Electronic Supplementary Material (ESI) for Green Chemistry

Supplementary Information

Design and Evaluation of Switchable-Hydrophilicity Solvents

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Contents:

1. Identification of Secondary Amine Salts By ^{13}C {^{1}H} NMR Spectroscopy

Equal volume mixtures of secondary amine and carbonated, nondeuterated water were characterized by ^{13}C {^{1}H} NMR using the nitrile carbon in CH_3CN as a reference (119.68 ppm) in order to determine if bicarbonate or carbamate ions were present in solution. The peak associated with the bicarbonate ion appears near 162 ppm, while the peak associated with the carbamate ion appears near 165 ppm.[1] Dipropylamine, di-*sec*-butylamine, and N-propyl-*sec*-butylamine were investigated in this way; expansions of their ^{13}C {^{1}H} NMR spectra are shown in Fig S1. The dipropylamine spectrum contains peaks at 165 and 162 ppm, indicating the presence of both carbamate and bicarbonate ions, while the spectra of the other amines only contain peaks near 162 ppm, indicating the presence of bicarbonate ions alone. These results suggest that the carbamate salts of sterically hindered secondary amines are either not formed or are rapidly hydrolyzed.

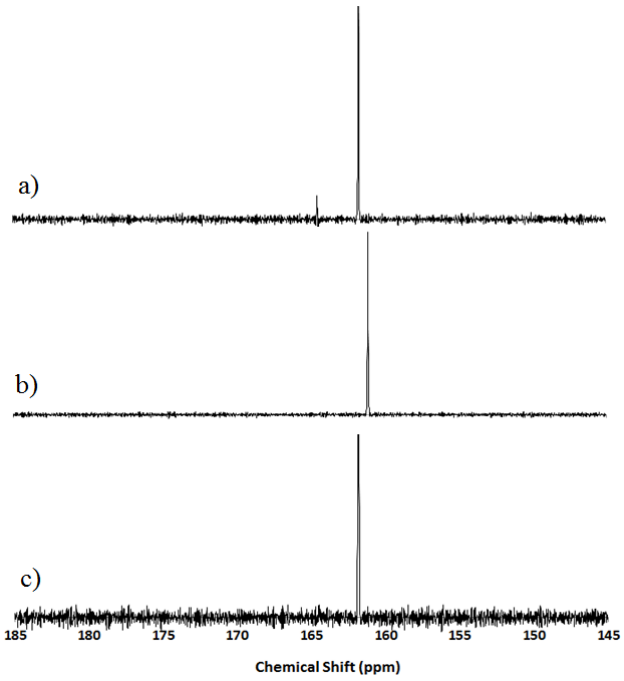

Fig. S1 Expansions of ^{13}C $\{^{1}H\}$ NMR spectra of carbonated H_2O and a) dipropylamine, b) *sec*-butylpropylamine, and c) di-*sec*-butylamine.

2. Evaluation of the Accuracy of LD_{50} Predictions by the TEST Program

The LD_{50} (oral, rat) values of 8 amine SHSs and 14 amines which are not SHSs were predicted using the consensus method offered in the TEST software[2] and compared to reported values from MSDS. The predicted values were plotted against the reported values. The predicted values were found to be within a factor of 3 of the known values 95% of the time (21/22).

Amine	Experimental LD_{50} (oral, rat) (mg kg^{-1})	Predicted LD_{50} (oral, rat) (mg kg^{-1})
N,N-dimethylcyclohexylamine	348[3]	320
N-ethylpiperidine	280[4]	640
N,N-dimethylbutylamine	188[5]	320
triethylamine	460[3]	1,300
diisopropylaminoethanol	860[6]	2,300
dibutylaminoethanol	1,070[3]	1,500
dipropylamine	460[3]	250
methylamine	100[7]	130
ethylamine	400[3]	920
propylamine	570[8]	300
butylamine	372[9]	630
sec-butylamine	152[9]	420
dibutylamine	220[3]	460
dimethylamine	698[3]	690
diethylamine	540[3]	840
trimethylamine	500[10]	600
tripropylamine	72[3]	280
tributylamine	540[11]	630
dimethylaminoethanol	2,000[3]	1,100
diethylaminoethanol	1,300[3]	1,200
triethanolamine	8,000[3]	4,800
N,N-dimethylbenzylamine	265[3]	530

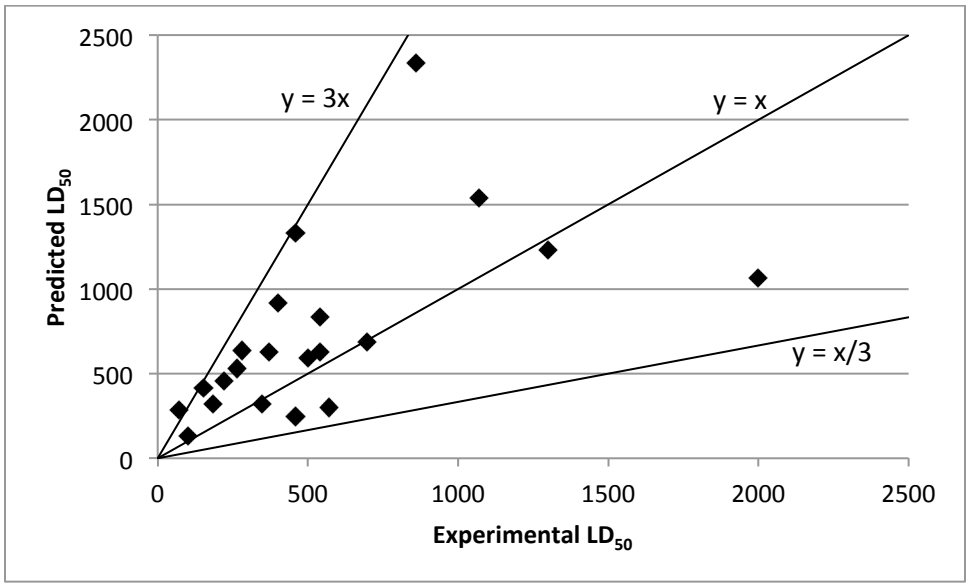

Fig S2 Predicted vs. experimental LD_{50} values of various amines. The three lines signify an accurate prediction (y = x) and factors of 3 away from an accurate prediction (y = 3x and y = x/3)

3. Evaluation of the Accuracy of Flash Points Predicted by the TEST Program

The flash points of 24 amines were predicted using the consensus method offered in the TEST software and compared to reported values from MSDS. Fifteen SHSs with known flash points were used in the analysis, as were 9 other amines. The predicted values were plotted against the known values. The predicted flash points do not correlate well with reported flash points when the reported values are below 0 ^{o}C or the predicted values are below 31 ^{o}C. For amines with experimental flashpoints above 20 ^{o}C, the predicted values are within 8 ^{o}C of the reported flash points 81% of the time (13 of 16).

Amine	Experimental Flash Point (^{o}C)	Predicted Flash Point (^{o}C)
N,N-dimethylcyclohexylamine	43[12]	38
N-ethylpiperidine	17[13]	27
N-butylpyrrolidine	35[14]	43
N,N-dimethylhexylamine	34[15]	29
N,N-dimethylbutylamine	-5[5]	7
N,N-diethylbutylamine	24[16]	29
N-methyldipropylamine	-3[17]	19
triethylamine	-9[18]	5
diisopropylaminoethanol	64[19]	66
dibutylaminoethanol	95[20]	96
4,4-diethoxy-*N,N*-dimethylbutanamine	70[21]	68
N,N-dimethylphenethylamine	71[22]	70
dipropylamine	17[18]	16
di-*sec*-butylamine	21[23]	24
butylamine	-1[24]	31
sec-butylamine	-19[18]	4
dibutylamine	40[25]	44
trimethylamine	-7[3]	-11
tripropylamine	41[18]	41
tributylamine	63[26]	70
dimethylaminoethanol	41[12]	41
diethylaminoethanol	50[27]	63
triethanolamine	179[18]	153
N,N-dimethylbenzylamine	53[28]	67

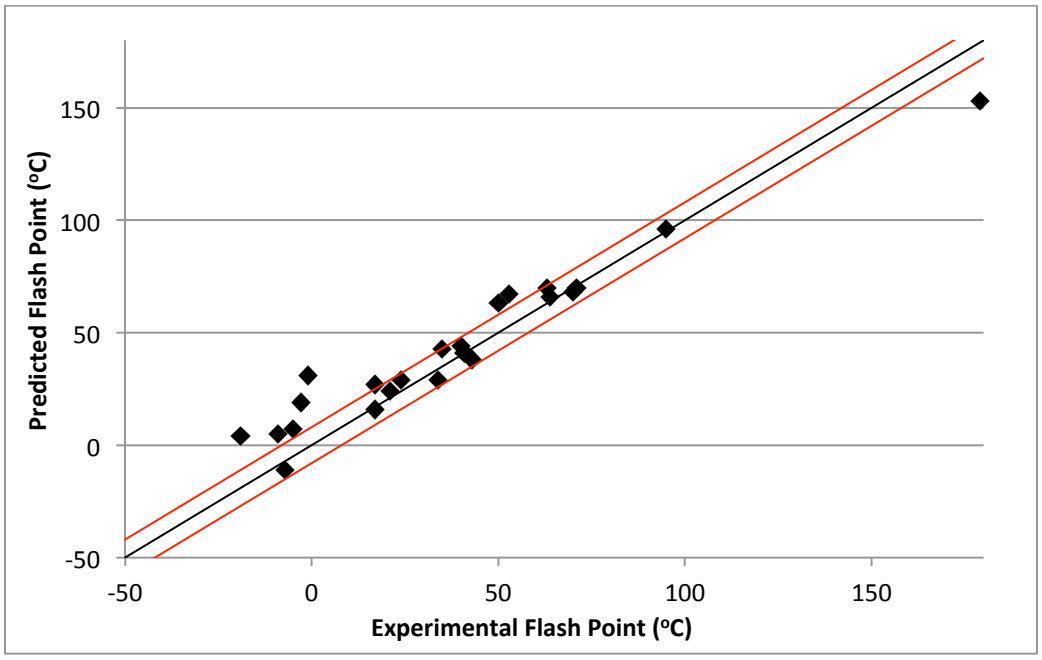

Fig S3 Predicted vs. experimental flash points of various amines. The black line represents an accurate prediction and the red lines represent differences of 8 ^{o}C from an accurate prediction.

4. Spectroscopic Data for Synthetic Products

a) Ethyl 3-(diethylamino)propanoate

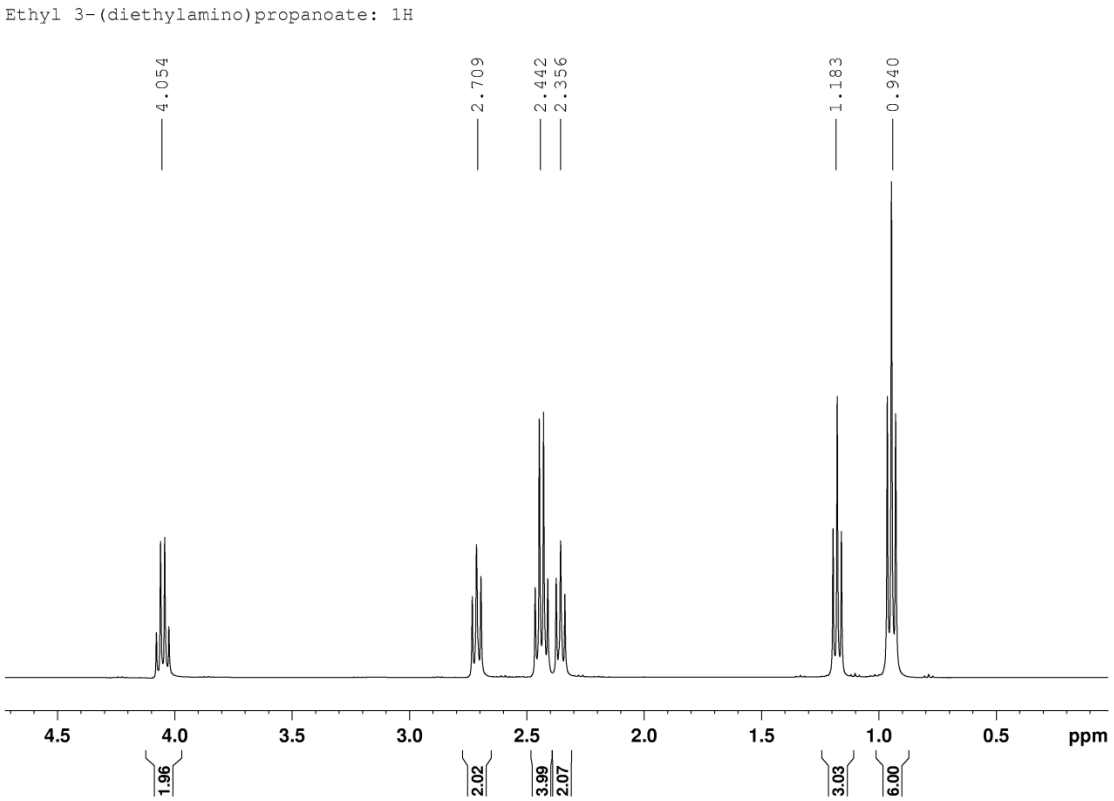

Fig S4 ^{1}H NMR spectrum of ethyl 3-(diethylamino)propanoate ($CDCl_3$, 300 MHz).

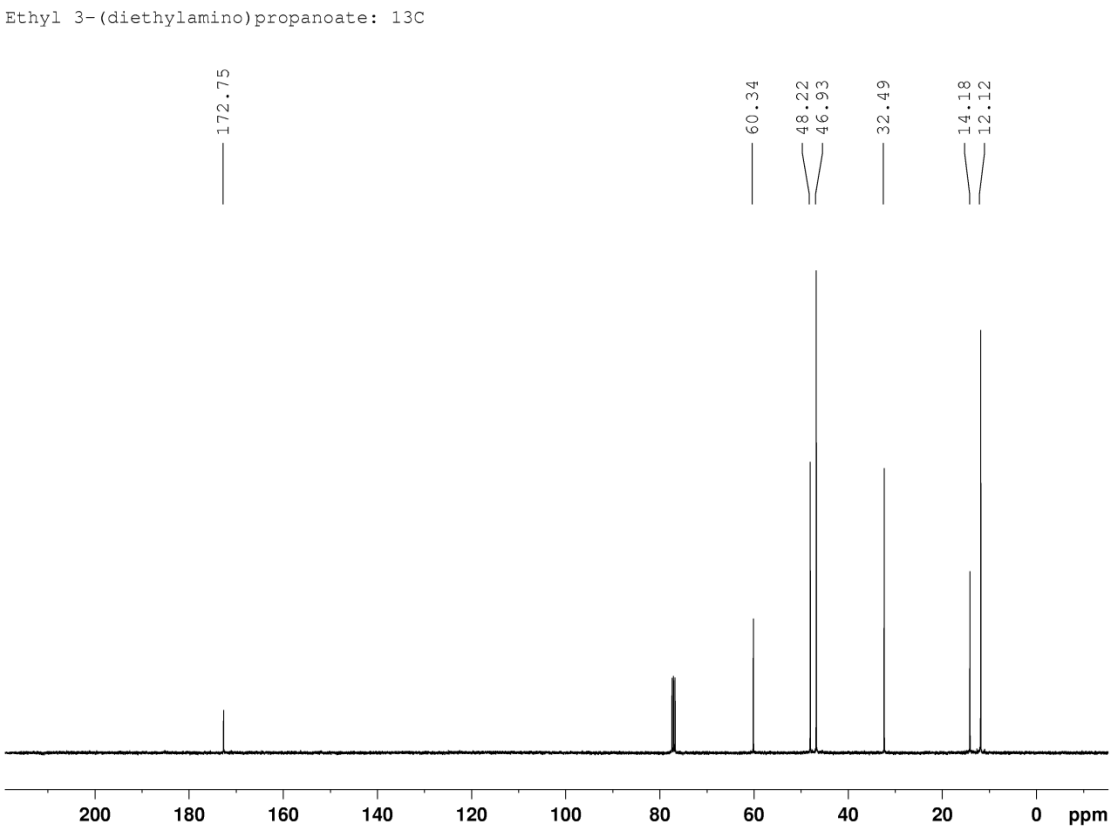

Fig S5 ^{13}C NMR spectrum of ethyl 3-(diethylamino)propanoate ($CDCl_3$, 300 MHz).

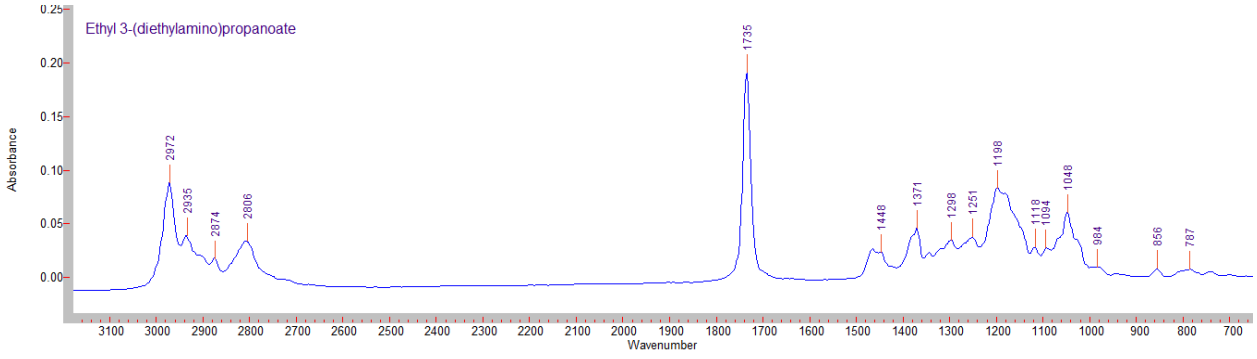

Fig S6 IR spectrum of ethyl 3-(diethylamino)propanoate.

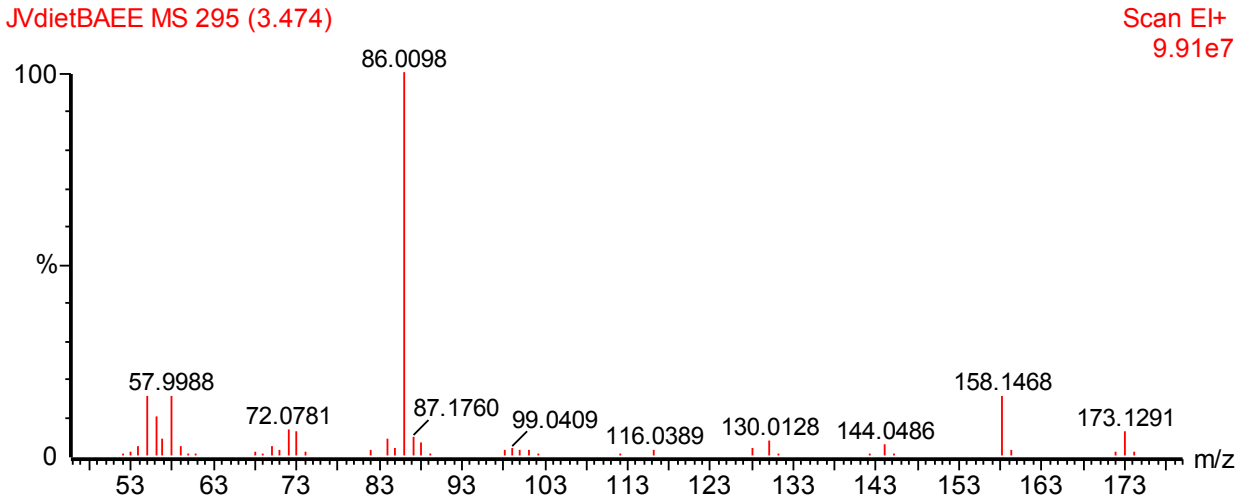

Fig S7 Mass spectrum of ethyl 3-(diethylamino)propanoate (EI).

b) Ethyl 3-(dipropylamino)propanoate

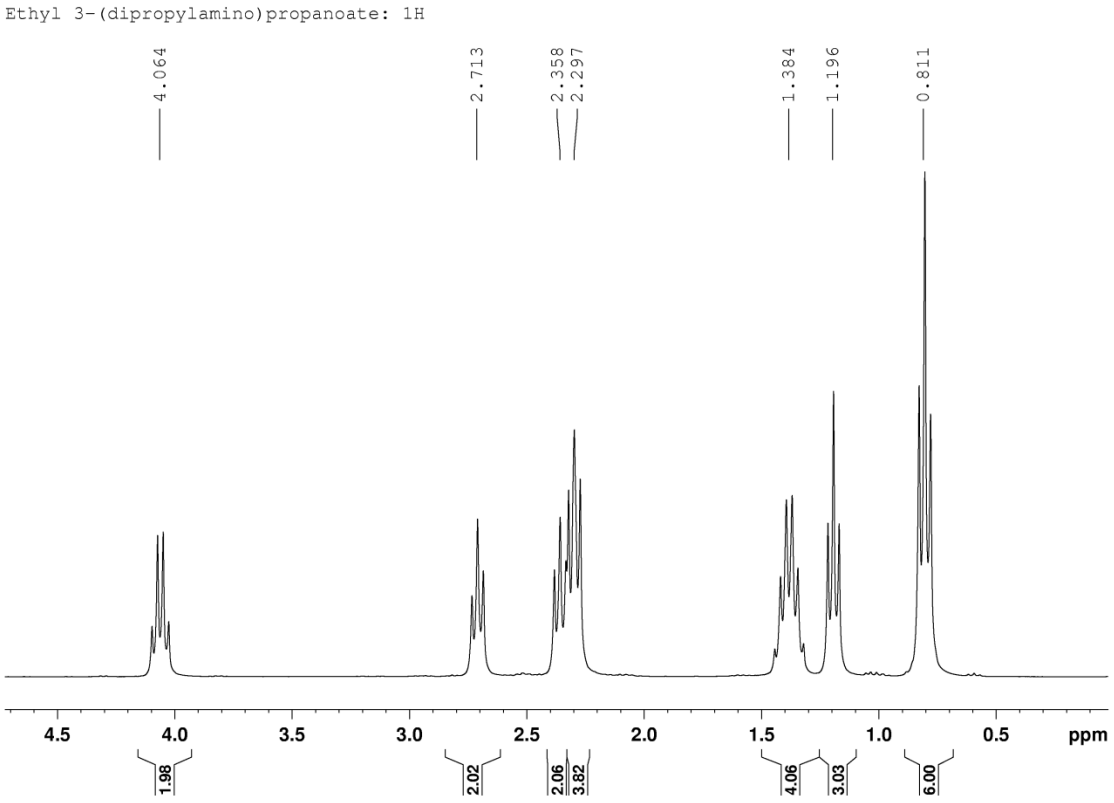

Fig S8 ^{1}H NMR spectrum of ethyl 3-(dipropylamino)propanoate ($CDCl_3$, 300 MHz).

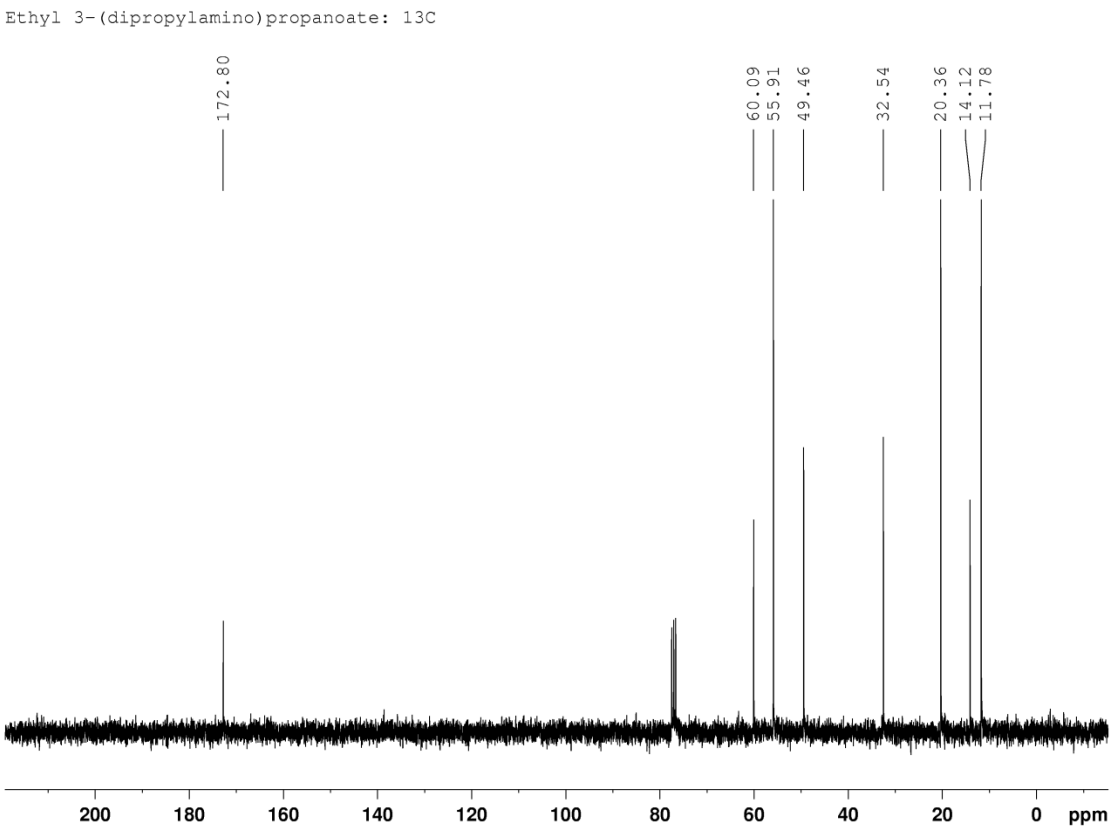

Fig S9 ^{13}C NMR spectrum of ethyl 3-(dipropylamino)propanoate ($CDCl_3$, 300 MHz).

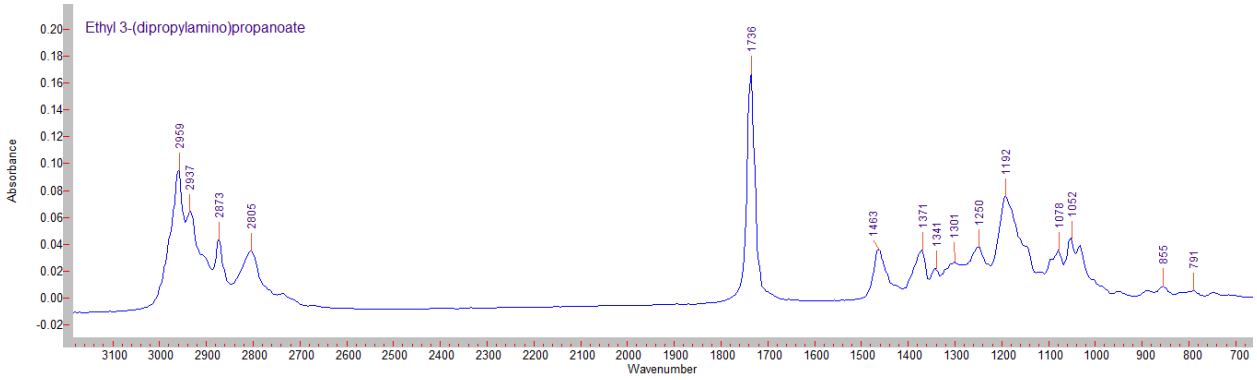

Fig S10 IR spectrum of ethyl 3-(dipropylamino)propanoate.

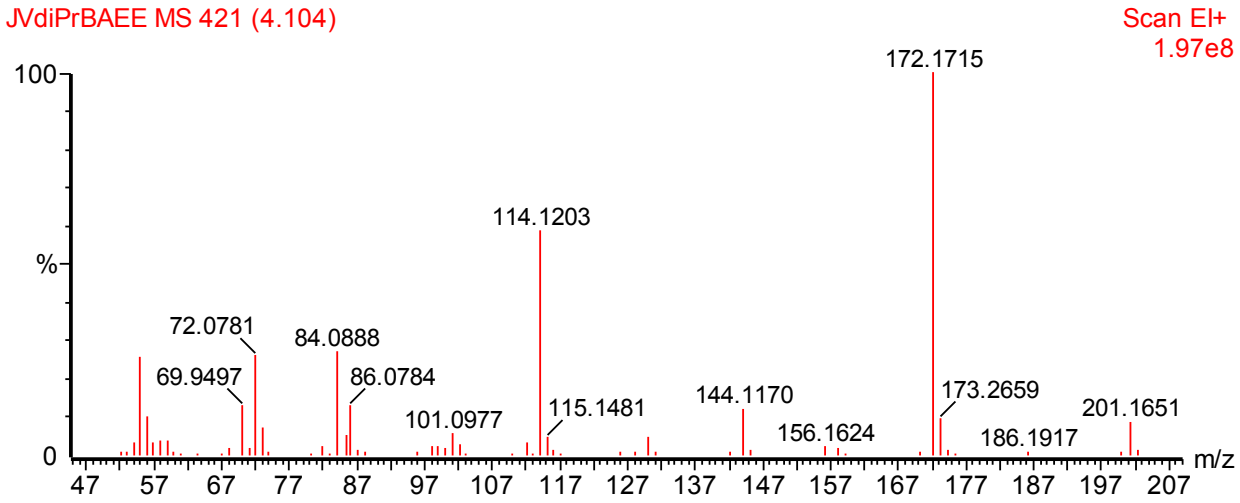

Fig S11 Mass spectrum of ethyl 3-(dipropylamino)propanoate (EI).

c) Ethyl 4-(diethylamino)butanoate

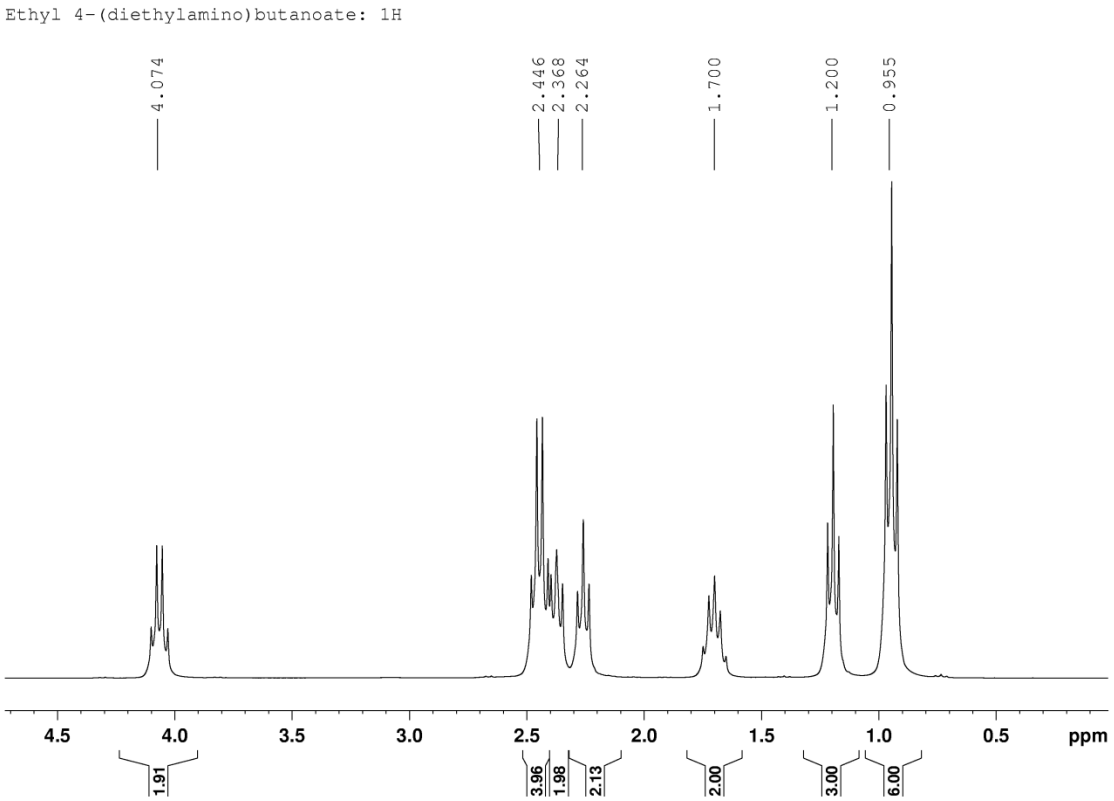

Fig S12 ^{1}H NMR spectrum of ethyl 4-(diethylamino)butanoate ($CDCl_3$, 300 MHz).

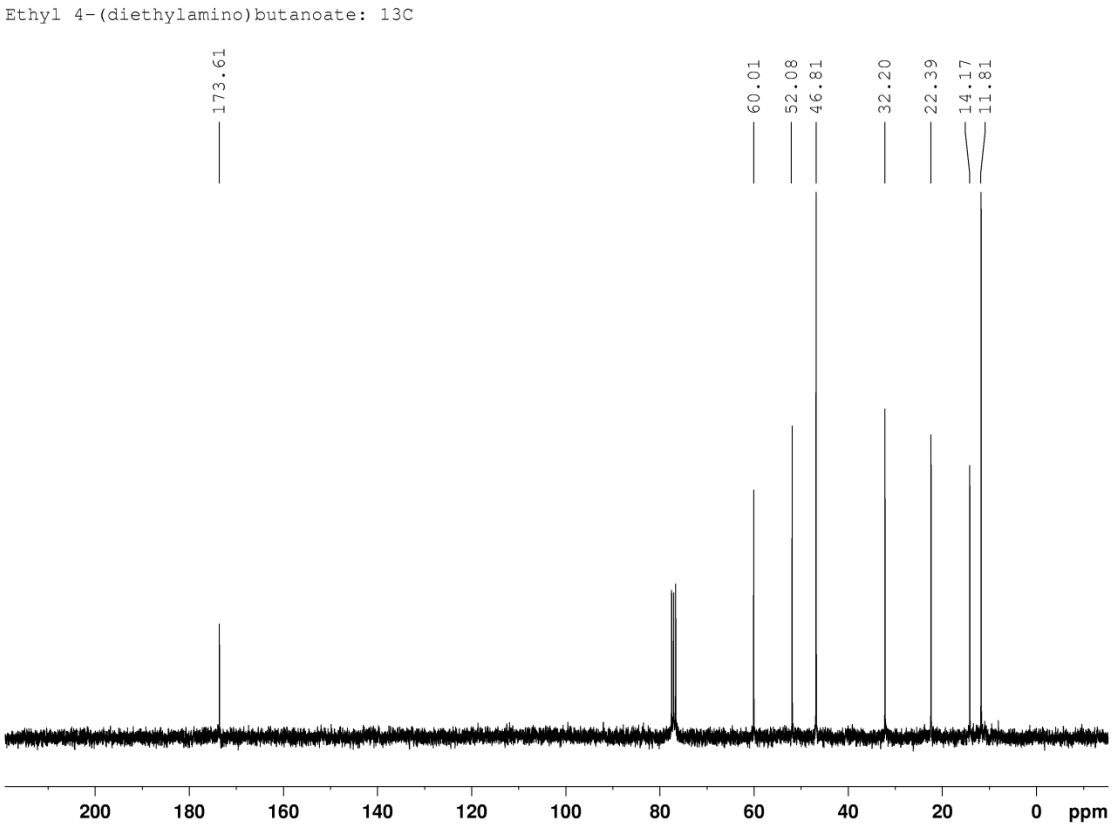

Fig S13 ^{13}C NMR spectrum of ethyl 4-(diethylamino)butanoate ($CDCl_3$, 300 MHz).

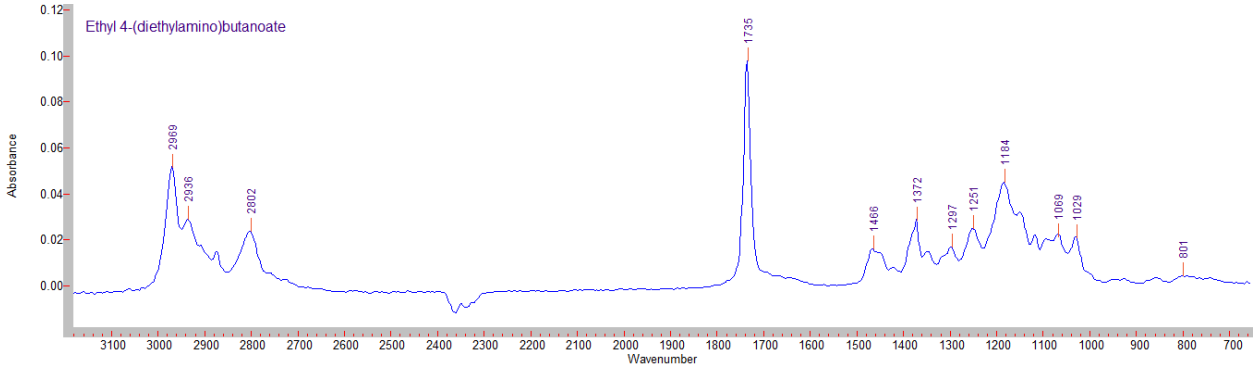

Fig S14 IR spectrum of ethyl 4-(diethylamino)butanoate.

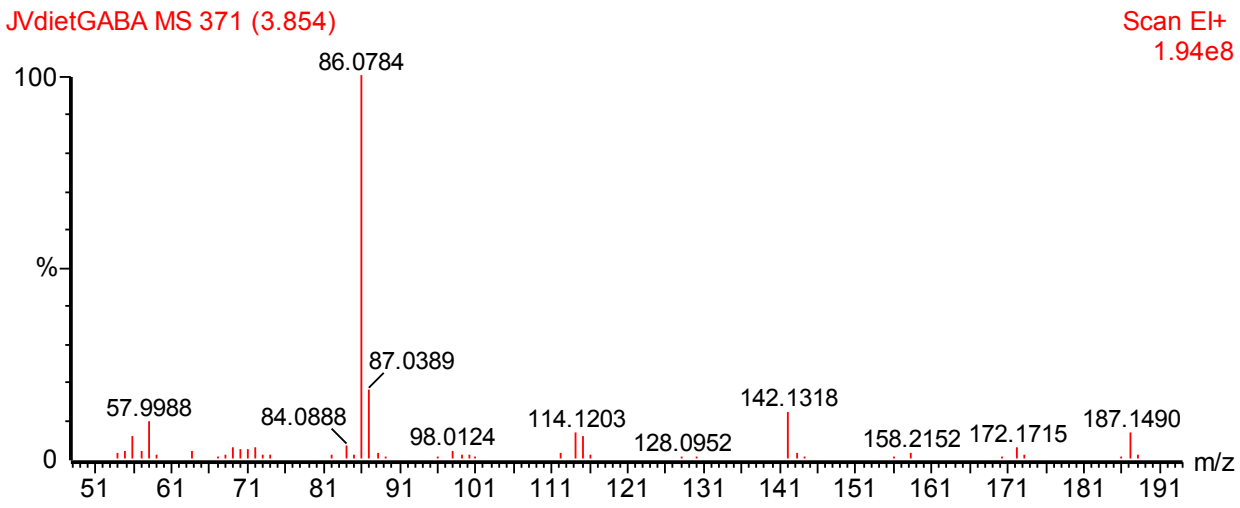

Fig S15 Mass spectrum of ethyl 4-(diethylamino)butanoate (EI).

d) Ethyl 3-(*sec*-butylamino)propanoate

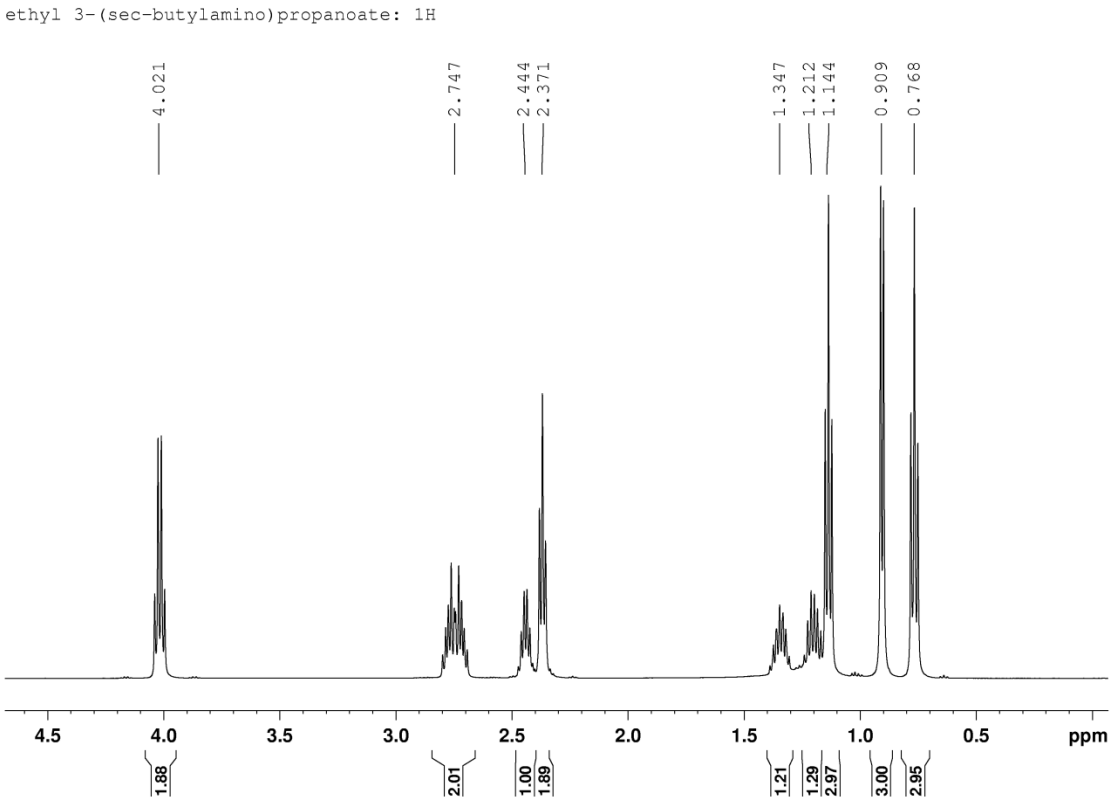

Fig S16 ^{1}H NMR spectrum of ethyl 3-(*sec*-butylamino)propanoate ($CDCl_3$, 500 MHz).

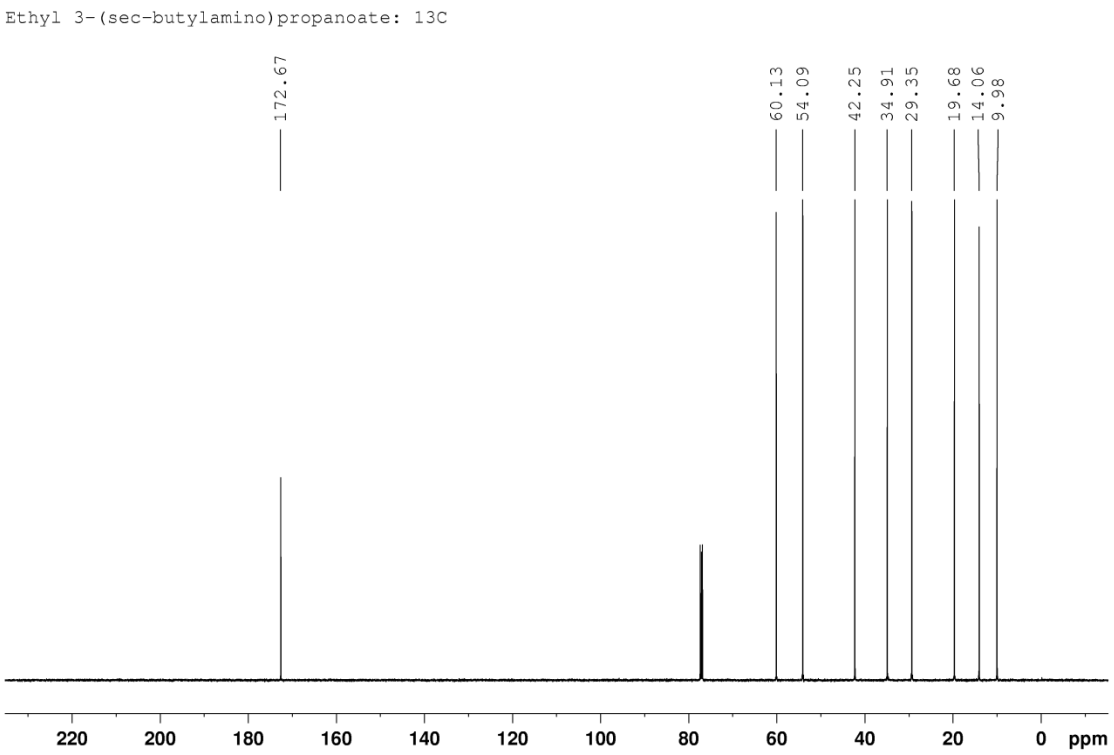

Fig S17 ^{13}C NMR spectrum of ethyl 3-(*sec*-butylamino)propanoate ($CDCl_3$, 500 MHz).

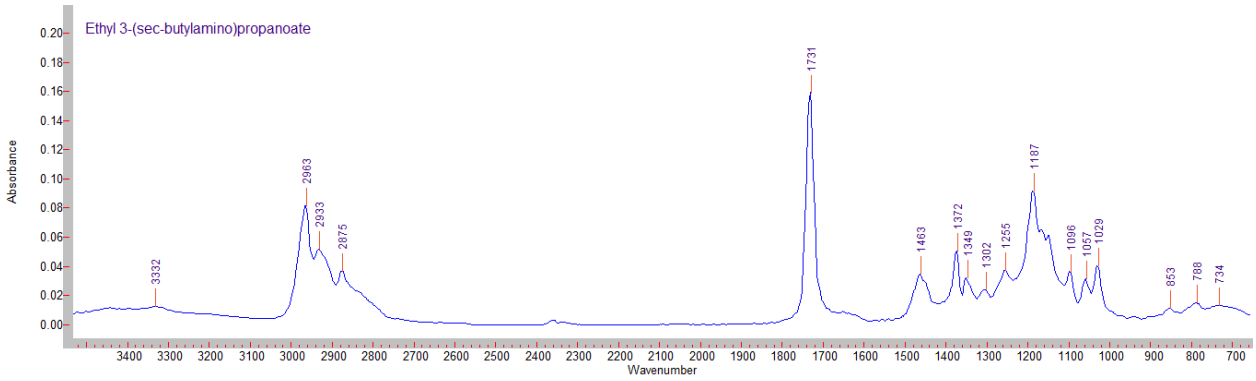

Fig S18 IR spectrum of ethyl 3-(*sec*-butylamino)propanoate.

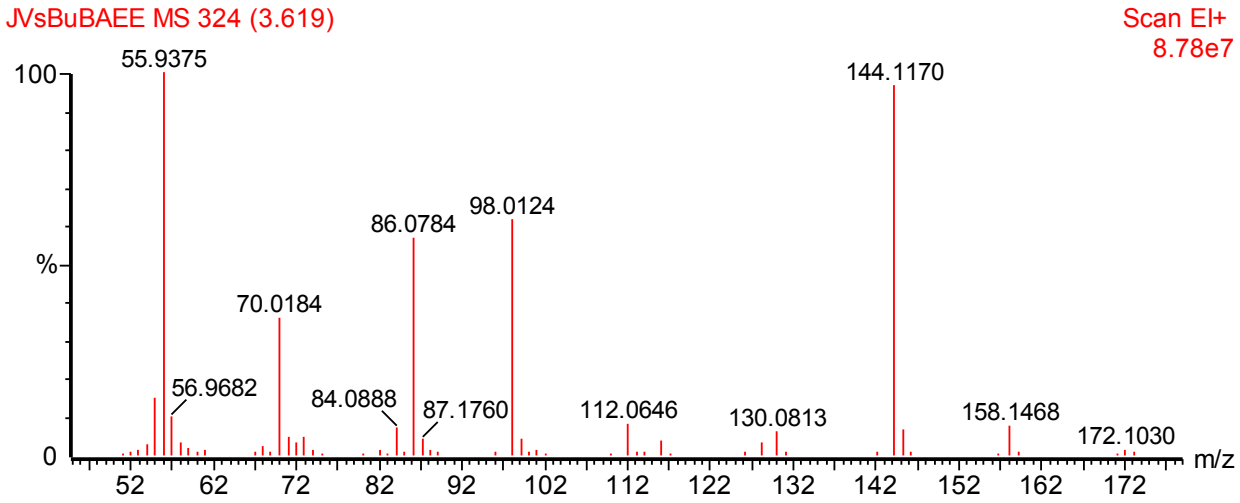

Fig S19 Mass spectrum of ethyl 3-(*sec*-butylamino)propanoate (EI).

e) Ethyl 3-(*tert*-butylamino)propanoate

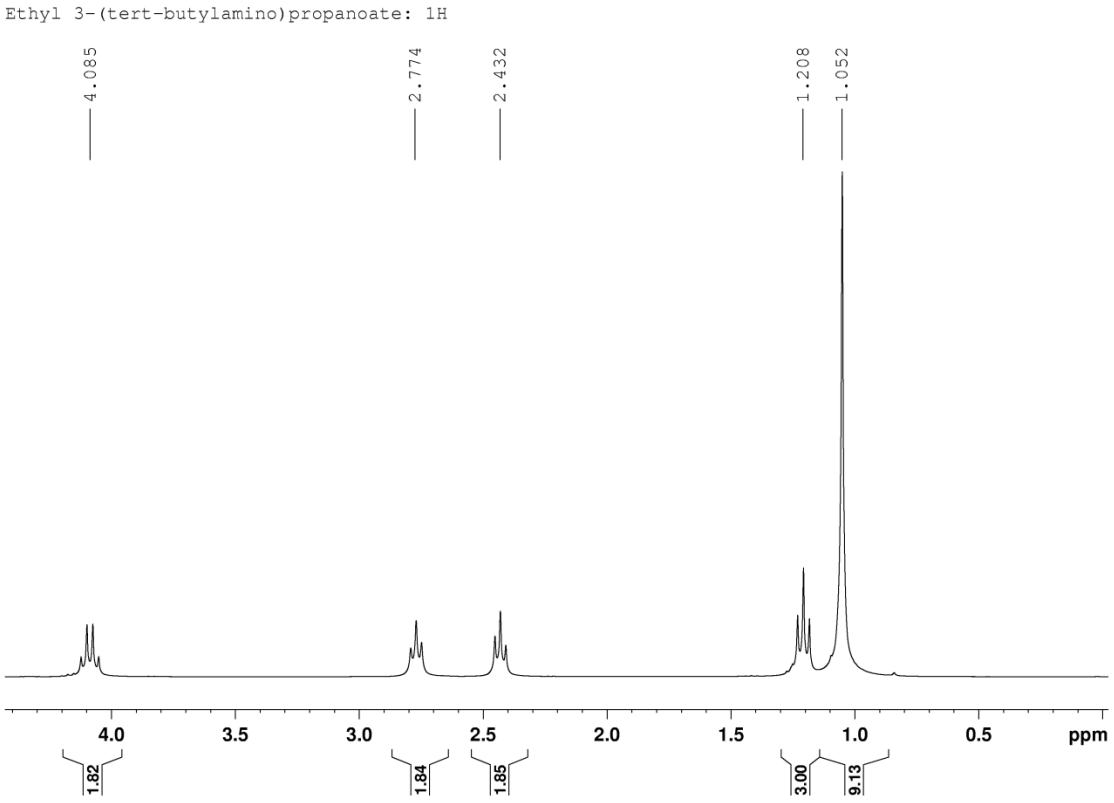

Fig S20 ^{1}H NMR spectrum of ethyl 3-(*tert*-butylamino)propanoate ($CDCl_3$, 300 MHz).

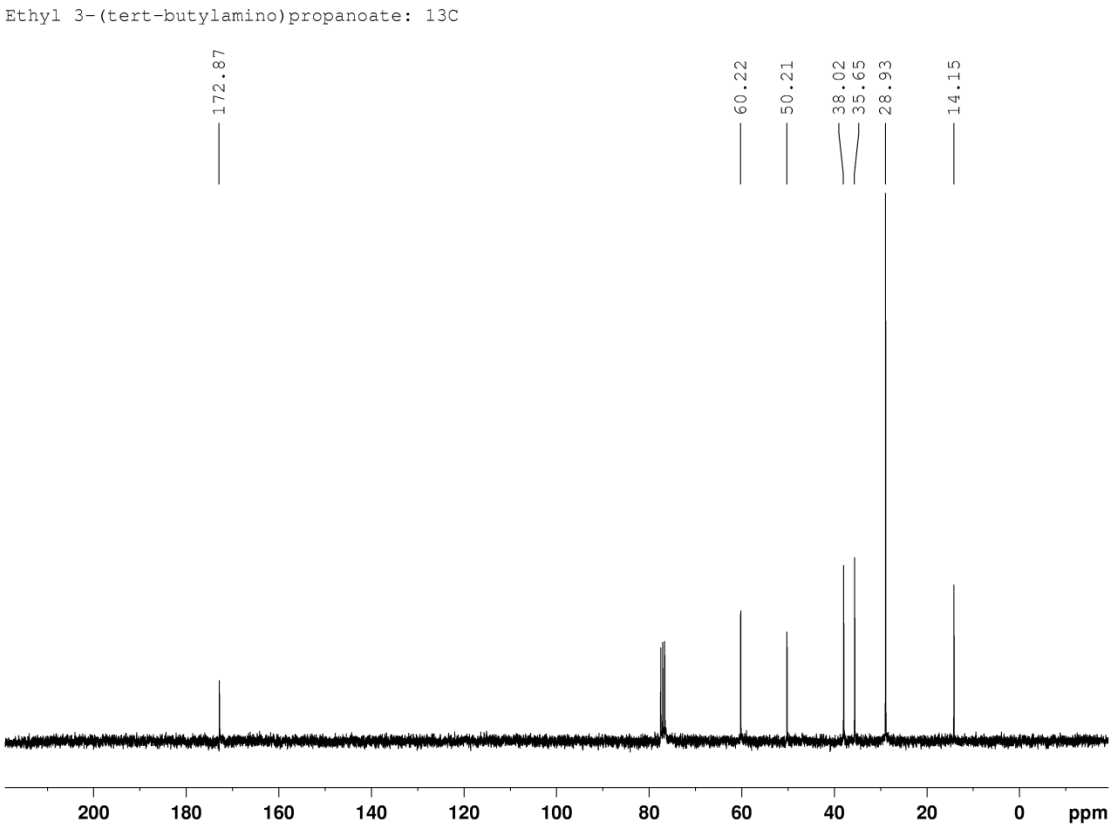

Fig S21 ^{13}C NMR spectrum of ethyl 3-(*tert*-butylamino)propanoate ($CDCl_3$, 300 MHz).

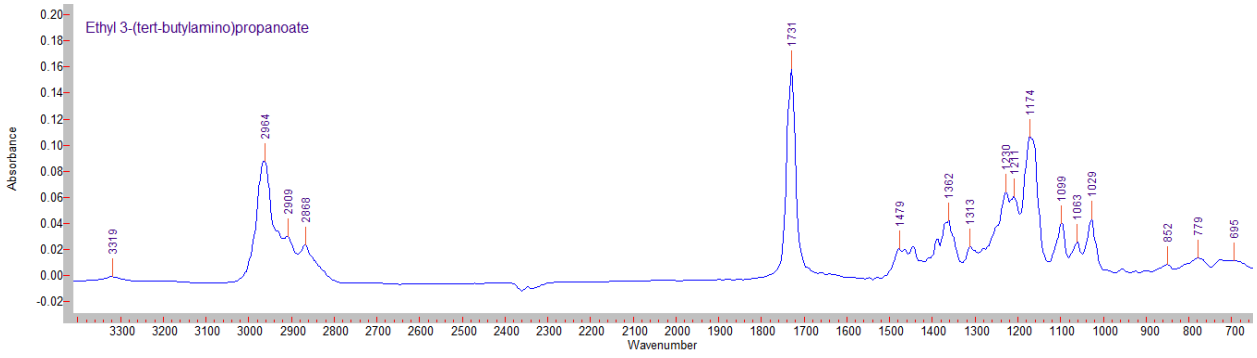

Fig S22 IR spectrum of ethyl 3-(*tert*-butylamino)propanoate.

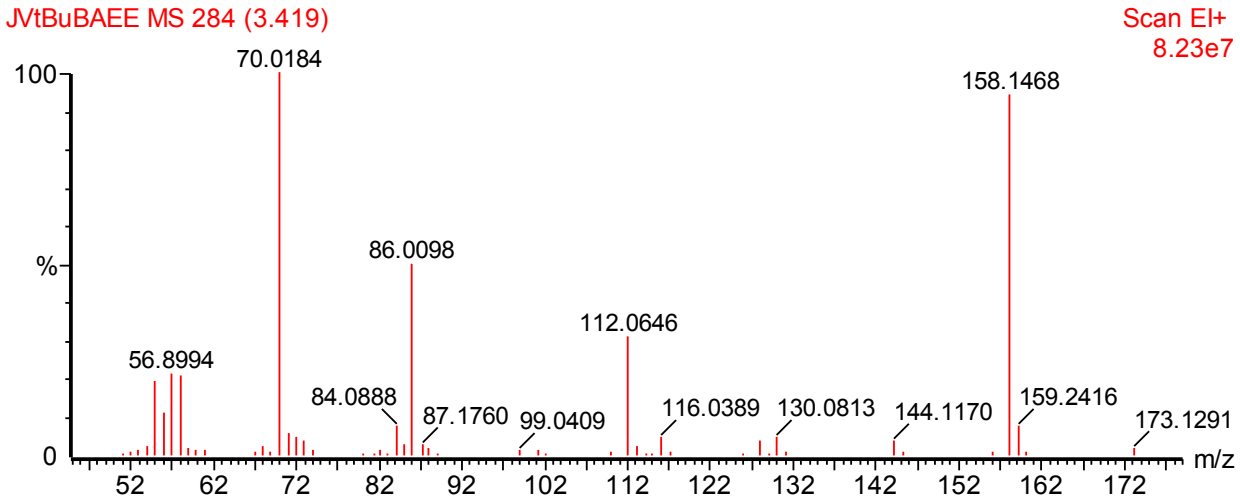

Fig S23 Mass spectrum of ethyl 3-(*tert*-butylamino)propanoate (EI).

f) Ethyl 3-(isobutylamino)propanoate

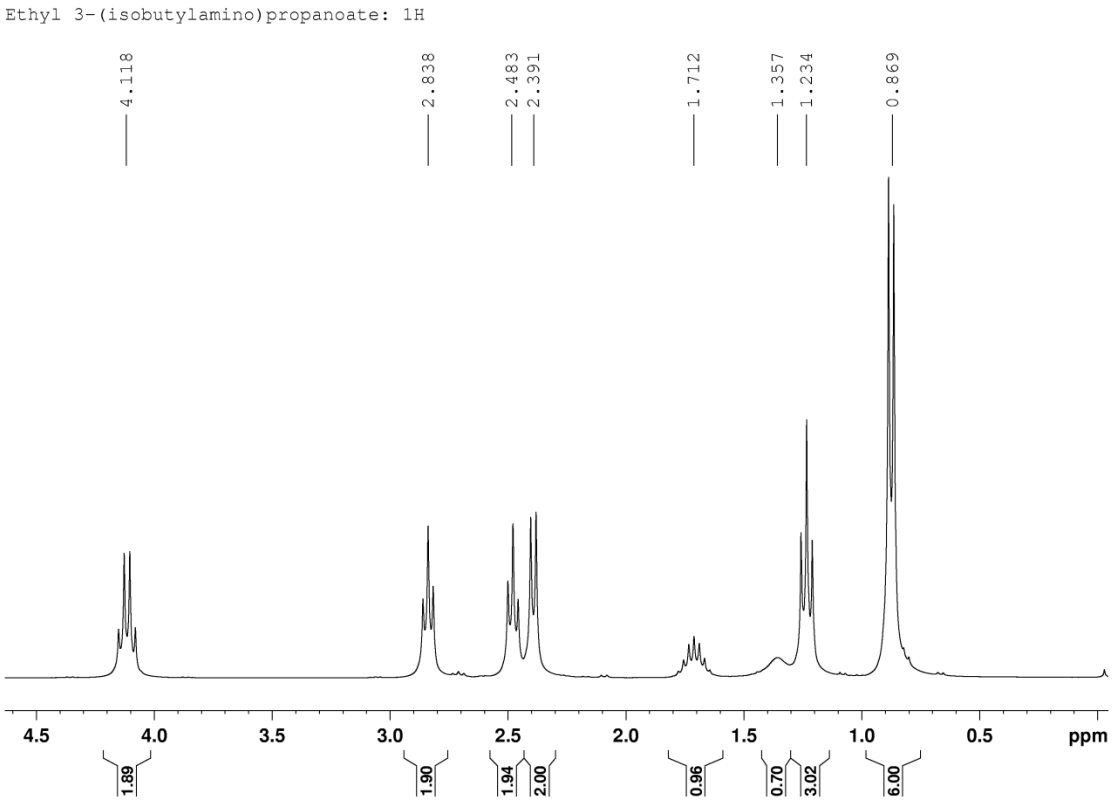

Fig S24 ^{1}H NMR spectrum of ethyl 3-(isobutylamino)propanoate ($CDCl_3$, 300 MHz).

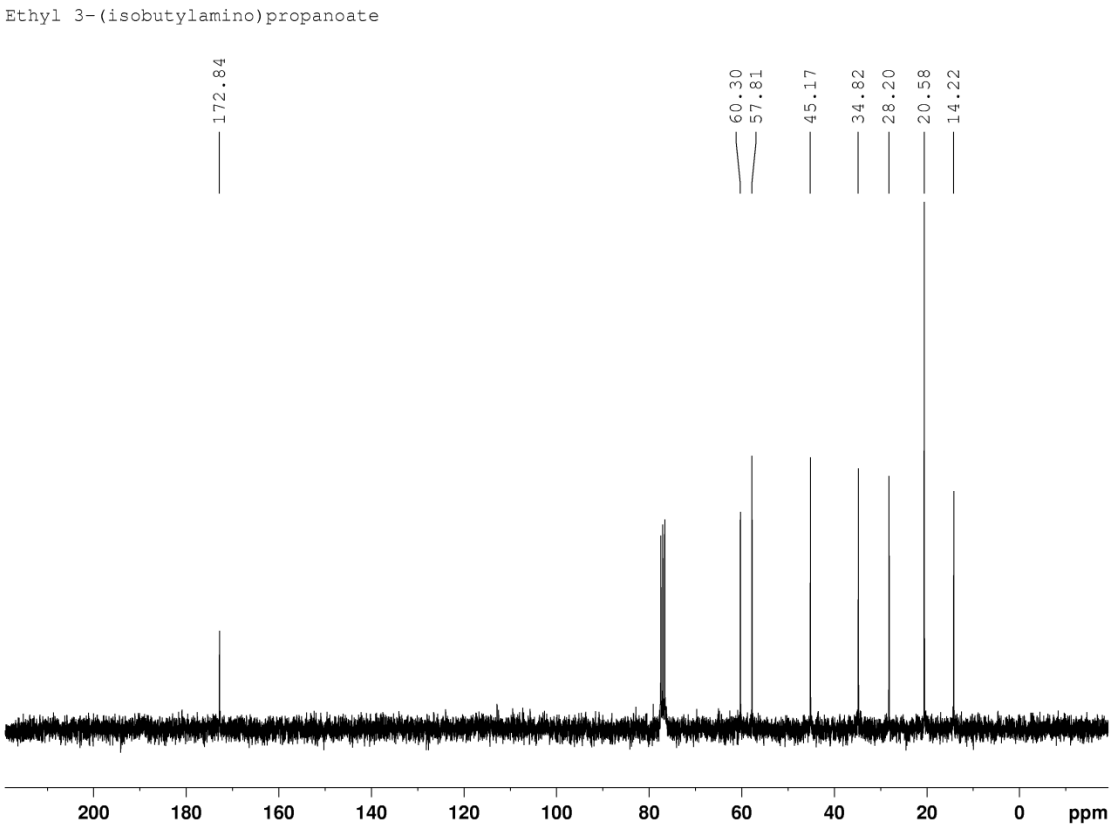

Fig S25 ^{13}C NMR spectrum of ethyl 3-(isobutylamino)propanoate ($CDCl_3$, 300 MHz).

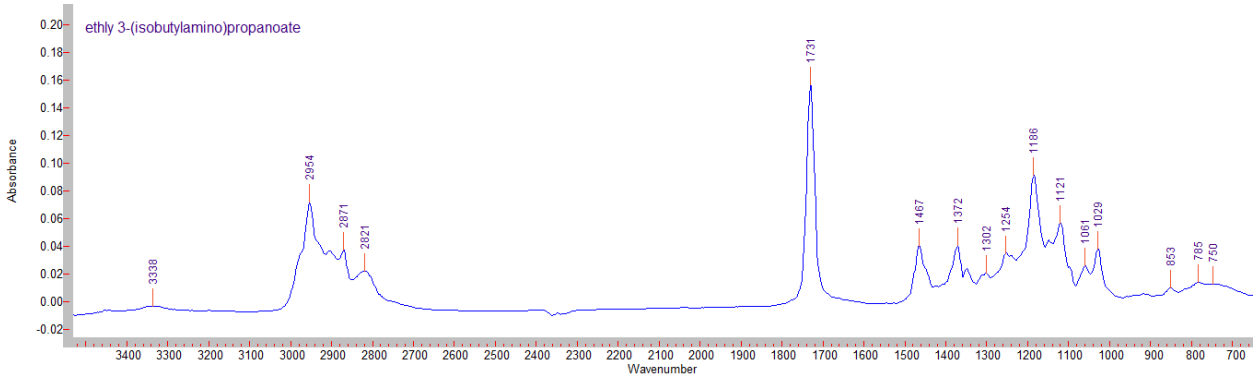

Fig S26 IR spectrum of ethyl 3-(isobutylamino)propanoate.

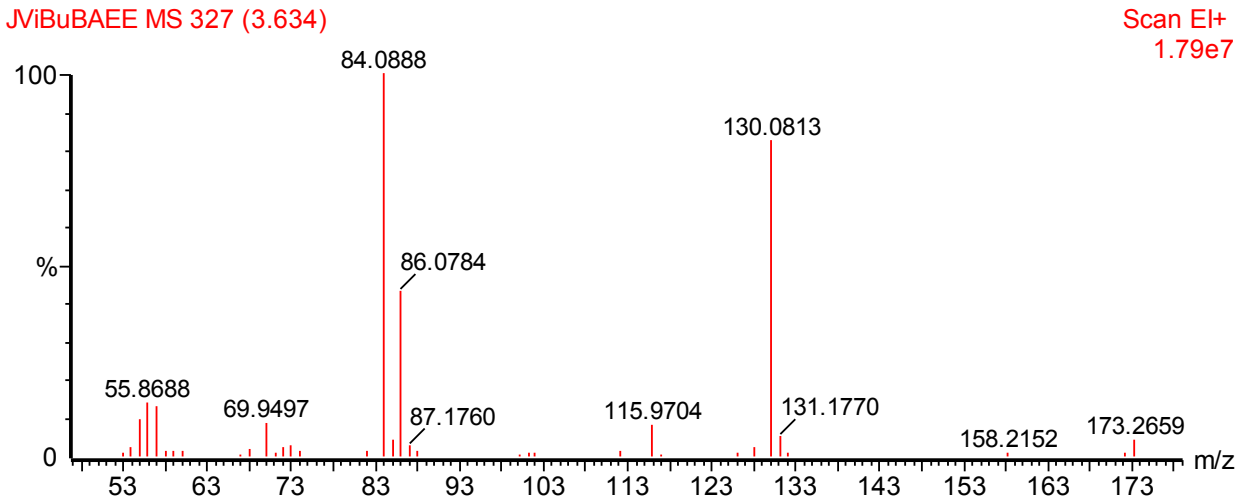

Fig S27 Mass spectrum of ethyl 3-(isobutylamino)propanoate (EI)

g) 5-(diethylamino)pentan-2-one

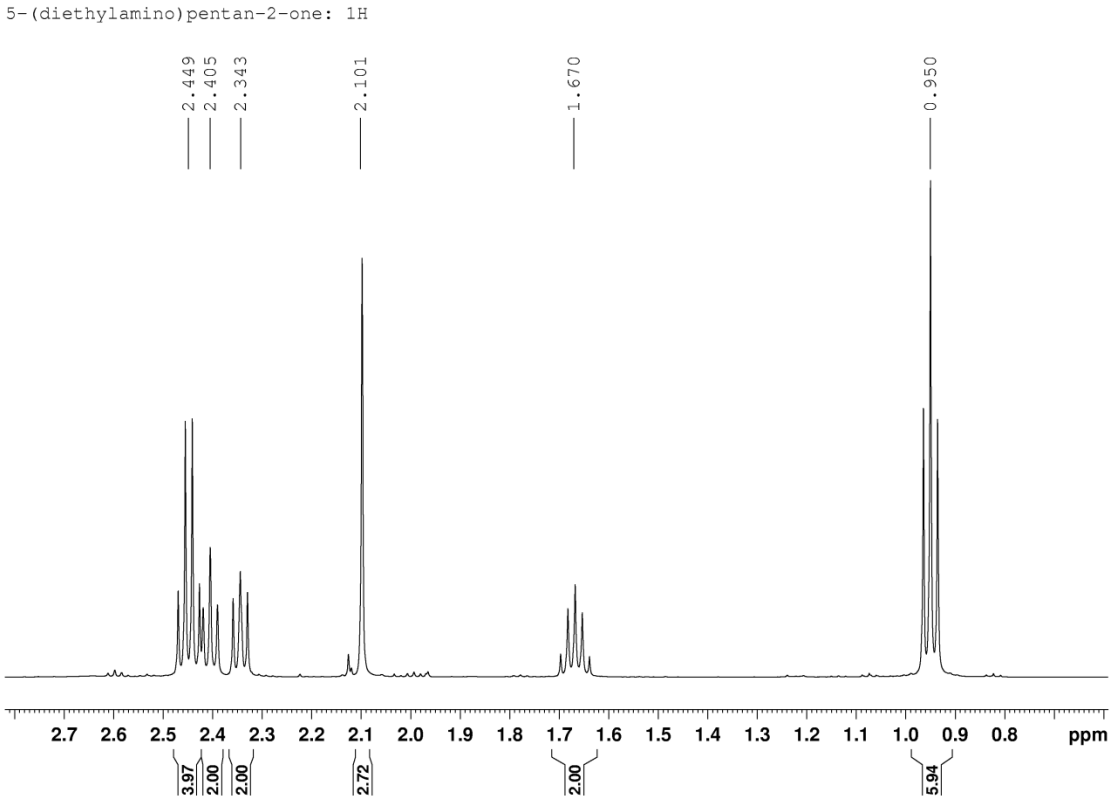

Fig S28 ^{1}H NMR spectrum of 5-(diethylamino)pentan-2-one ($CDCl_3$, 500 MHz).

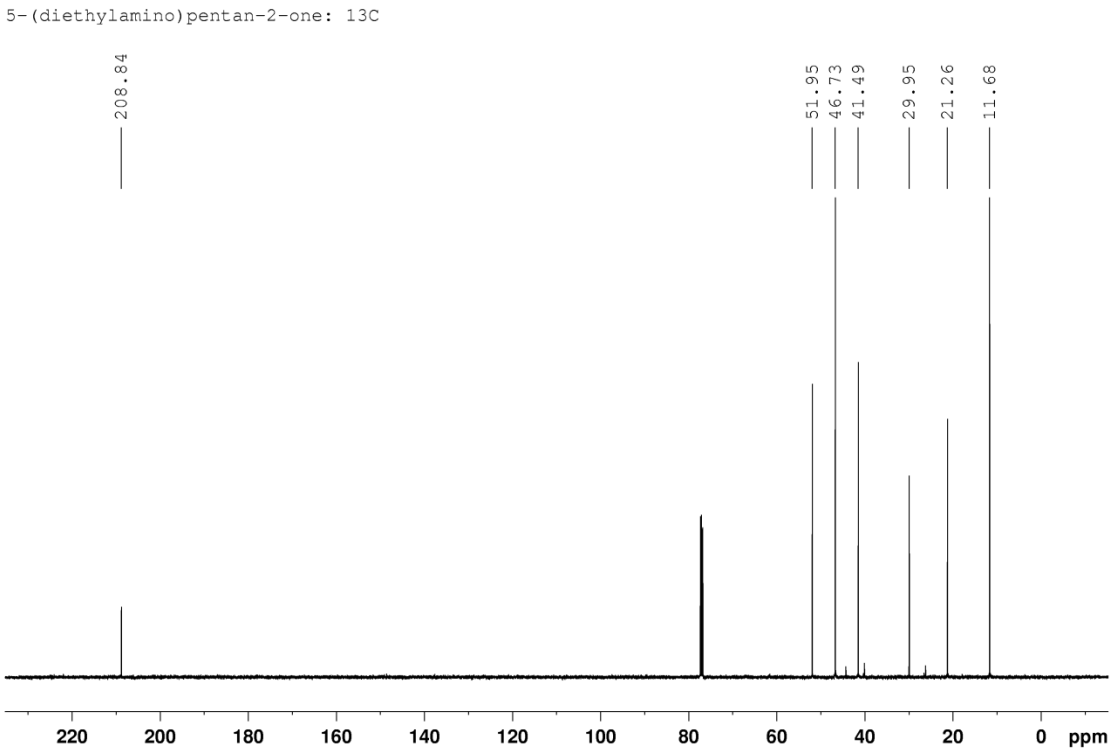

Fig S29 ^{13}C NMR spectrum of 5-(diethylamino)pentan-2-one ($CDCl_3$, 500 MHz).

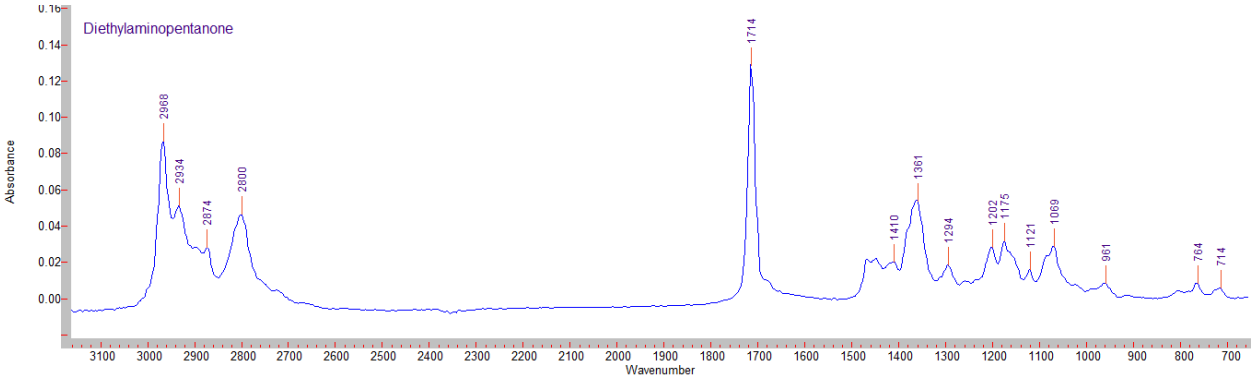

Fig S30 IR spectrum of 5-(diethylamino)pentan-2-one.

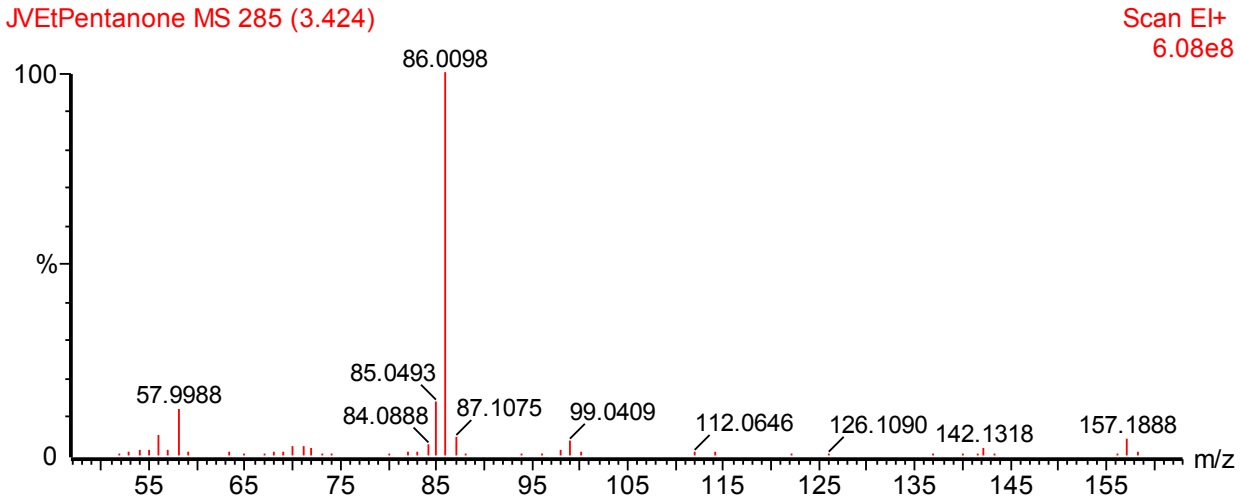

Fig S31 Mass spectrum of 5-(diethylamino)pentan-2-one (EI).

h) 5-(dipropylamino)pentan-2-one

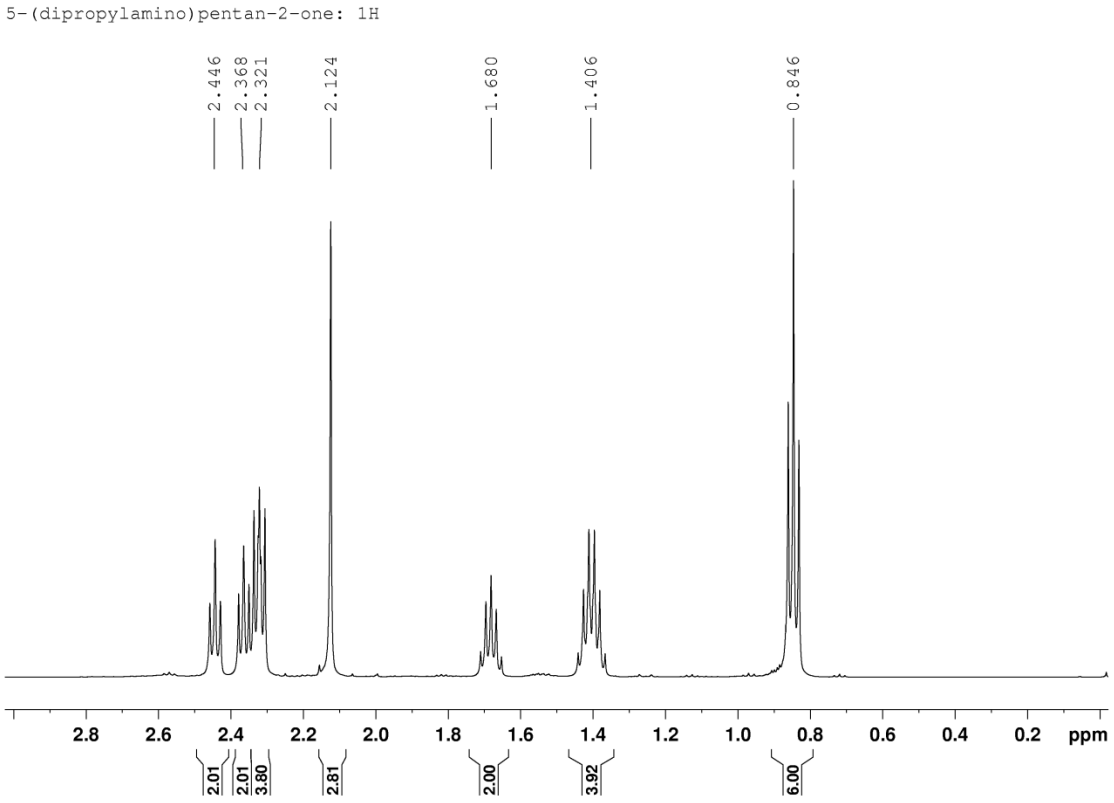

Fig S32 ^{1}H NMR spectrum of 5-(dipropylamino)pentan-2-one ($CDCl_3$, 500 MHz).

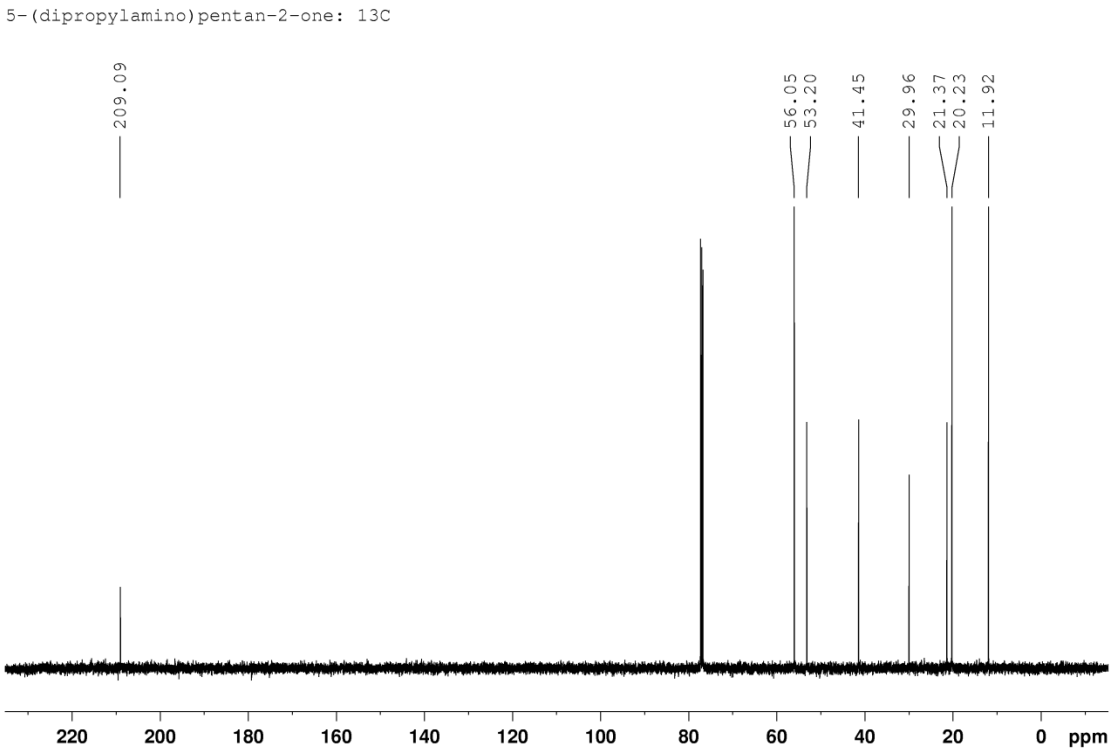

Fig S33 ^{13}C NMR spectrum of 5-(dipropylamino)pentan-2-one ($CDCl_3$, 500 MHz).

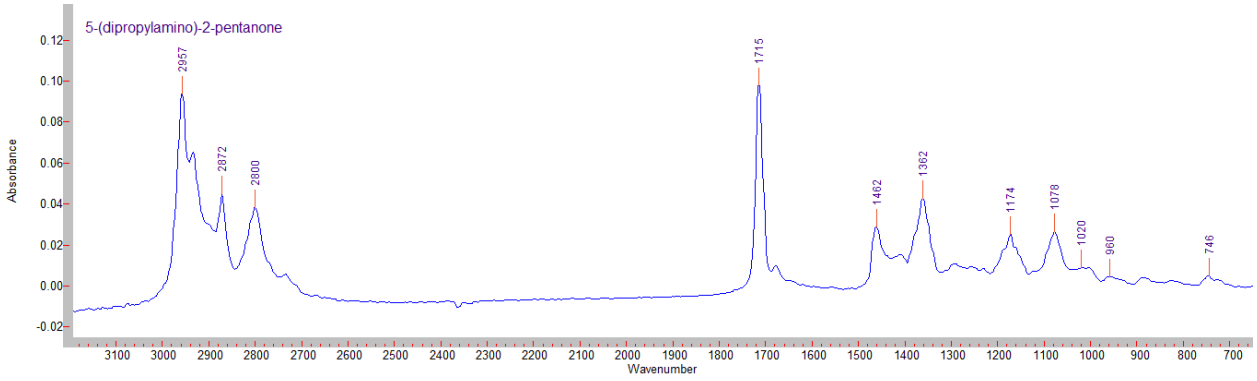

Fig S34 IR spectrum of 5-(dipropylamino)pentan-2-one.

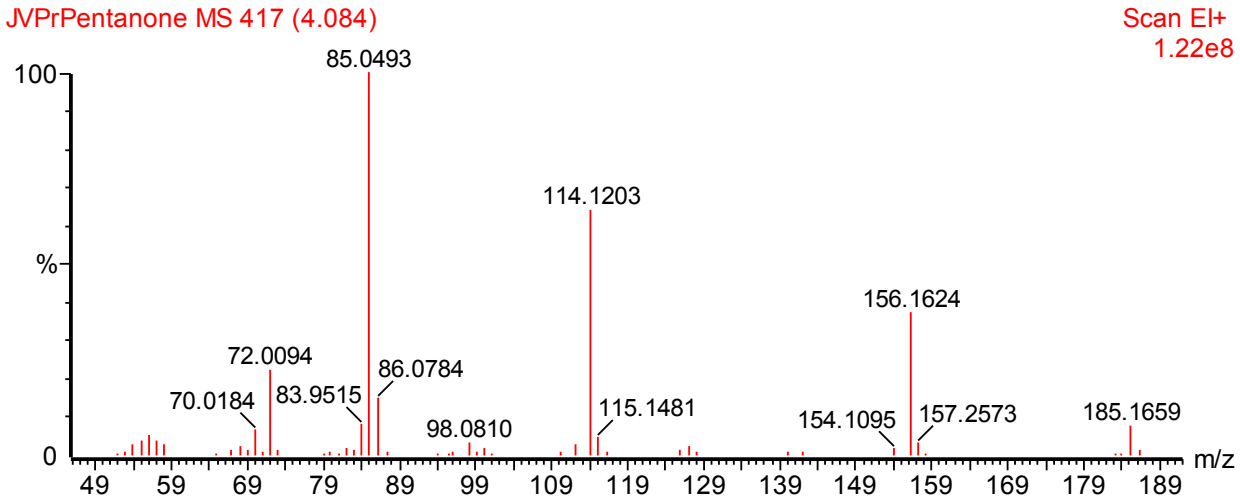

Fig S35 Mass spectrum of 5-(dipropylamino)pentan-2-one (EI).

i) Ethyl 4-(*tert*-butylamino)butanoate

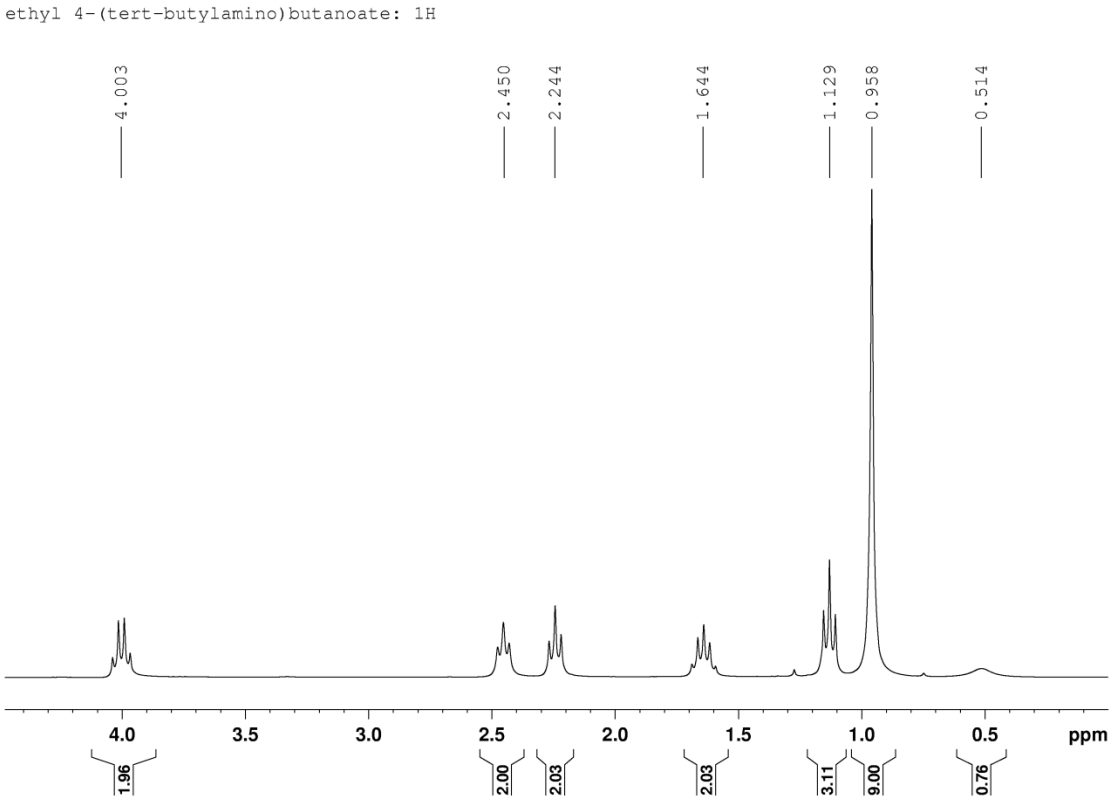

Fig 36 ^{1}H NMR spectrum of ethyl 4-(*tert*-butylamino)butanoate ($CDCl_3$, 300 MHz).

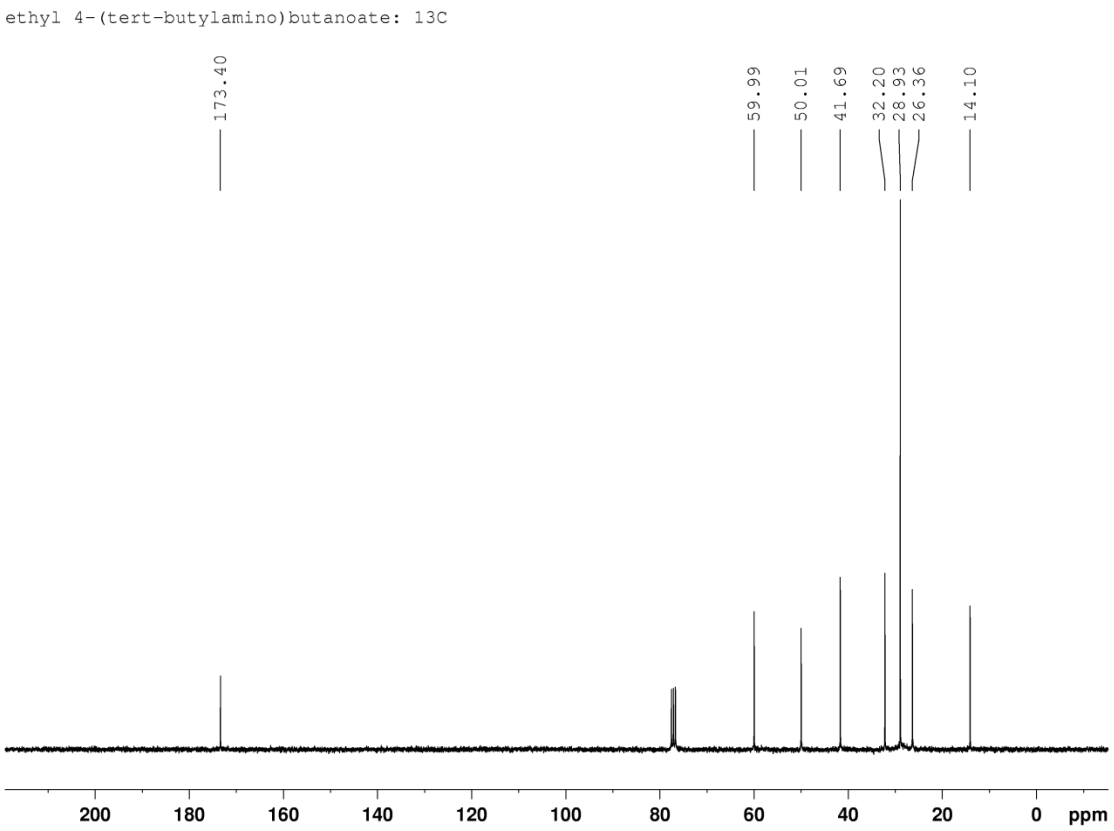

Fig 37 ^{13}C NMR spectrum of ethyl 4-(*tert*-butylamino)butanoate ($CDCl_3$, 300 MHz).

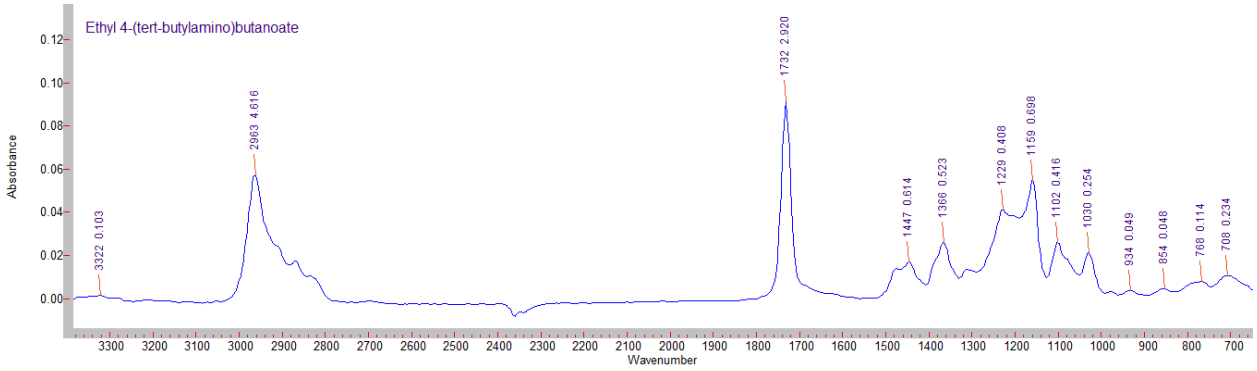

Fig 38 IR spectrum of ethyl 4-(*tert*-butylamino)butanoate.

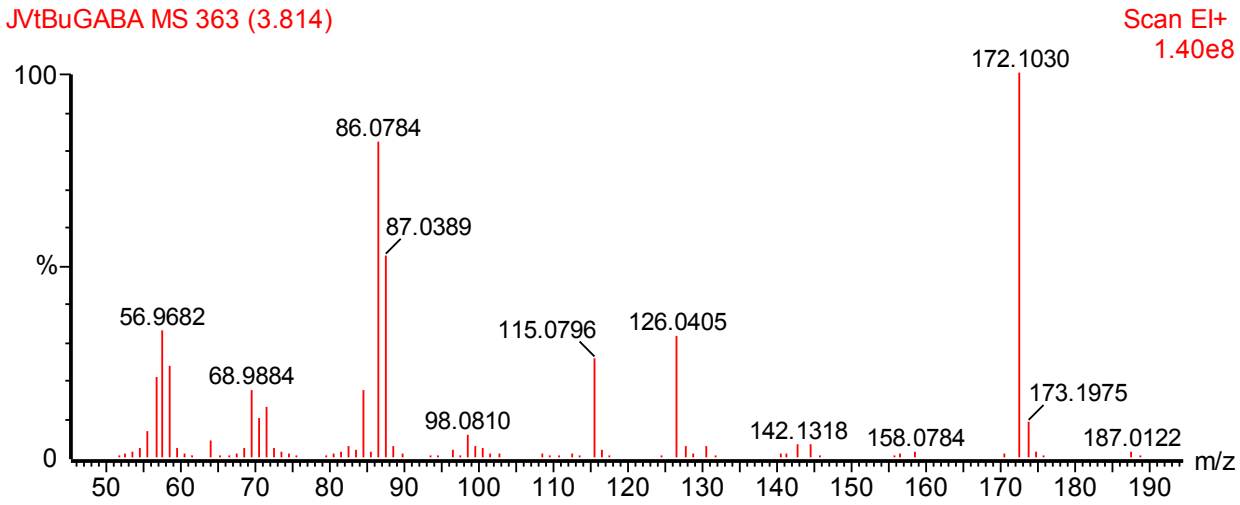

Fig 39 Mass spectrum of ethyl 4-(*tert*-butylamino)butanoate (EI).

j) Propyl 3-(*sec*-butylamino)propanoate

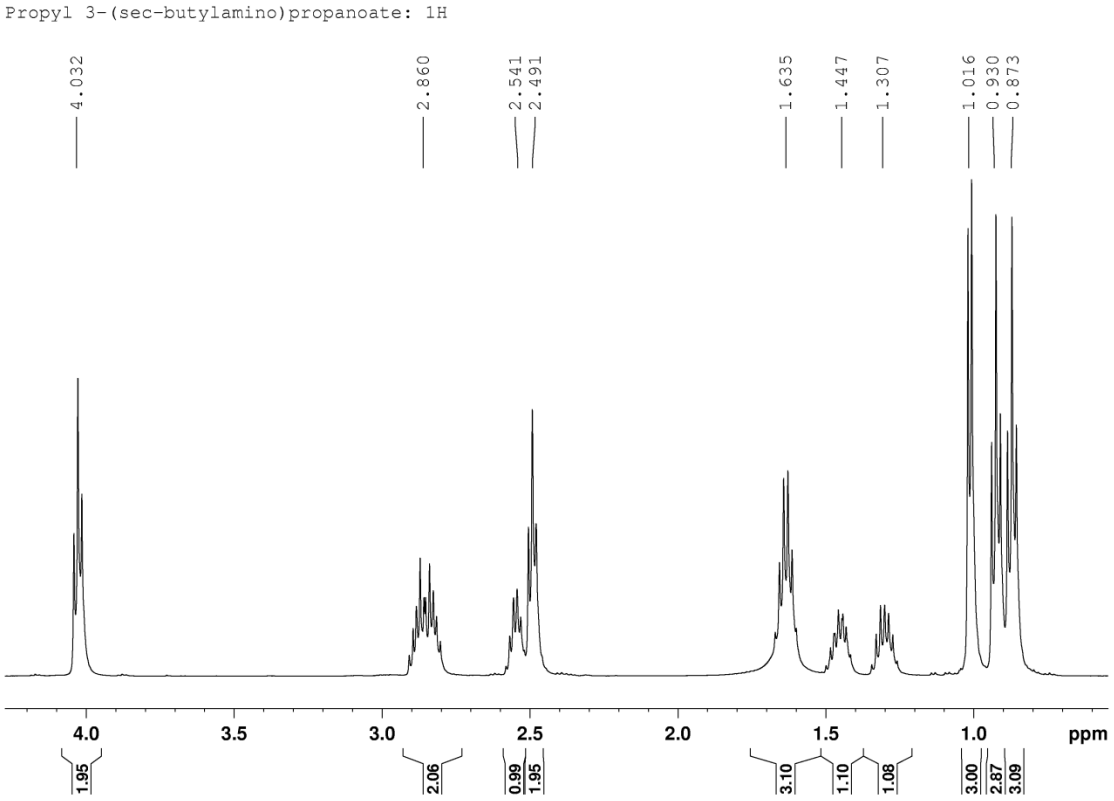

Fig S40 ^{1}H NMR spectrum of propyl 3-(*sec*-butylamino)propanoate ($CDCl_3$, 500 MHz).

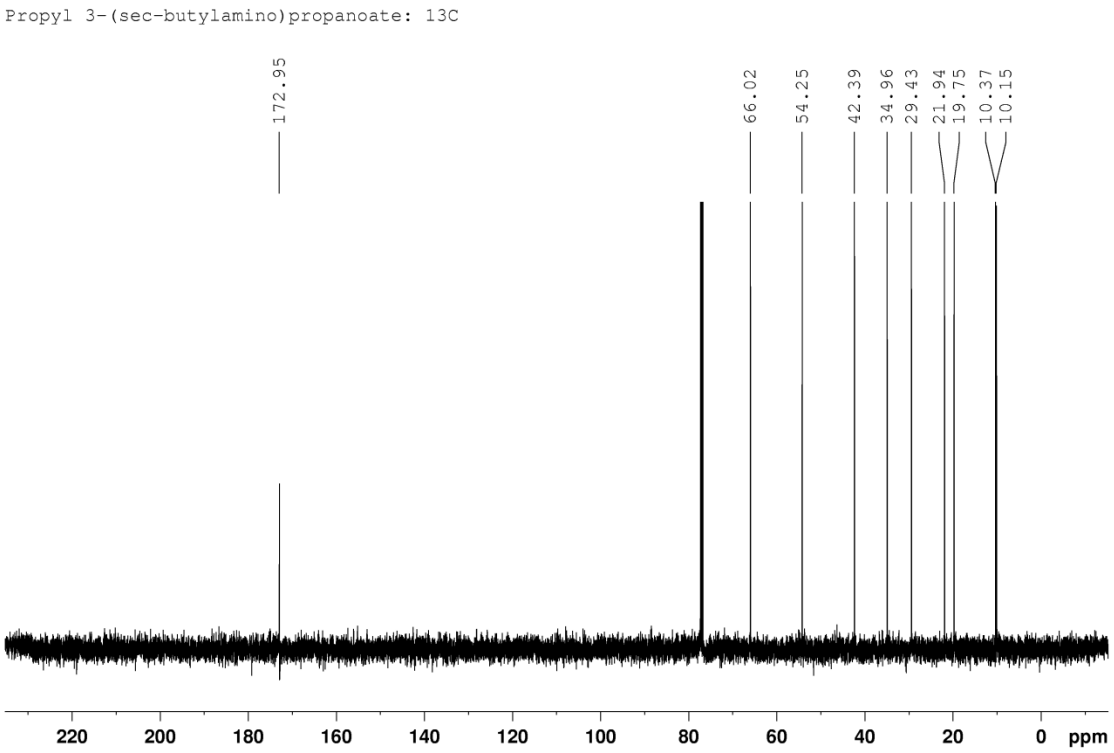

Fig S41 ^{13}C NMR spectrum of propyl 3-(*sec*-butylamino)propanoate ($CDCl_3$, 500 MHz).

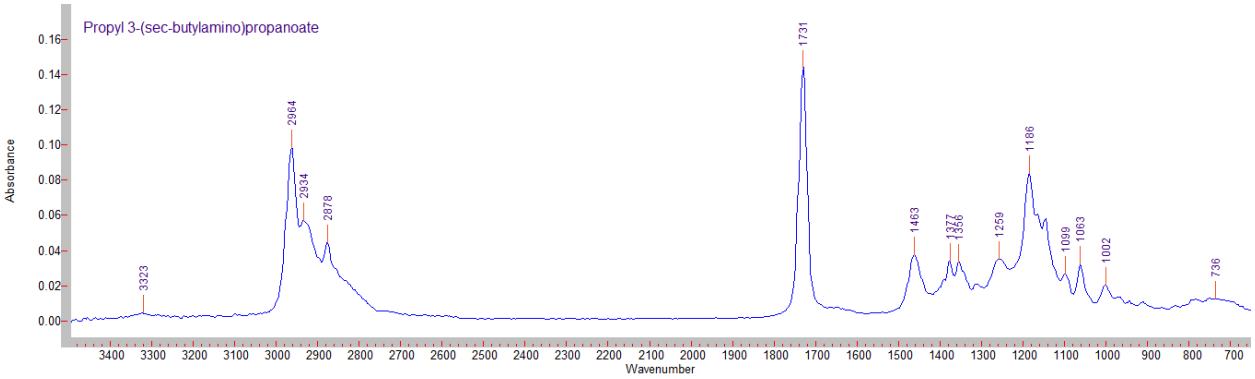

Fig S42 IR spectrum of propyl 3-(*sec*-butylamino)propanoate.

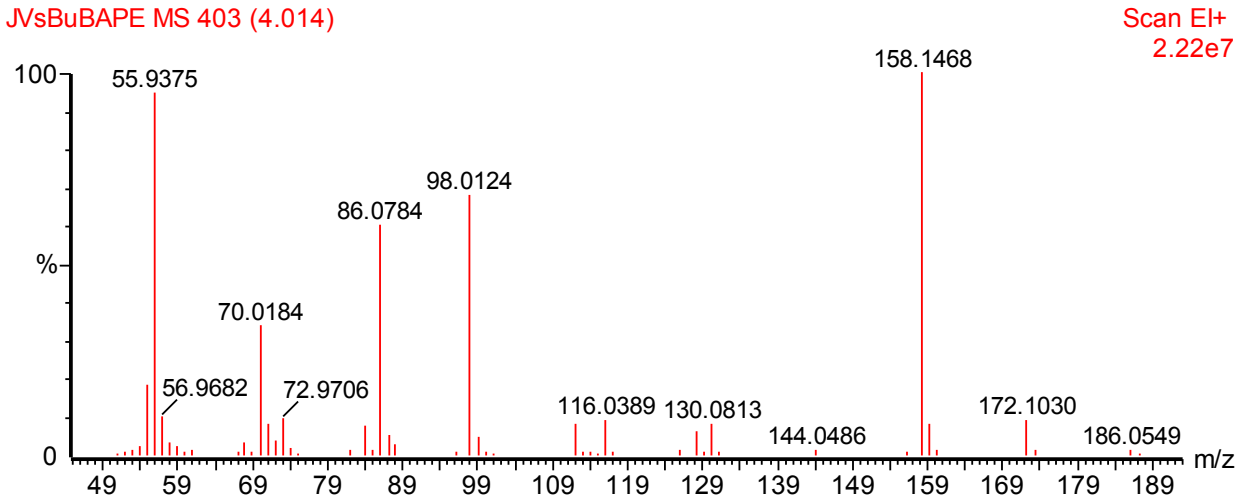

Fig S43 Mass spectrum of propyl 3-(*sec*-butylamino)propanoate (EI).

k) Butyl 3-(isopropylamino)propanoate

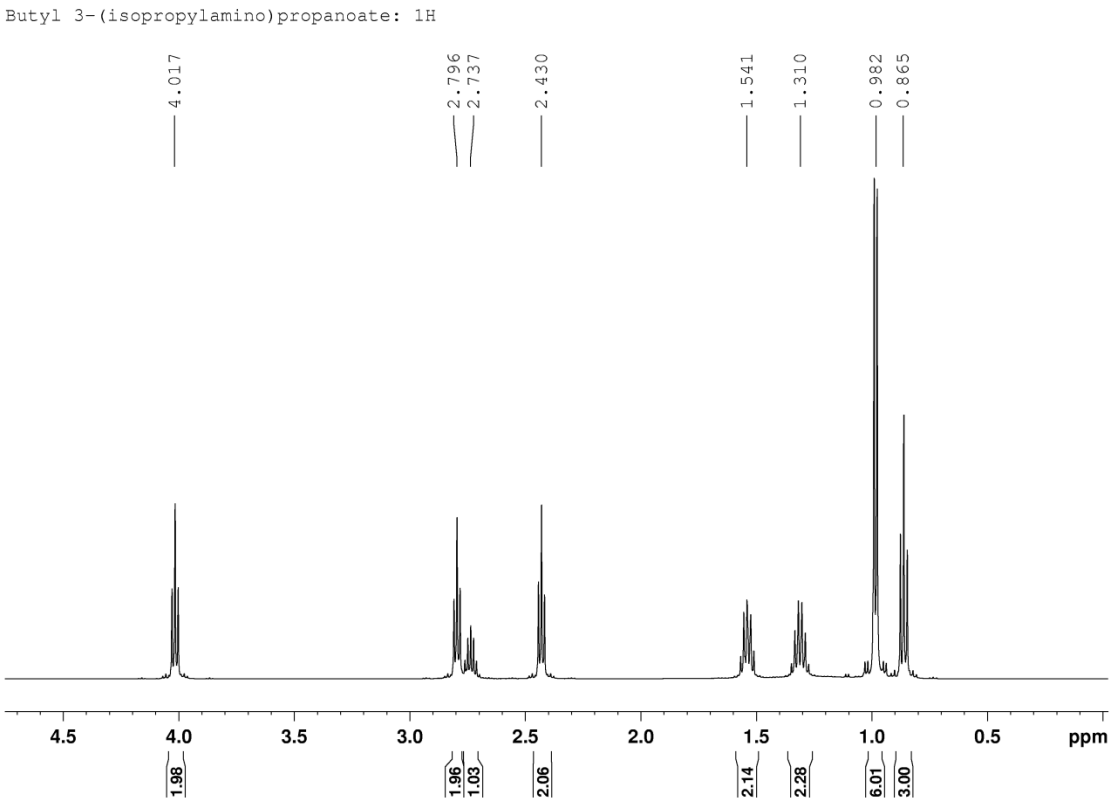

Fig S44 ^{1}H NMR spectrum of butyl 3-(isopropylamino)propanoate ($CDCl_3$, 500 MHz).

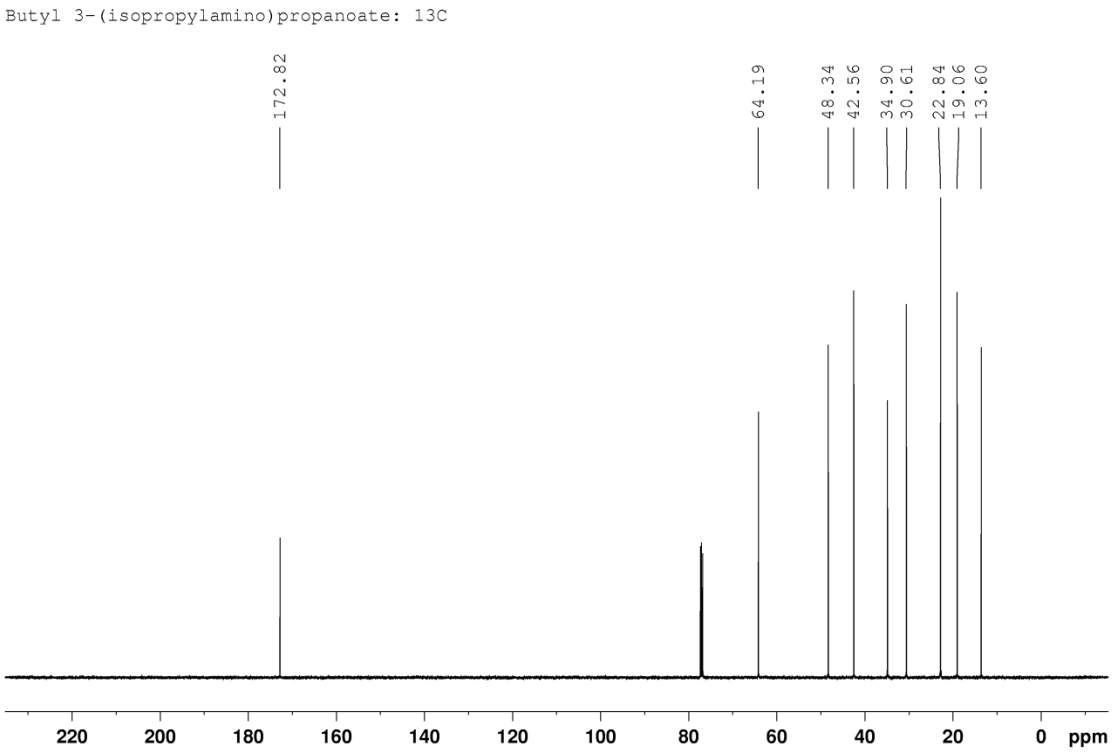

Fig S45 ^{13}C NMR spectrum of butyl 3-(isopropylamino)propanoate ($CDCl_3$, 500 MHz).

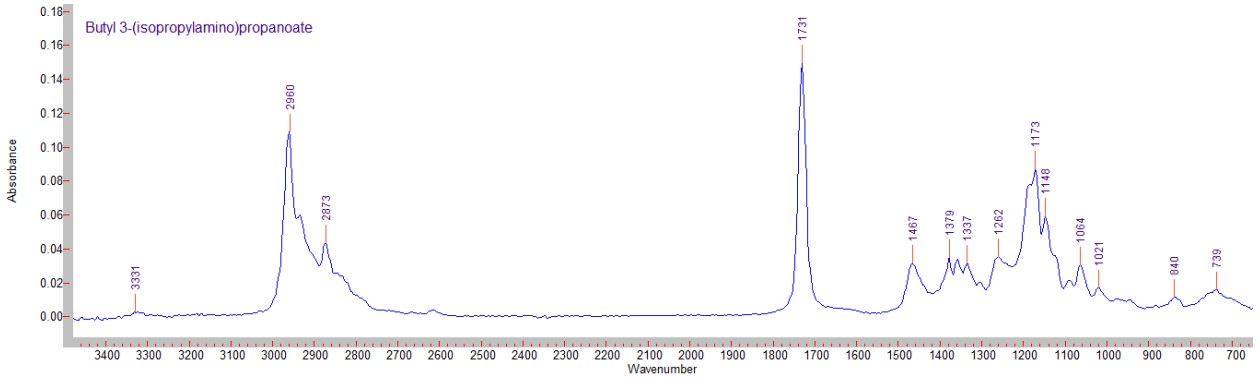

Fig S46 IR spectrum of butyl 3-(isopropylamino)propanoate.

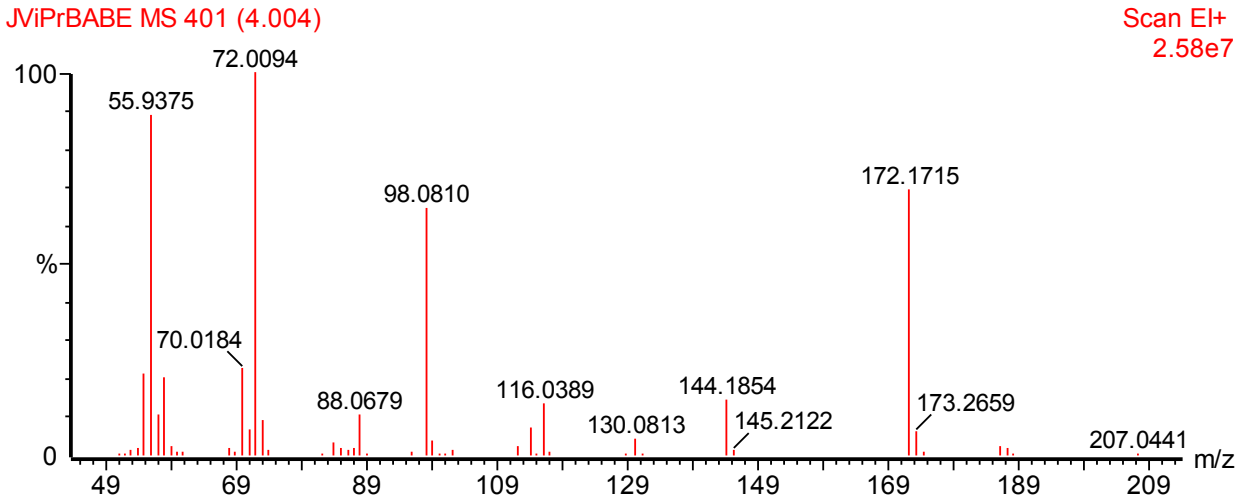

Fig S47 Mass spectrum of butyl 3-(isopropylamino)propanoate (EI).

l) Propyl 3-(diethylamino)propanoate

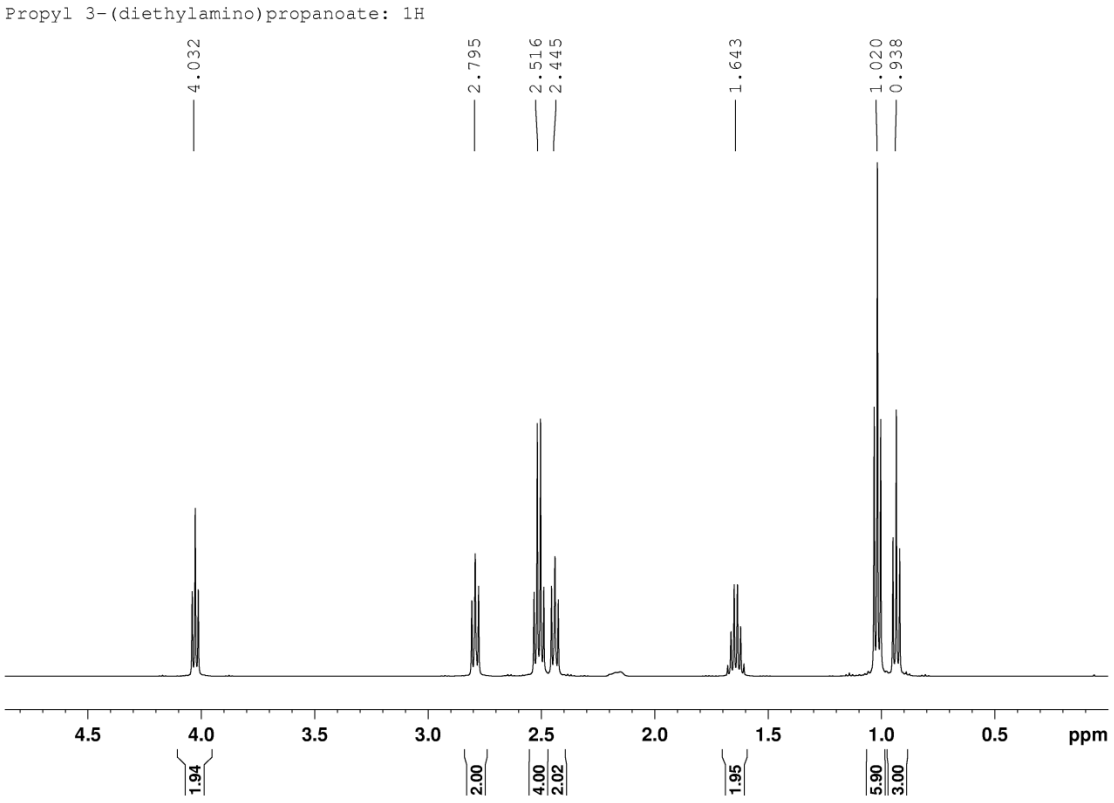

Fig S48 ^{1}H NMR spectrum of propyl 3-(diethylamino)propanoate ($CDCl_3$, 500 MHz).

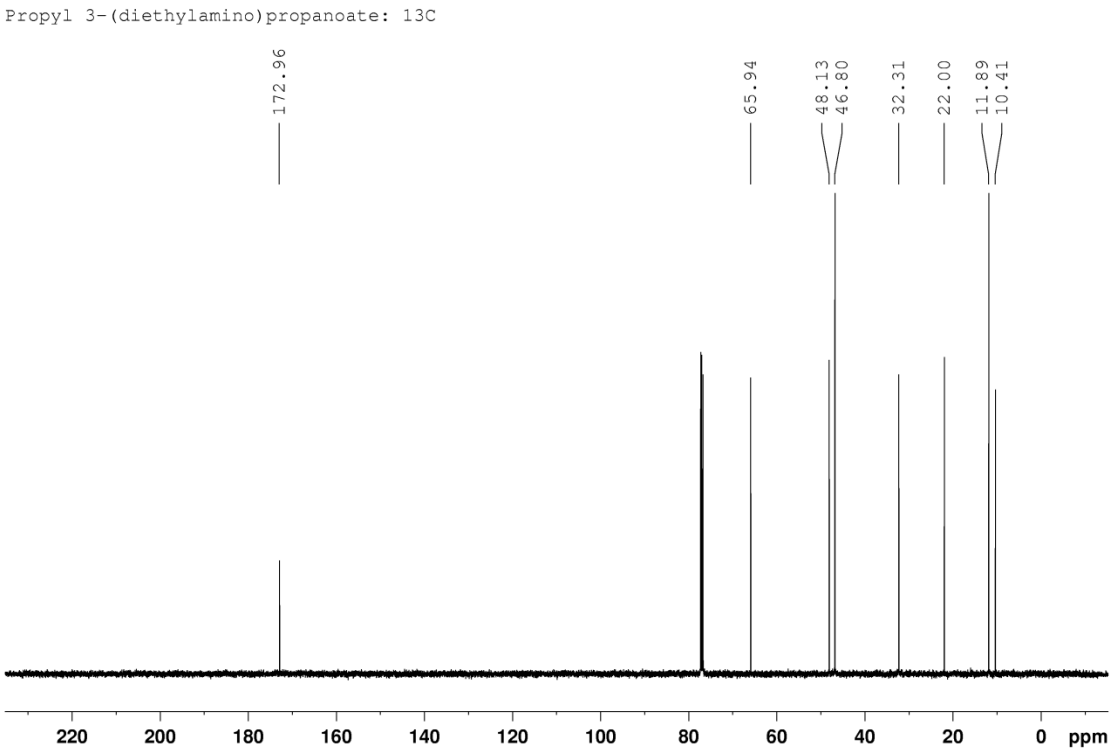

Fig S49 ^{13}C NMR spectrum of propyl 3-(diethylamino)propanoate ($CDCl_3$, 500 MHz).

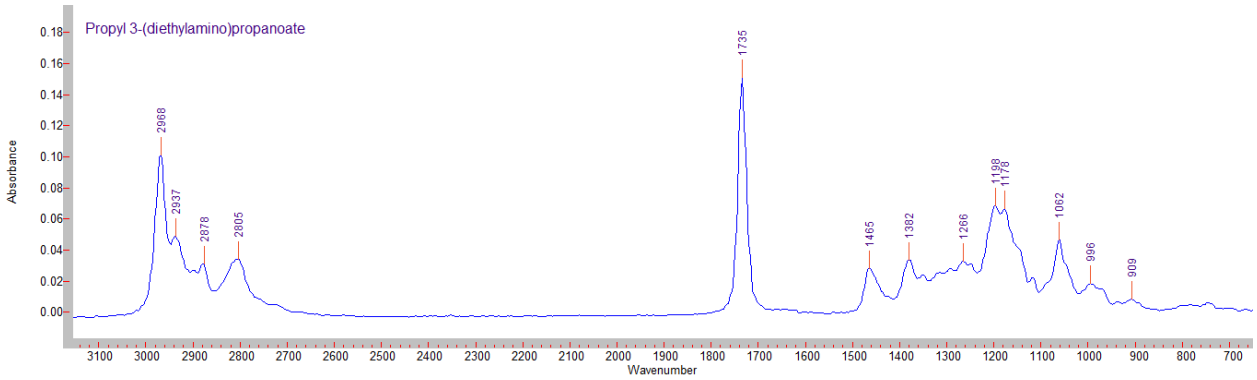

Fig S50 IR spectrum of propyl 3-(diethylamino)propanoate.

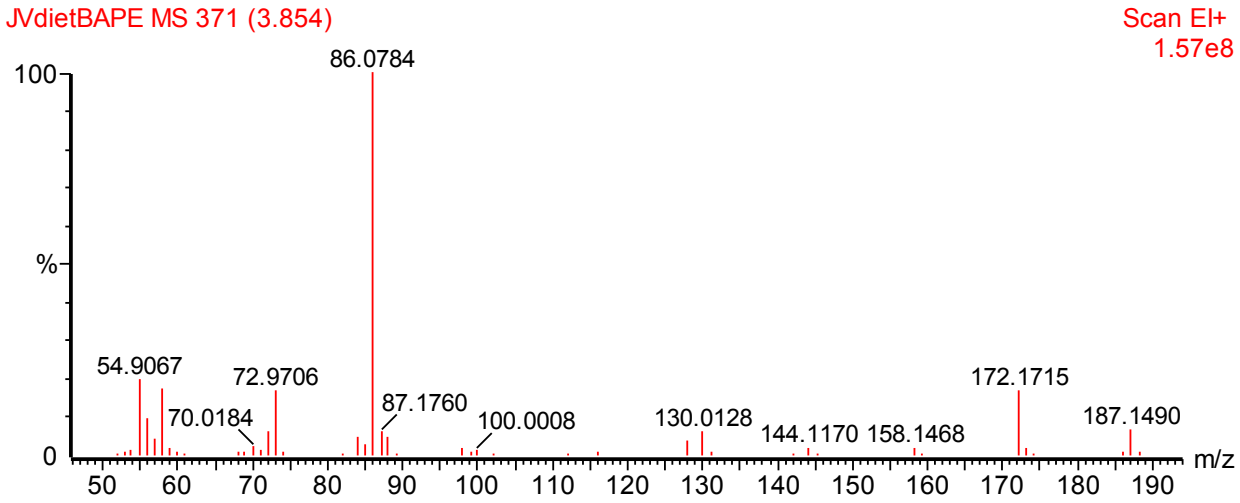

Fig S51 Mass spectrum of propyl 3-(diethylamino)propanoate (EI).

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