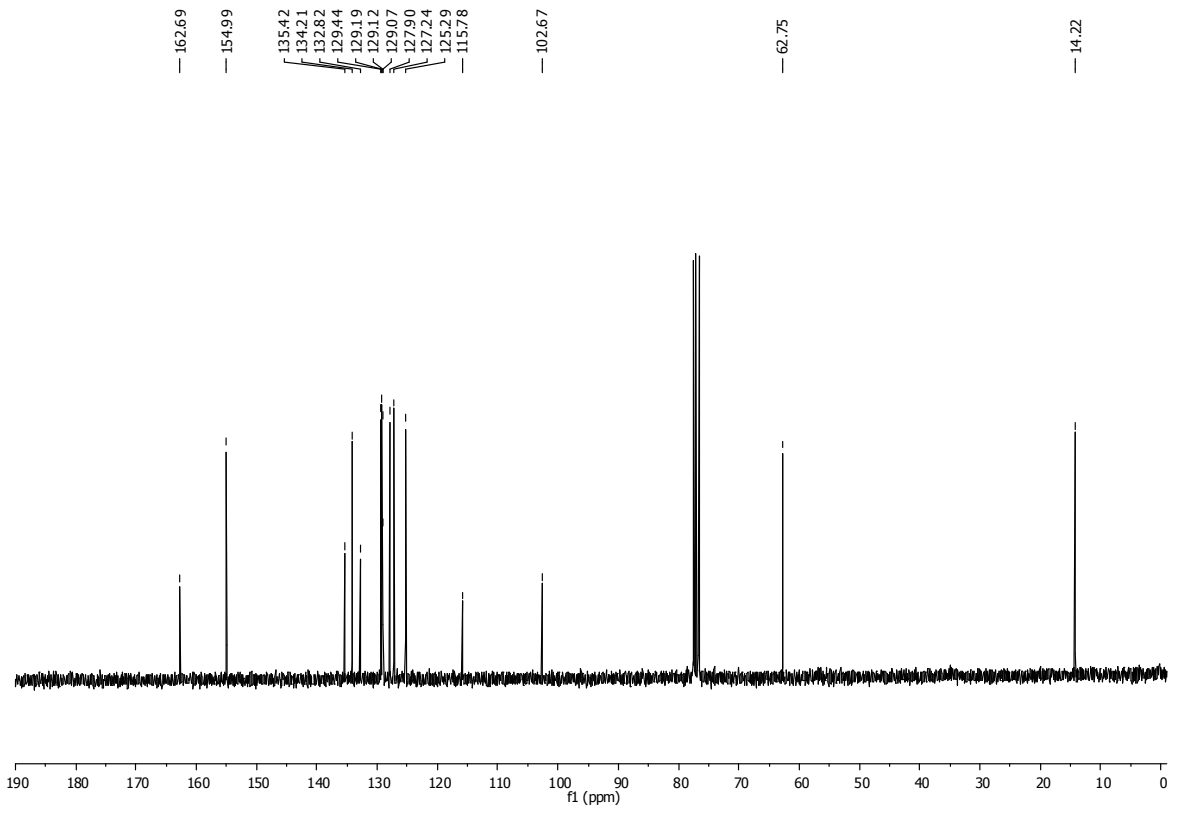
7.62
7.62
7.62
7.60
7.59
7.59
7.58
7.57
7.56
7.56
7.54
4.45
4.42
4.40
4.37
1.44
1.42
1.40
COOEt
CN
10c
1.99
1.00
3.04
2.03
2.01
3.00
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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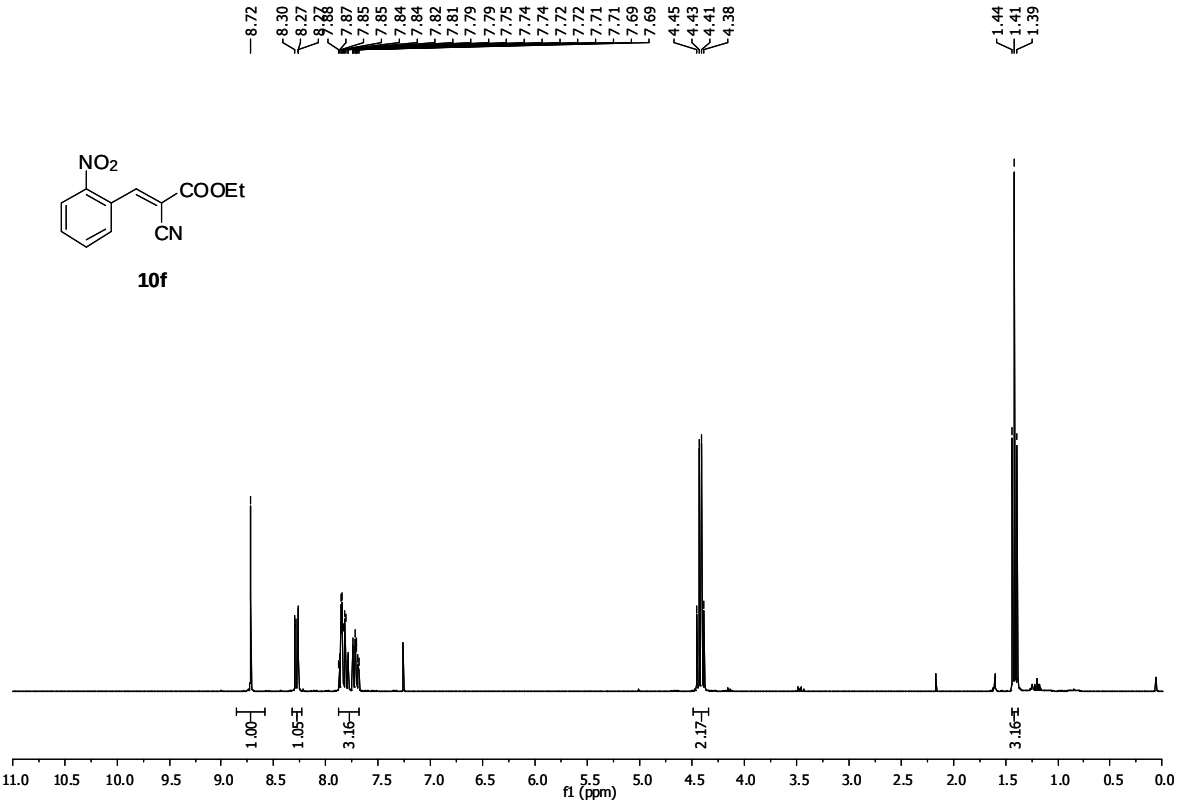
154.99
135.42
134.21
132.82
129.44
129.19
129.12
129.07
127.90
127.24
125.29
115.78
102.67
62.75
14.22
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)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8.30
8.27
7.87
7.85
7.84
7.84
7.82
7.81
7.79
7.79
7.75
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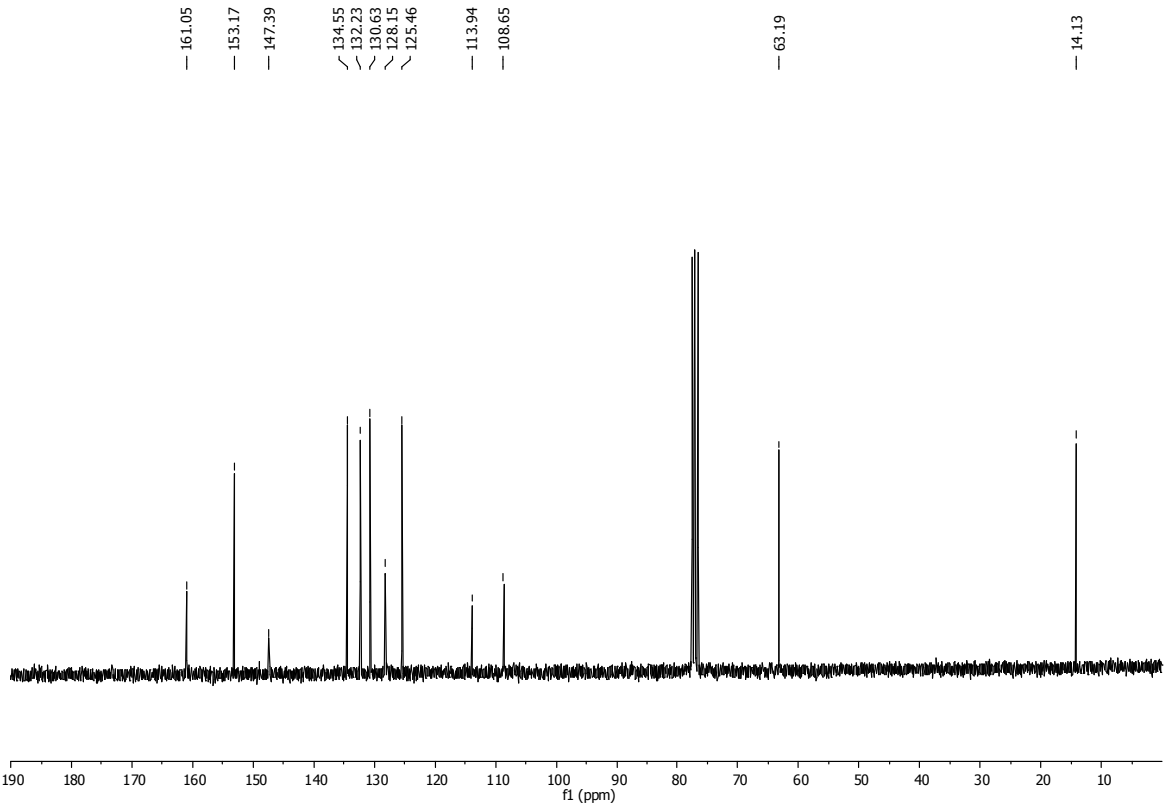
7.72
7.72
7.71
7.71
7.69
7.69
4.45
4.43
4.41
4.38
1.44
1.41
1.39
NO2
COOEt
CN
10f
1.00
1.05
3.16
2.17
3.16
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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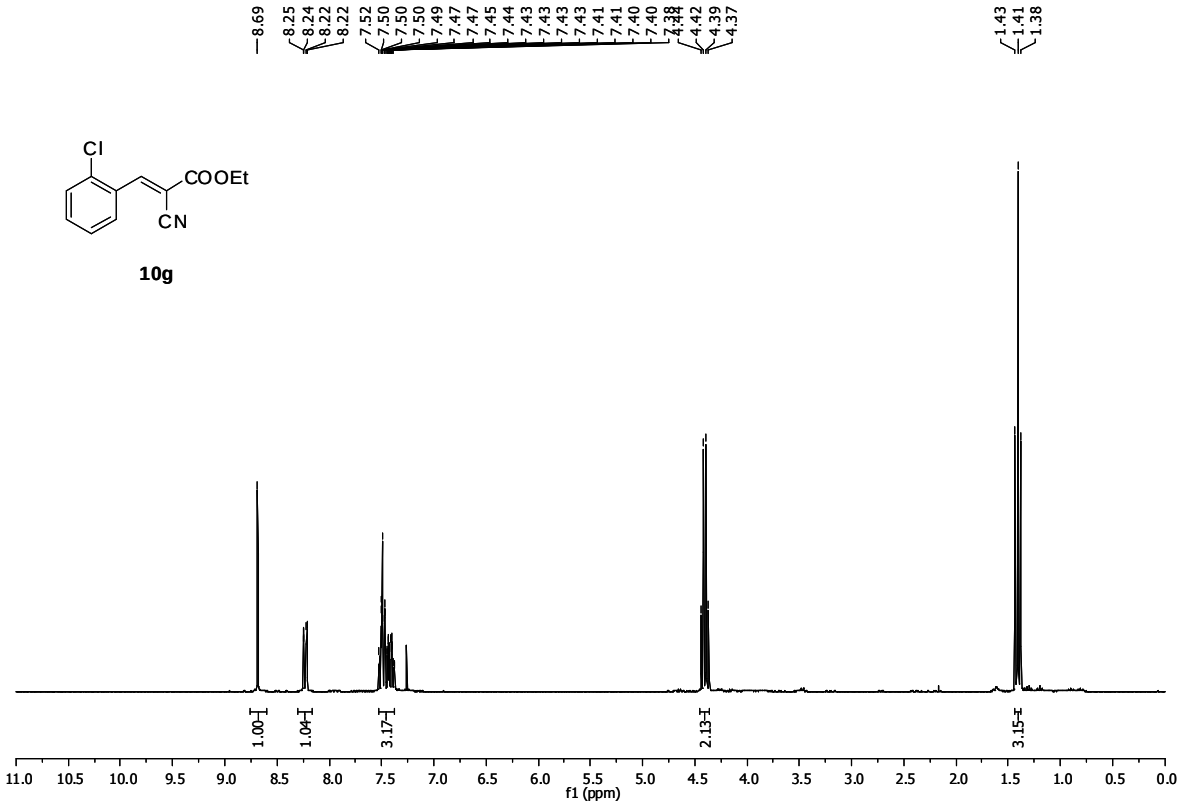
153.17
147.39
134.55
132.23
130.63
128.15
125.46
113.94
108.65
63.19
14.13
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)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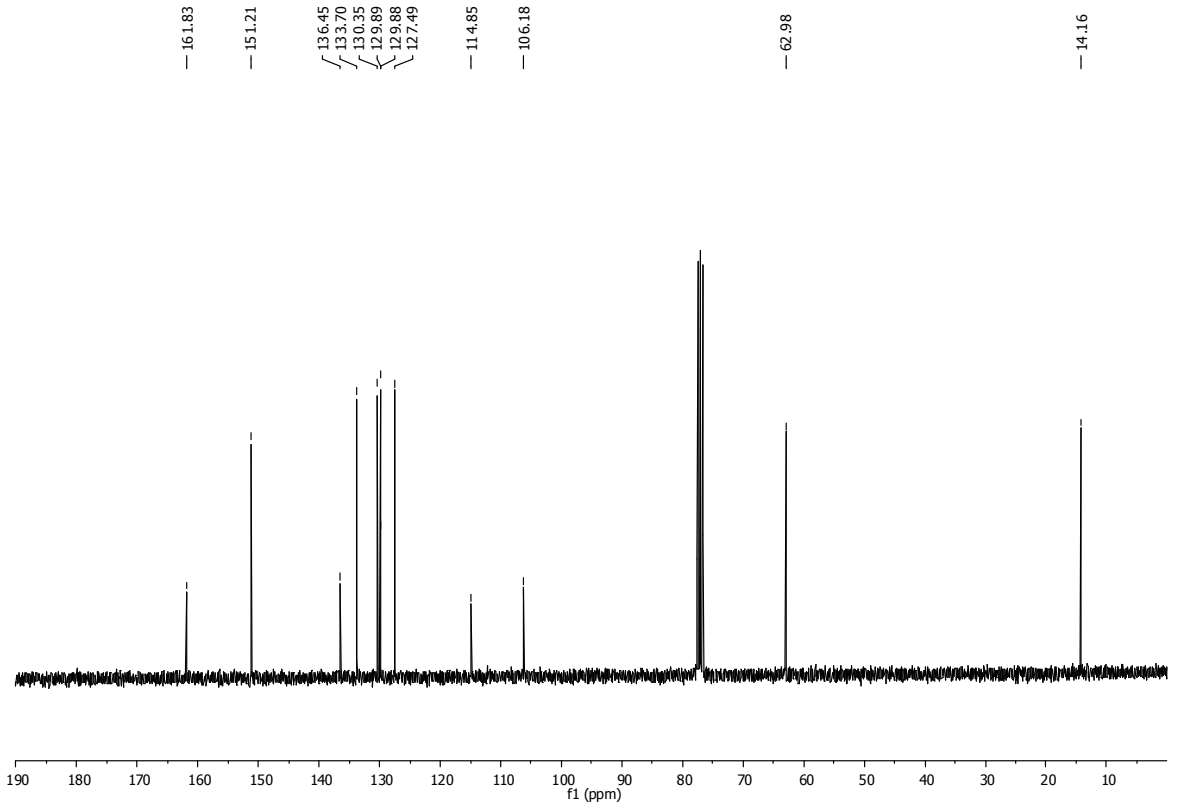
8.25
8.24
8.22
8.22
7.52
7.50
7.50
7.50
7.49
7.47
7.47
7.45
7.44
7.43
7.43
7.43
7.43
7.41
7.41
7.40
7.40
4.42
4.39
4.37
1.43
1.41
1.38
Cl
COOEt
CN
10g
1.00
1.04
3.17
2.13
3.15
f1 (ppm)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114.85
106.18
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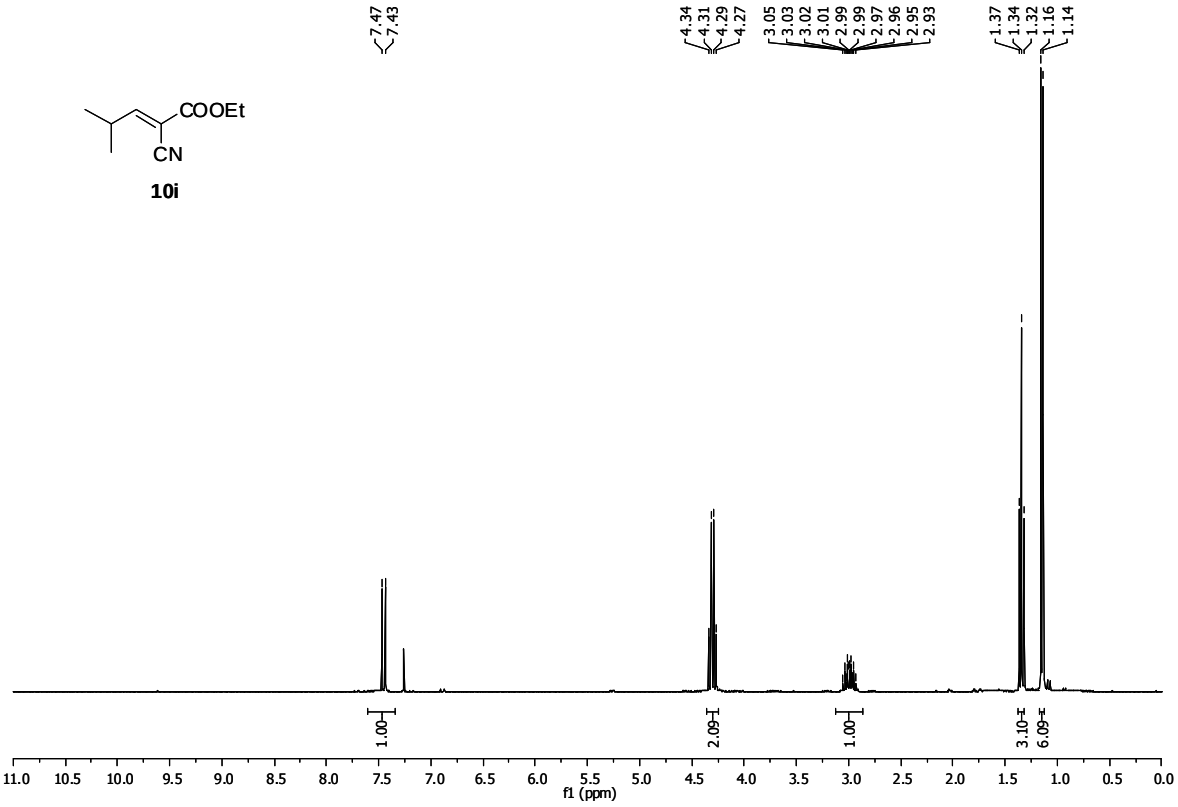
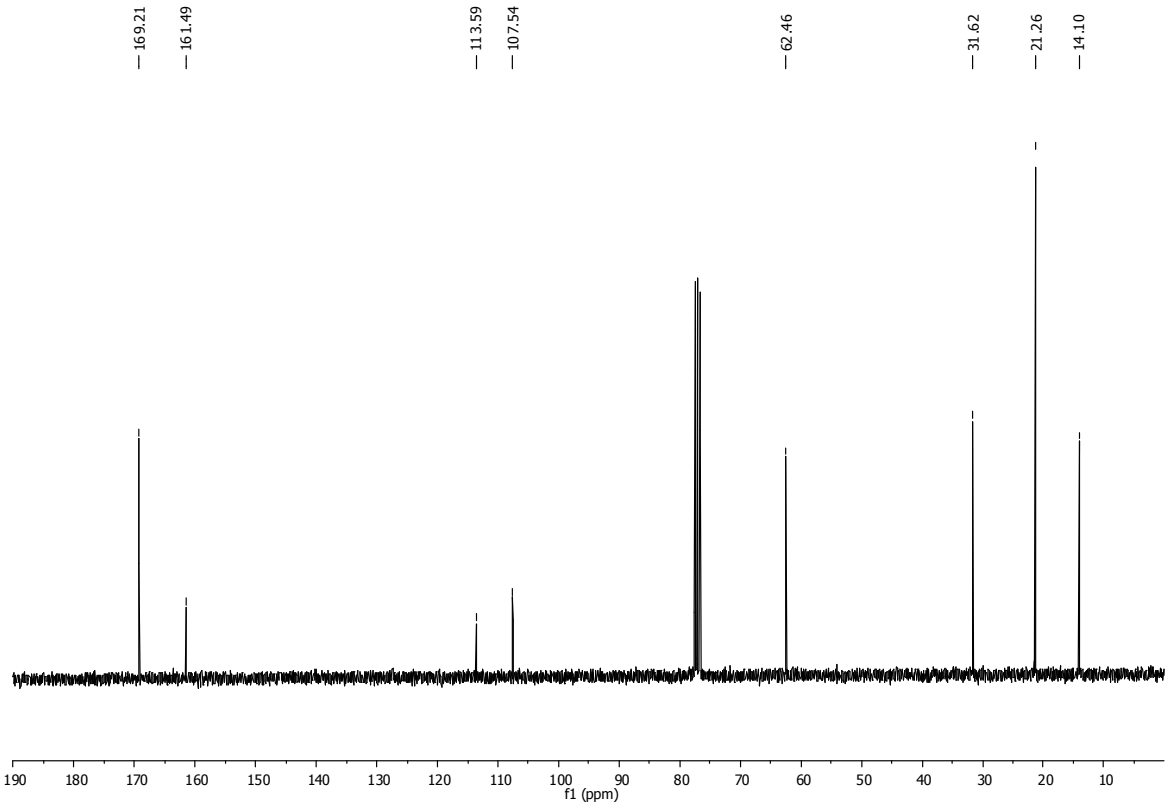
14.16
f1 (ppm)


COOEt
CN
10i
7.47
7.43
4.34
4.31
4.29
4.27
3.05
3.03
3.02
3.01
2.99
2.99
2.97
2.96
2.95
2.93
1.37
1.34
1.32
1.16
1.14
1.00
2.09
1.00
3.10
6.09
f1 (ppm)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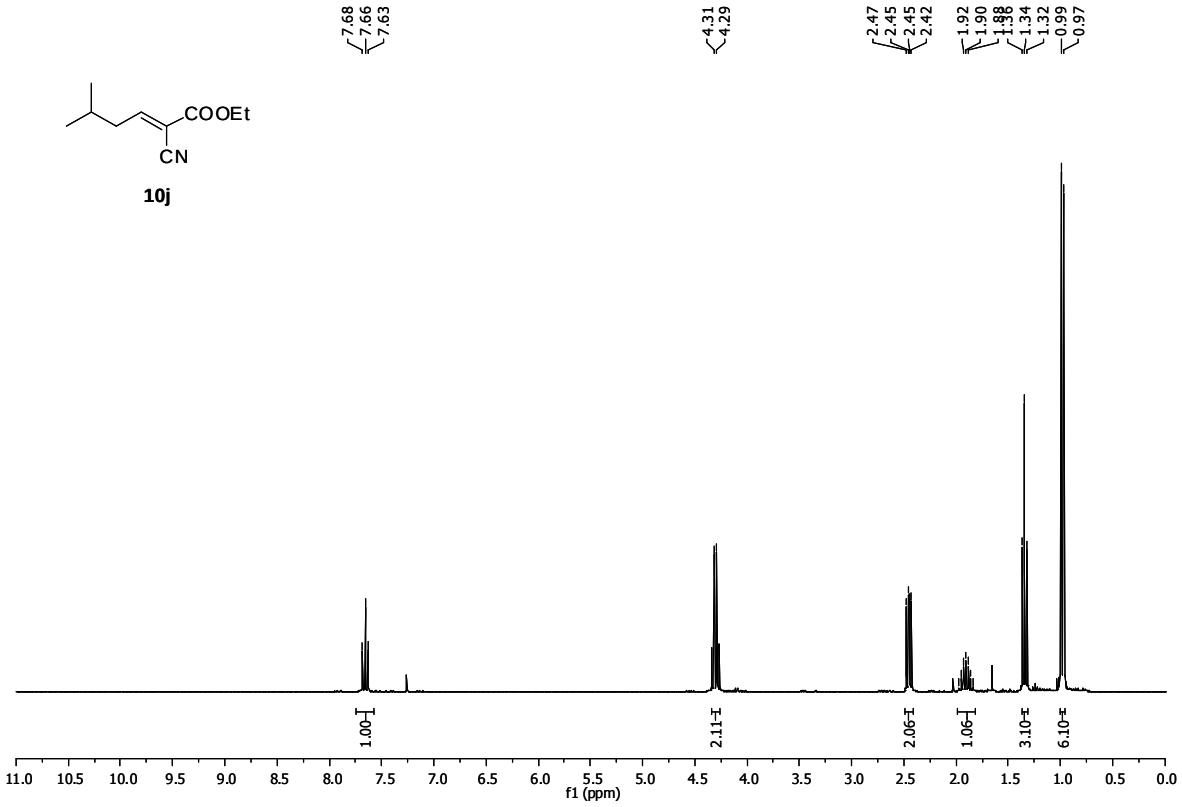
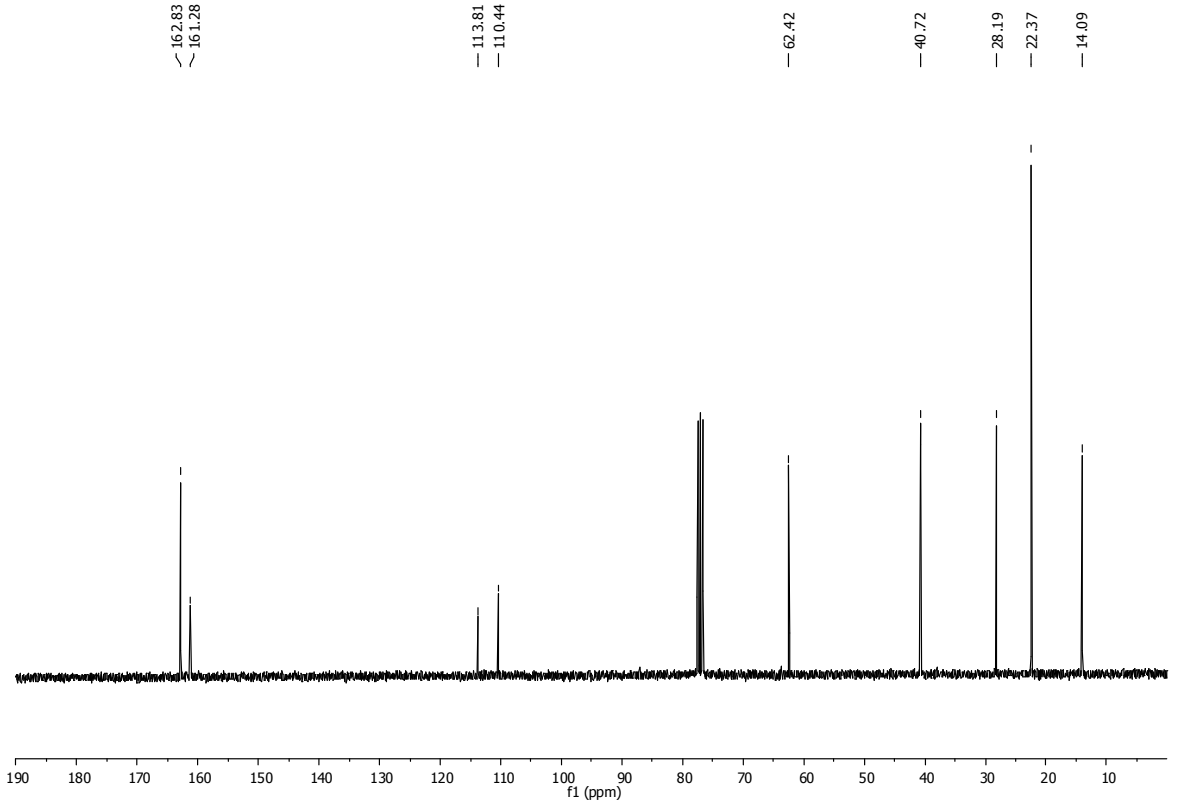
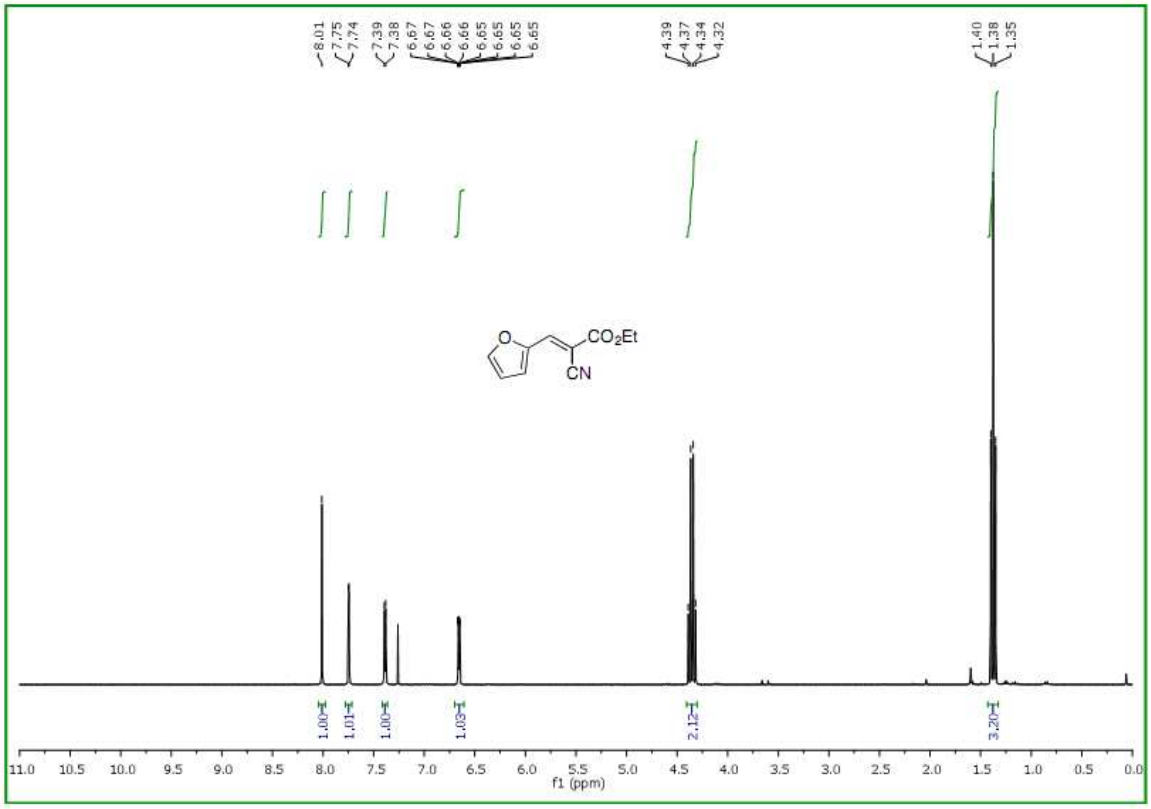
107.54
62.46
31.62
21.26
14.10
f1 (ppm)


7.68
7.66
7.63
4.31
4.29
2.47
2.45
2.42
1.92
1.90
1.34
1.32
0.99
0.97
COOEt
CN
10j
1.00
2.11
2.06
1.06
3.10
6.10
f1 (ppm)


162.83
161.28
113.81
110.44
62.42
40.72
28.19
22.37
14.09
f1 (ppm)

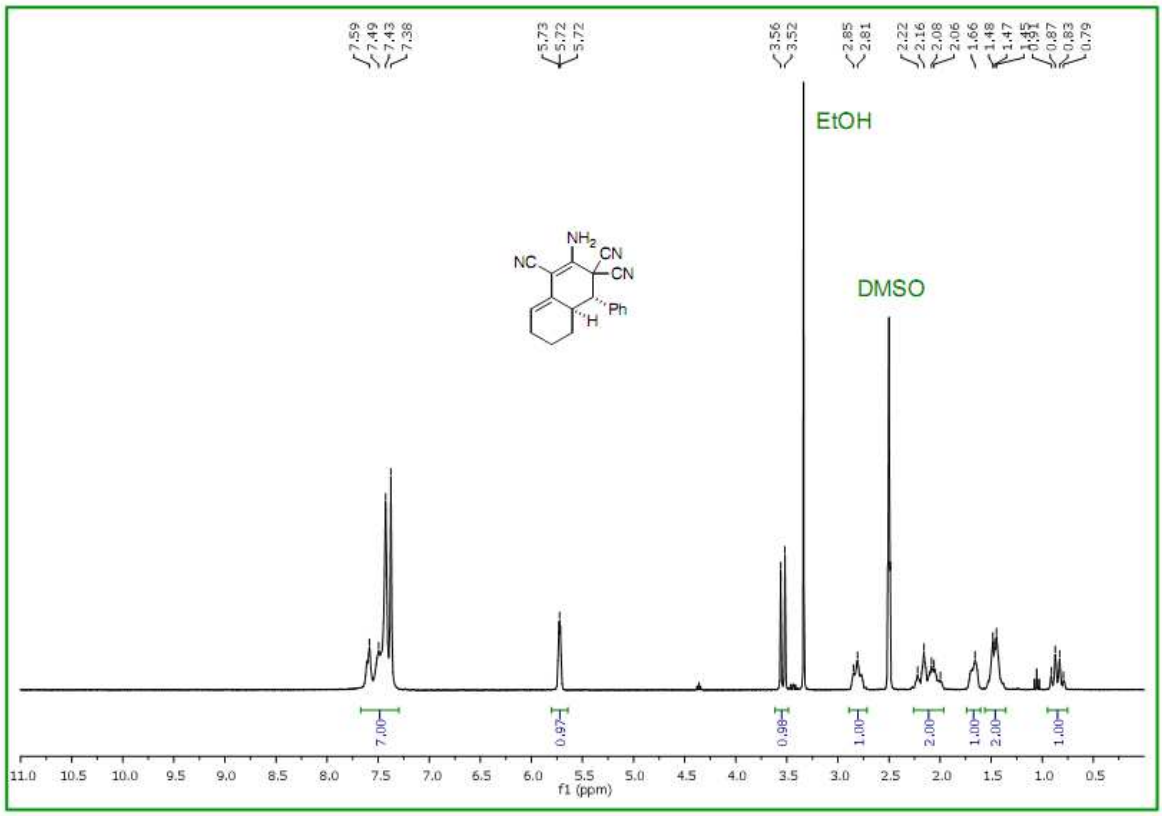
3. Selected ^{1}H NMR spectra

- Isolated compound **10k**



^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 8.02 (s, 1 H), 7.75 (d, *J* =1.6 Hz, 1 H), 7.39 (d, *J* = 3.7 Hz, 1 H), 6.70-6.62 (m, 1 H), 4.36 (q, *J* = 7.1 Hz, 2 H), 1.38 (t, *J* = 7.1 Hz, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) = 162.6, 148.7, 148.2, 139.4, 121.7, 115.3, 113.8, 98.6, 62.5, 14.1.

- Isolated compound **19**



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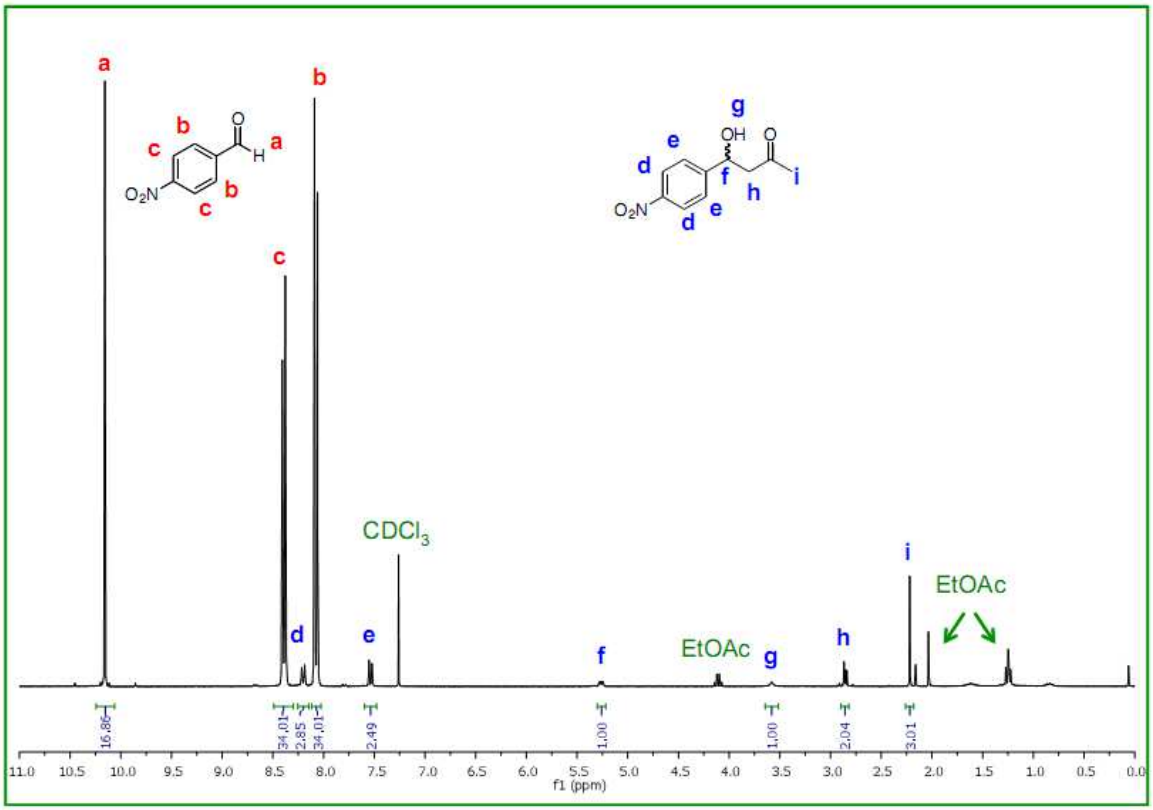
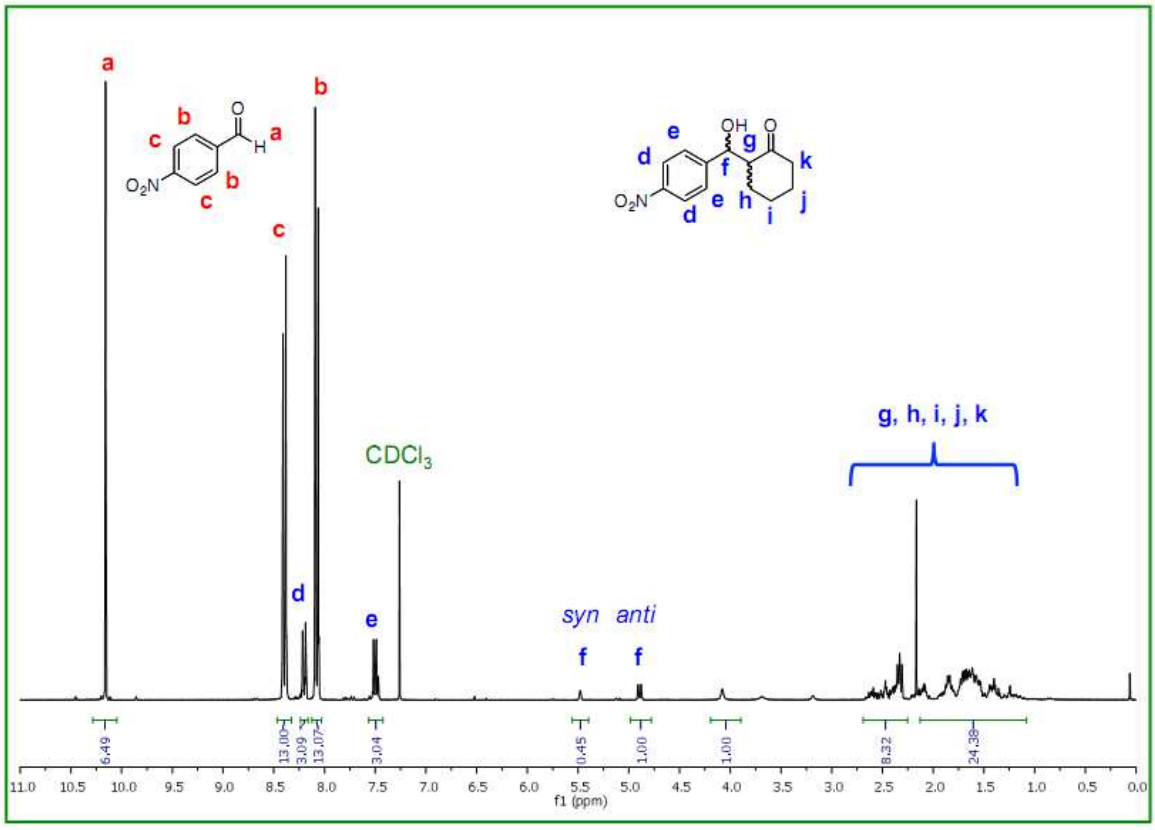


- Table 2, entry 6



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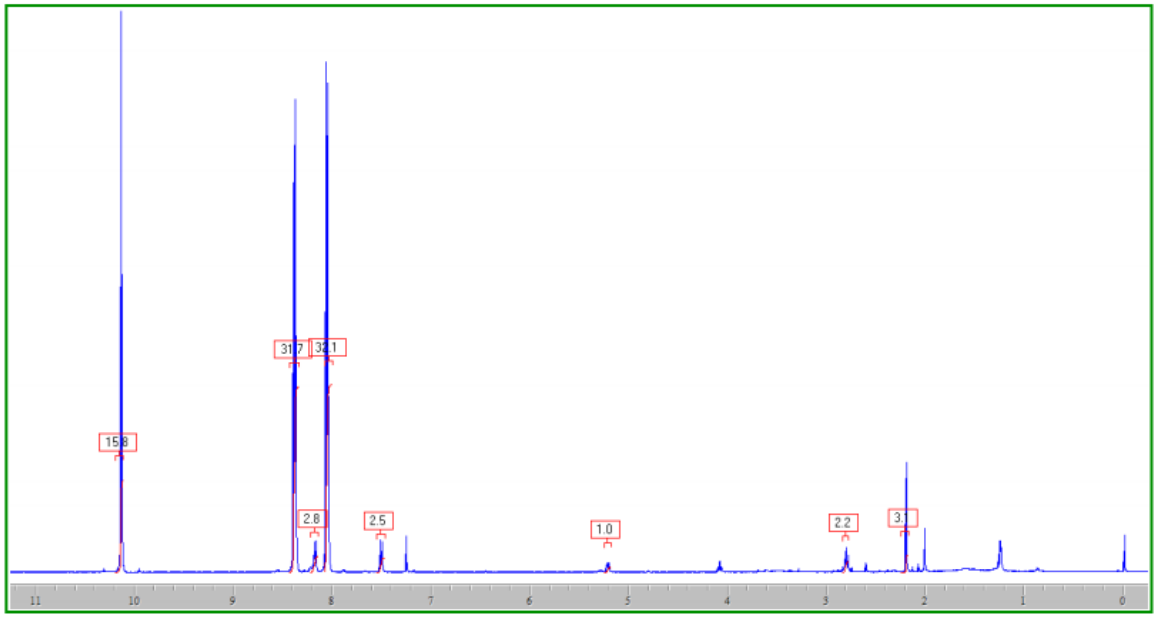

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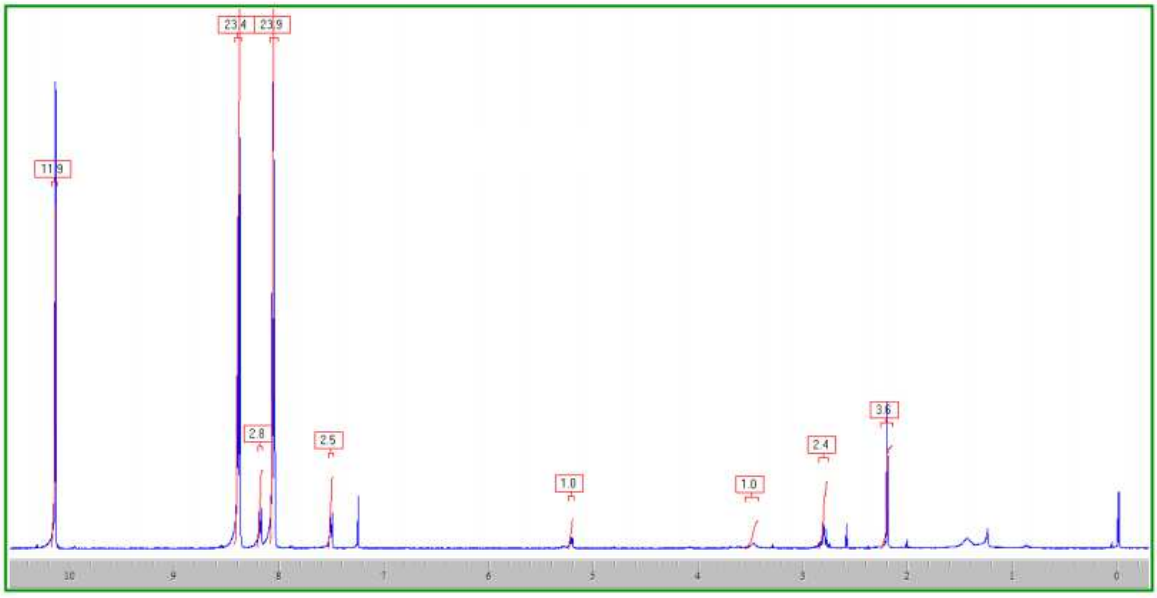

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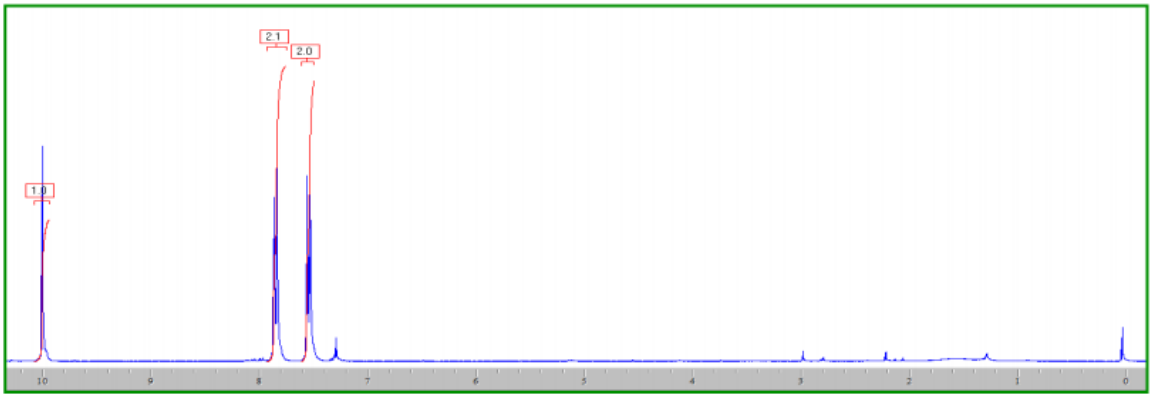

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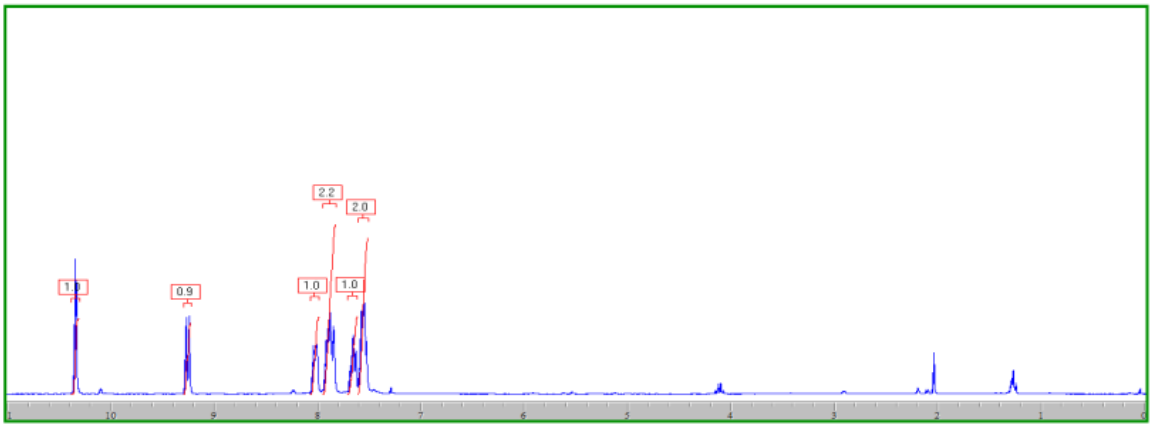

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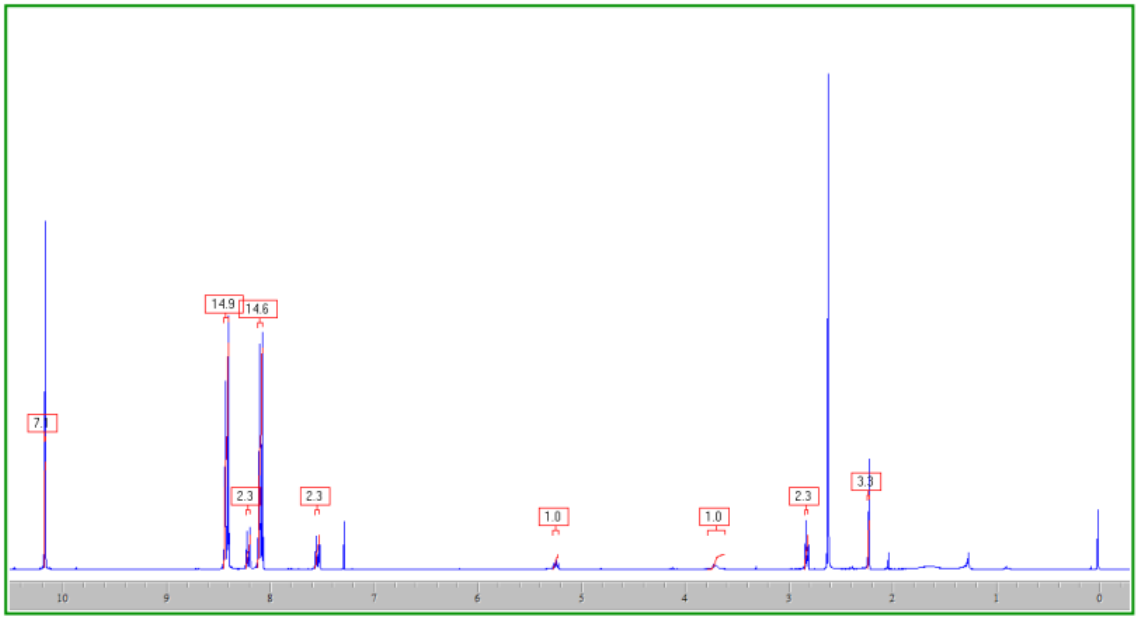

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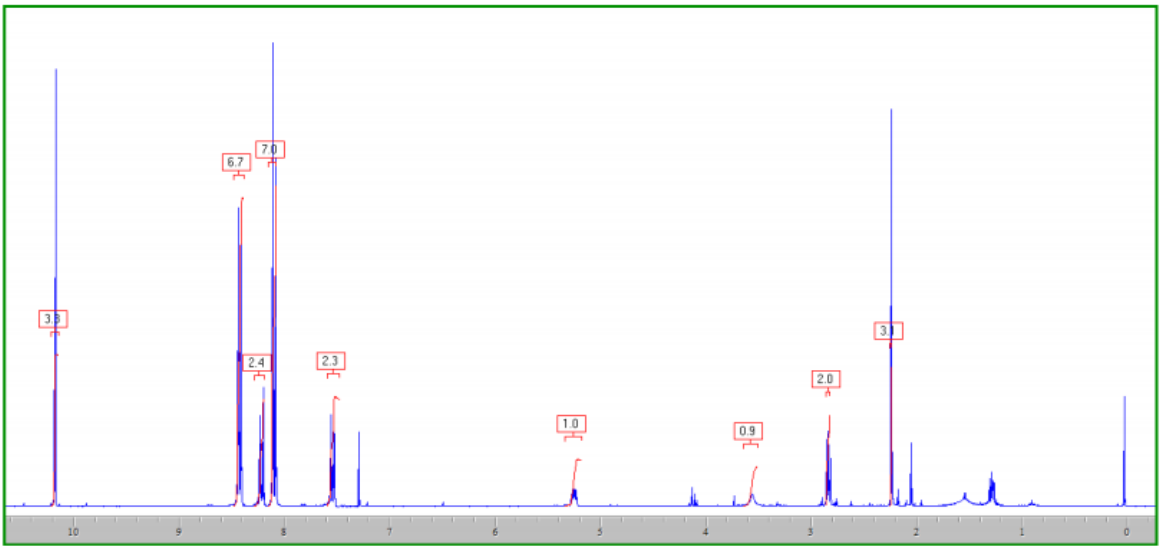

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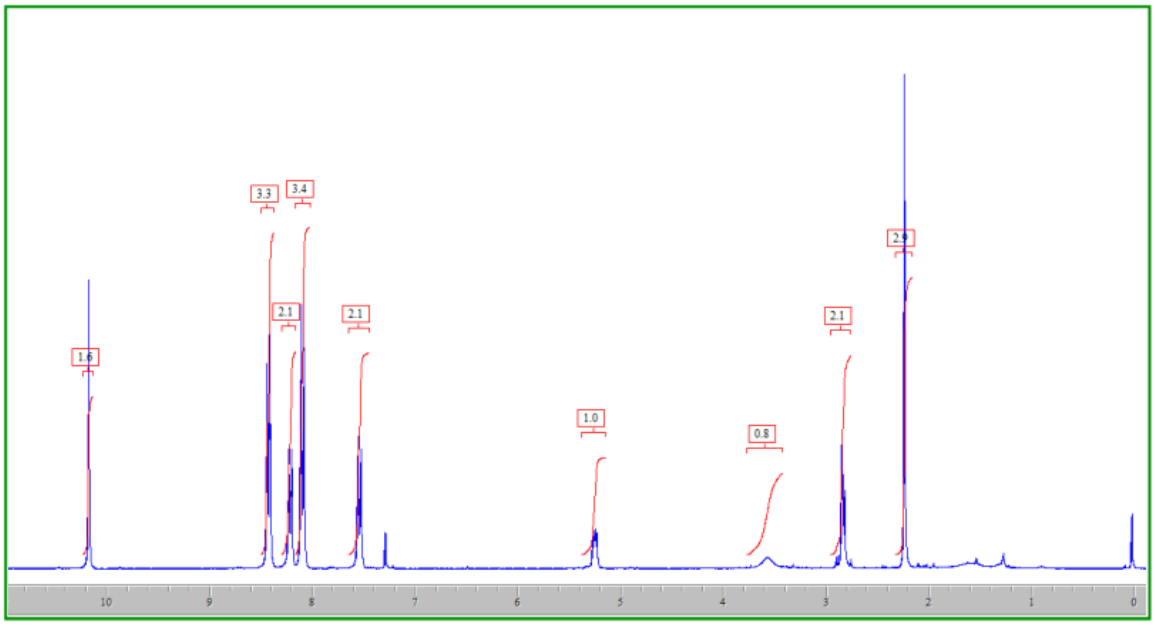

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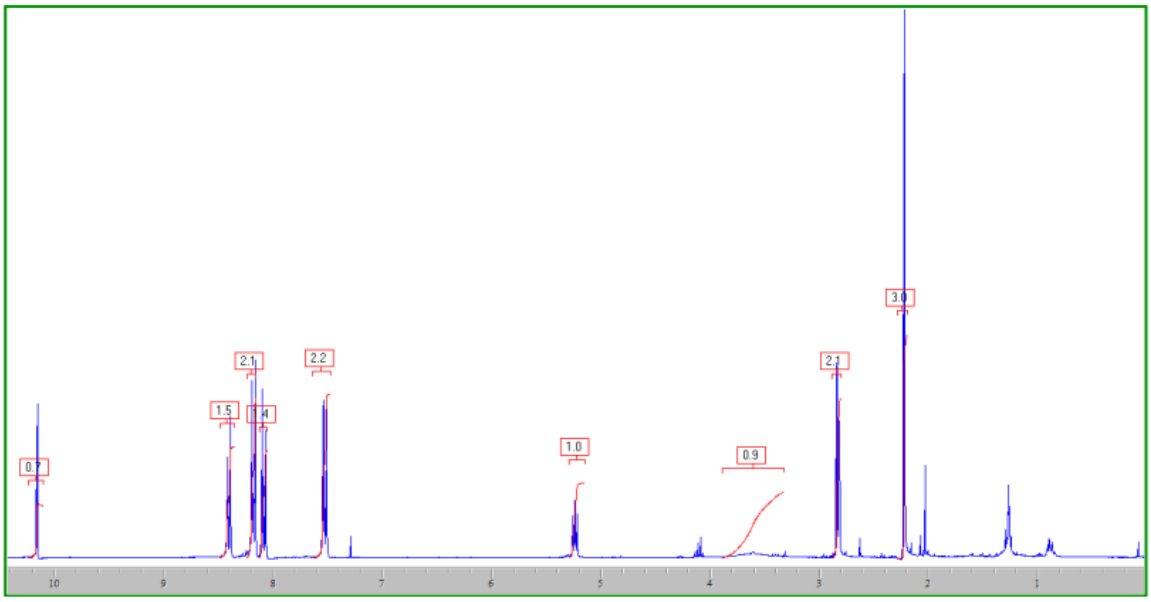

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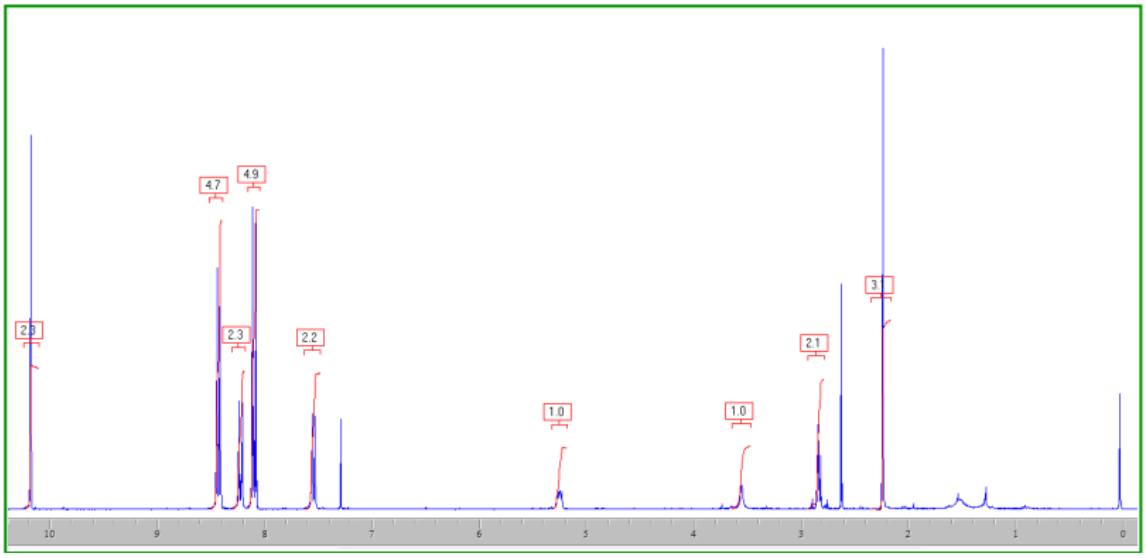

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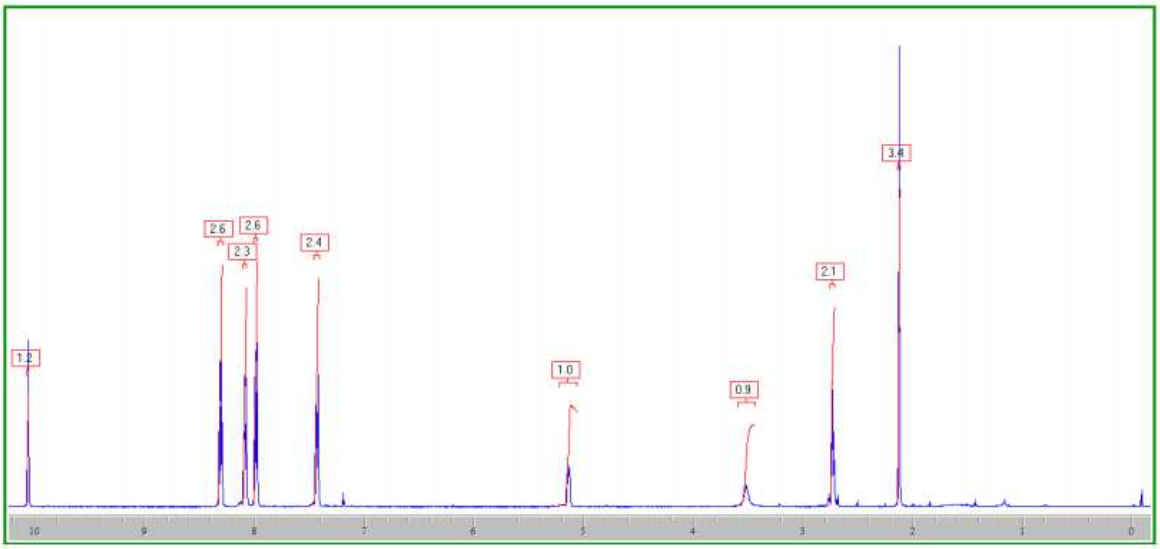

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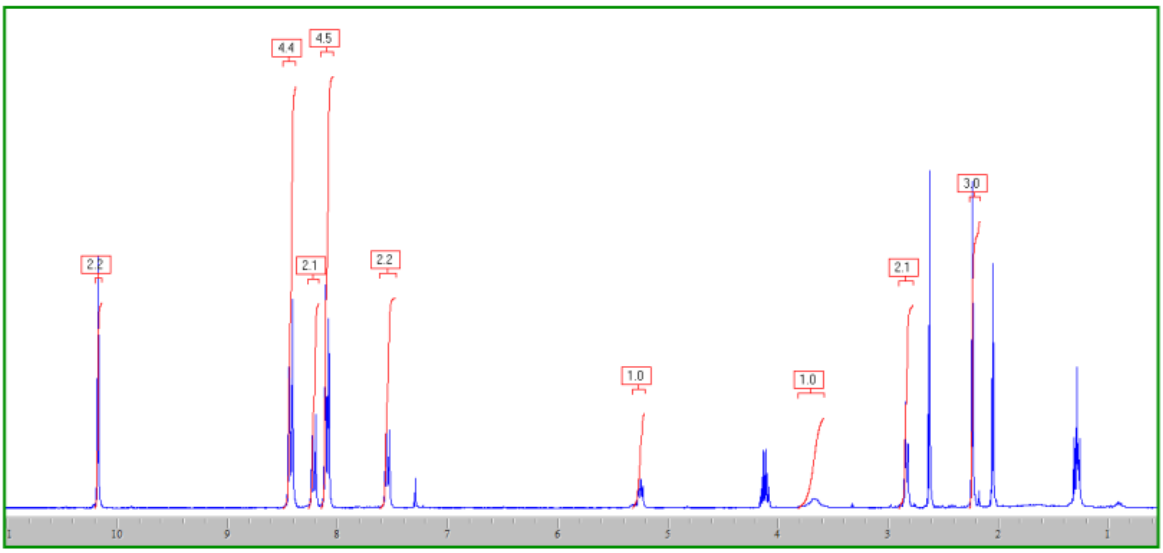

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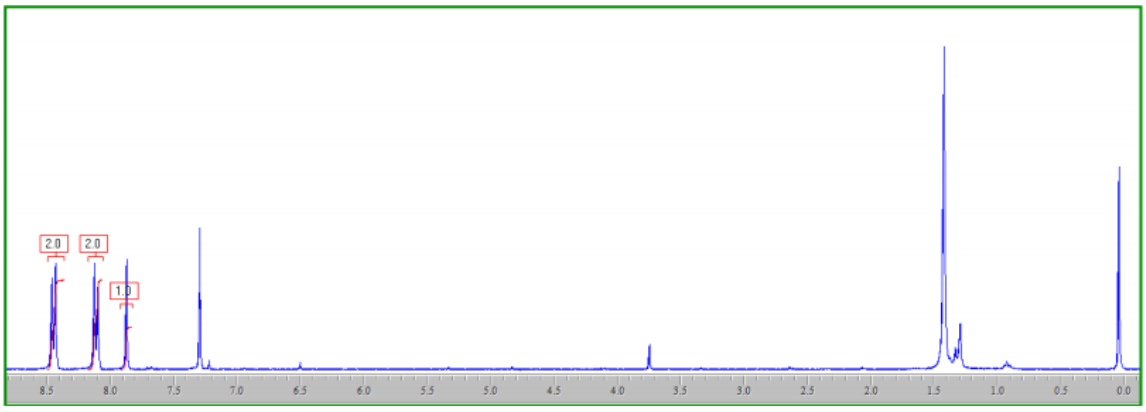

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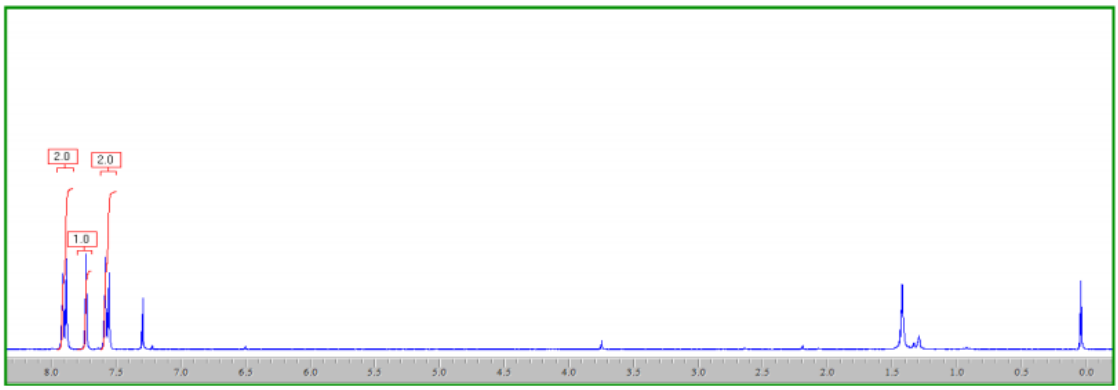

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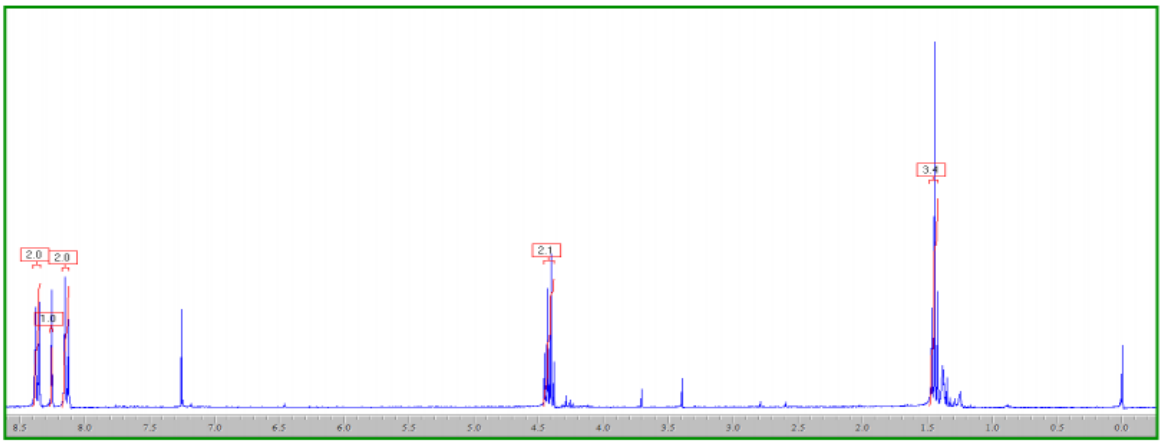

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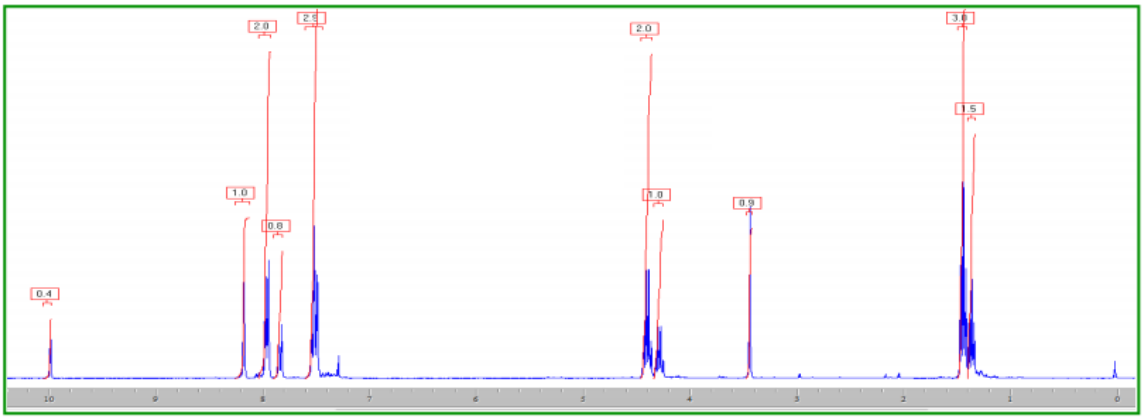


4. Additional photographs

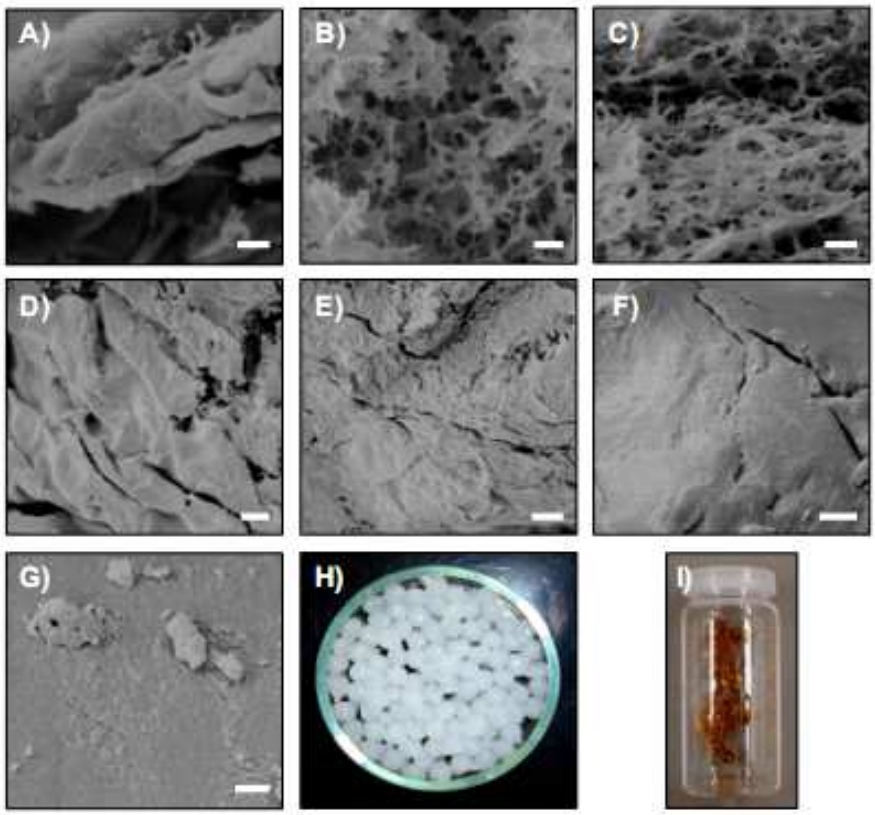


Figure S1. A) SEM image of LMW PCS (scale bar 2 μm; magnification 5000×); B)-C) SEM images of the xerogels made from CSHB (scale bars 2 μm; magnification 5000×); D)-E) SEM images of different surface areas of freeze-dried CSHB (D: scale bar 10 μm; magnification 1000×; E: scale bar 50 μm; magnification 200×); F) SEM image of xerogel made from the freeze-dried CSHB after the 3rd cycle in the model nitroaldol reaction between **1a** and **11** in H_2O (scale bar 20 μm; magnification 500×); G) SEM image of xerogel made from the freeze-dried glutaraldehyde cross-linked CSHB after the model Knoevenagel reaction between **1f** and **9** in DMSO (scale bar 2 μm; magnification 5000×); H) Freshly prepared 4 mm-diameter CSHB; I) CSHB after 4th cycle in the model Knoevenagel reaction between **1a** and **7** in DMSO. After each cycle the beads acquire a brownish color due to non-specific adsorption of reactants. However, both the mechanical integrity and catalytic activity of the beads towards the Knoevenagel reaction remain intact.

5. TGA plots

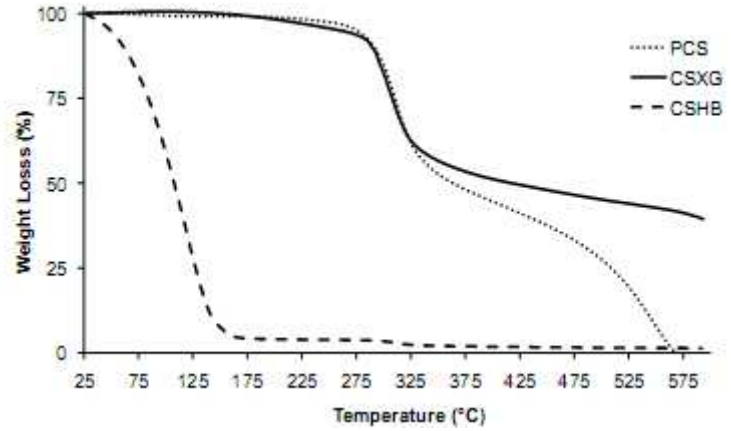
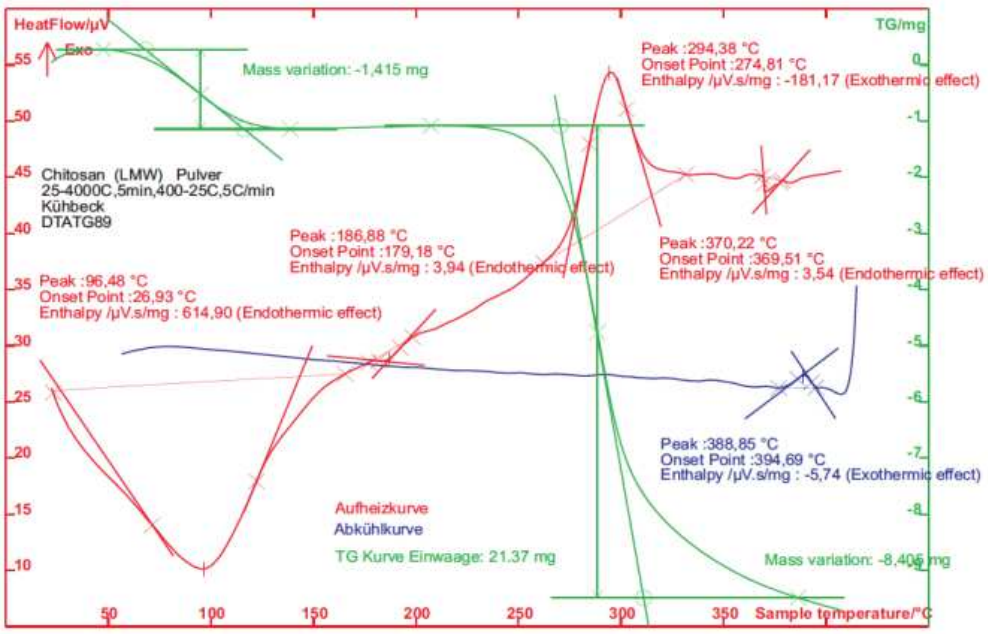


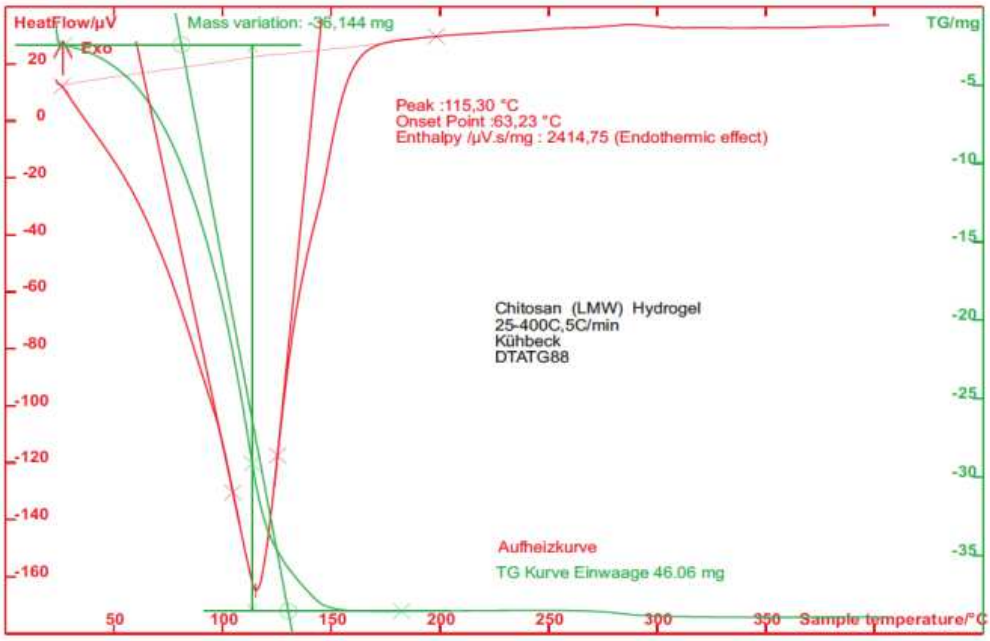
Figure S2. TGA spectra of PCS, CSHB (4 mm diameter) and air-dried chitosan beads (CSXG).

6. DSC thermograms

(a)



(b)



(c)

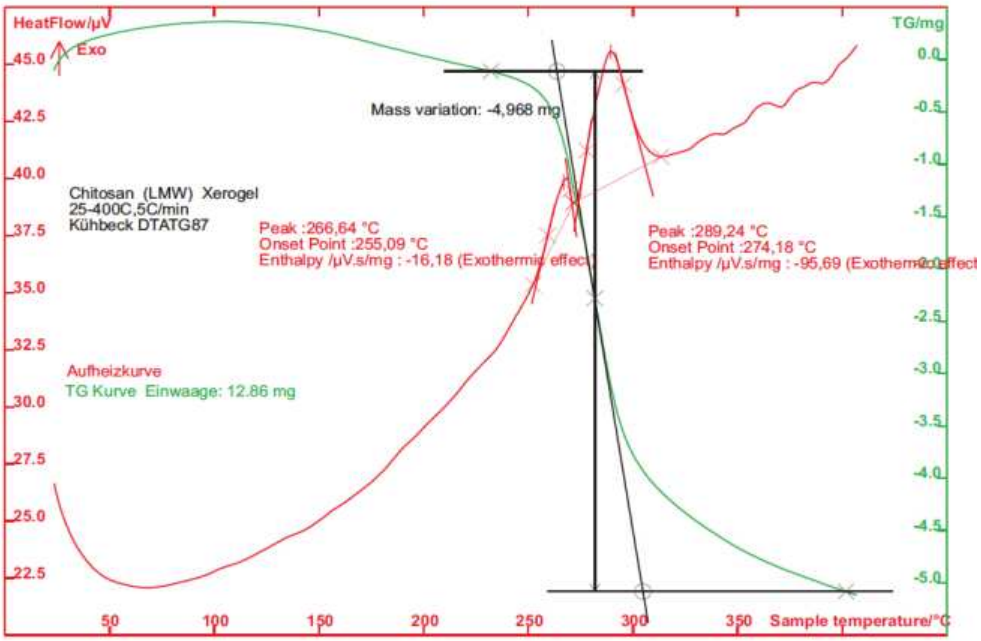


Figure S3. DSC curves for (a) PCS, (b) CSHB and (c) CSXG under argon atmosphere (low-rate flow, 1 L h^{-1}) at 5 °C min^{-1}. Temperature range: 25-400 °C. Sample mass: 21.37 mg (PCS); 46.06 mg (CSHB); 12.86 mg (CSXG). Note: The enthalpic contributions shown in the plots are related to the sample mass input at the beginning of the measurement. Due to the high water uptake ability of the CS, water normalization of the curves would be necessary in order to strictly compare the thermodynamic contributions of the different samples.

7. UV-Vis studies

Absorption of 2-nitrobenzaldehyde in DMSO was investigated at λ = 260 nm. The extinction coefficient (ε) was estimated in 60605 ± 1844 M^{-1} cm^{-1} from the corresponding calibration curve made from 5 independent measurements at each concentration value (Figure S4, A). 20 units of CSHB (17 mol% of free amine groups in respect to the aldehyde) were added to a 3 mL solution of 2-nitrobenzaldehyde (from a 0.3 M stock solution) and the absorption (A) values were measured over time (Figure S4, B). The reported values (<A>) correspond to the average of 5 independent measurements. The concentration (c) of 2-nitrobenzaldehyde was determined via the Beer-Lambert law (A = εcl; l = length of the light path = thickness of the cuvette)

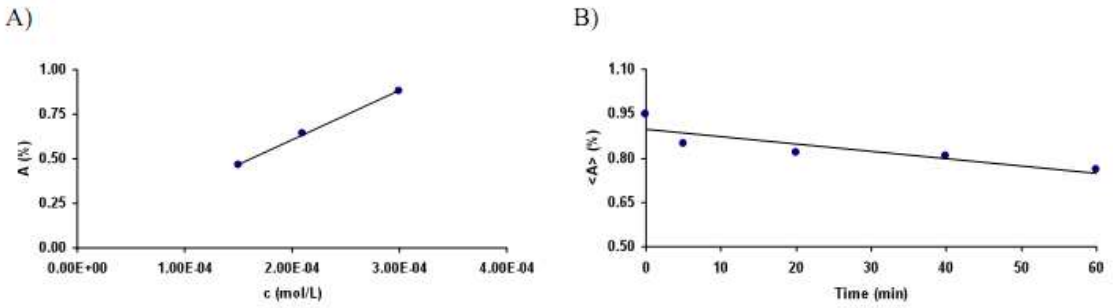


Figure S4. A) UV-Vis calibration curve of 2-NBA in DMSO; B) UV-Vis absorption of 2-NBA in DMSO over time.

8. Model kinetic study

The kinetic study of a model Knoevenagel condensation between 2-nitrobenzaldehyde (2-NBA) and ethylcyanoacetate in DMSO at room temperature catalyzed by CSHB was carried out within a reaction time range of 40 min (Figure S5). The yields were determind by NMR analysis using an internal standard (i.e. diemthylacetamide), which was added to the isolated crude product.

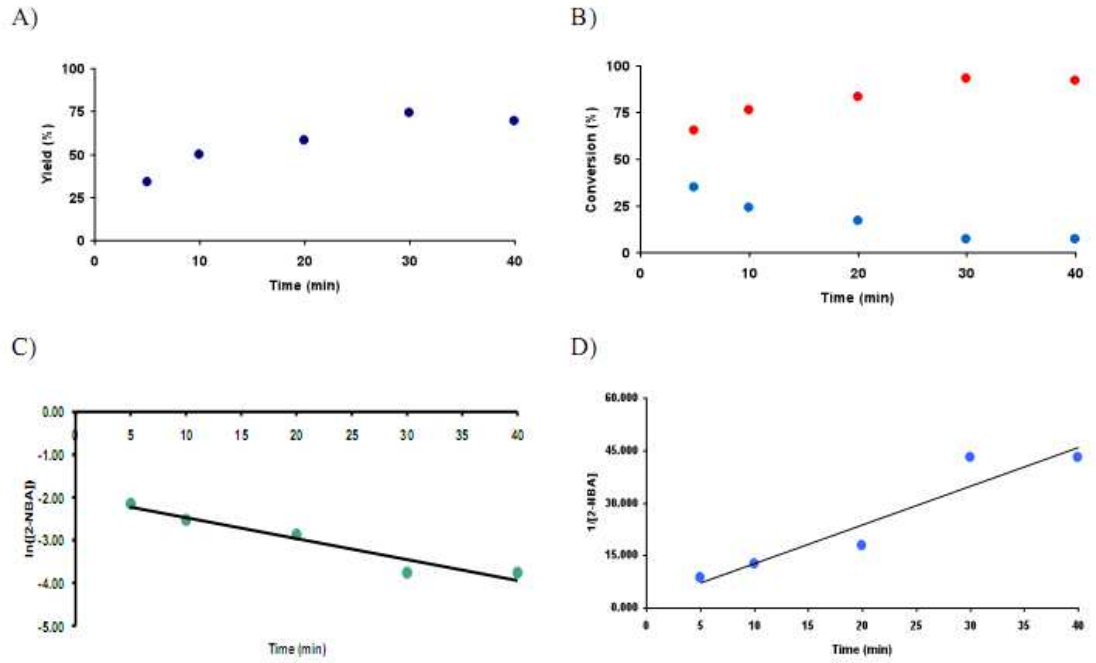


Figure S5. A) Plot of product yield (%) *vs.* time (min); B) Plot of reaction conversion (%) *vs.* time (min); Red dots: Disappeared 2-nitrobenzaldehyde during reaction; Blue dots: Remained 2-nitrobenzaldehyde during reaction; C) Plot of natural logarithm of the remained concentration of 2-nitrobenzaldehyde during reaction *vs.* time; D) Plot of reciprocal fraction of the remained concentration of 2-nitrobenzaldehyde during reaction *vs.* time.