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AZEPINE AND [1,3]OXAZEPINE FUSED RING CONSTRUCTION THROUGH AN CATIONIC CYCLIZATION: AN *N*-ACYLIMINIUM ION TRAPPING OF AN OXYGEN ATOM OR OLEFIN

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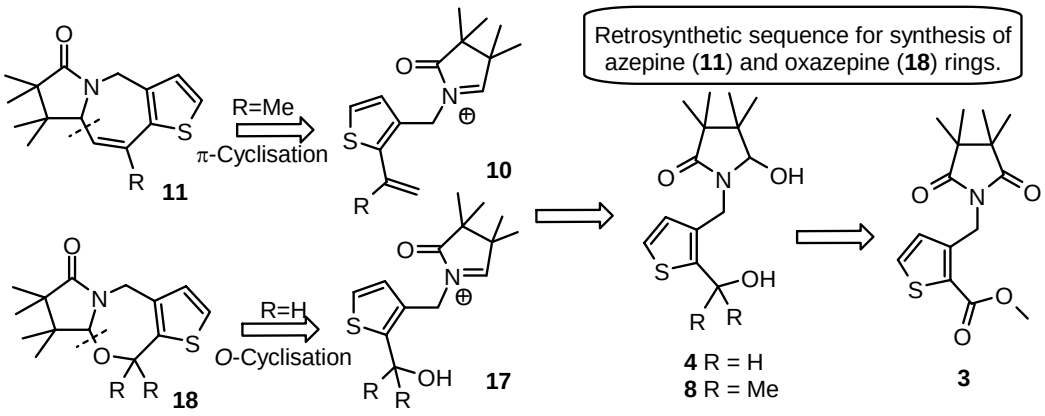
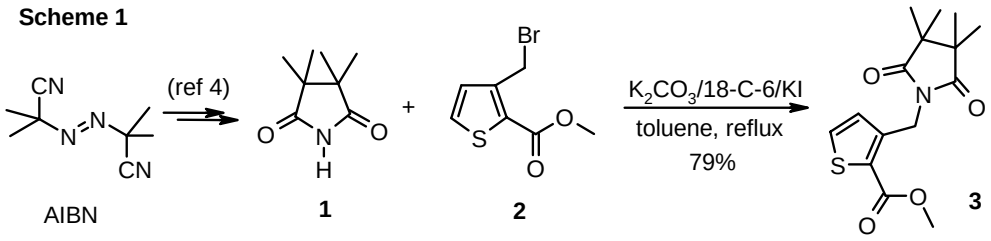
Abstract – Carbophilic addition on (and/or sodium borohydride reduction of) an imide ester functionality (**3**) proceeds with extremely high regioselectivety to produce bifunctionalized hydroxy-ω-carbinol lactam products (**4**) and (**8**). These species could act as *N*-acyliminium ion precursors and, *via* an *O*-cationic or π-cationic cyclization, and they led regioselectively in high yields to fused triheterocyclic azepine (**11**) or [1,3]oxazepine (**18**).

The α-amidoalkylation cyclization of *N*-acyliminium ions constitutes a versatile methodology for the carbon-carbon bond forming in organic synthesis.[1] During these process, *N*-acyliminium ion intermediates which generated in an acidic medium are, in turn, capable of trapping a wide variety of nucleophiles producing polyheterocyclic systems.[1,2] As an extension of our work on the synthetic utility of amidoalkylation reactions, allied with our interest in the development of synthetic approaches to diversely substituted polyheterocyclic systems, we have recently reported the preparation of polysubstituted benzoazepinoisoindolones and furoazepinoisoindolones by a tandem Grignard reaction-*N*-acyliminium ion cyclization in one pot reaction.[3] We now wish to describe our findings from our investigations of this tandem sequence with thienylmethylpyrrolidine system.



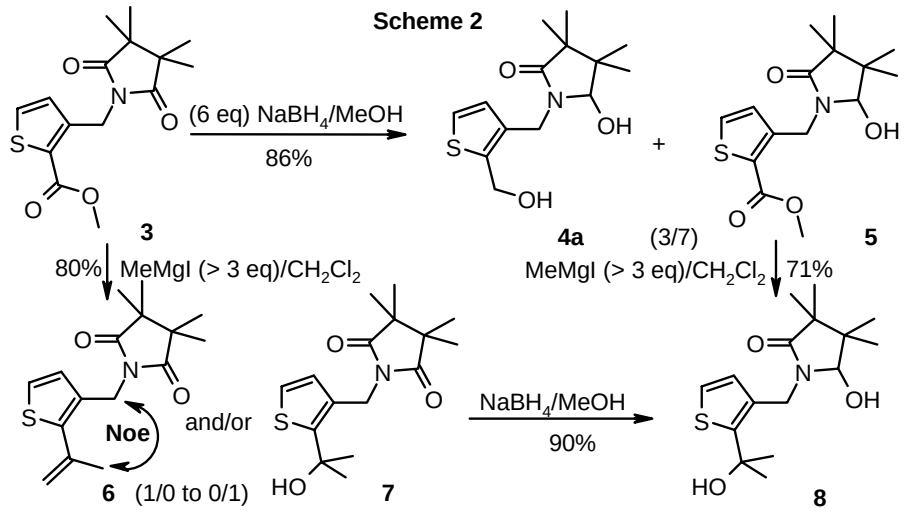
Actually, ω-carbinol lactam and hydroxy functions as in **8** could constitute respectively *N*-acyliminium ion and olefin precursors (**10**). Under certain conditions depending of the R group, only hydroxy *N*-acyliminium ion derivative (**17**) could be generated (retrosynthetic sequence). The ring closure could take place through an cationic cyclization with olefin or oxygen atom as internal nucleophile. Finally, the deprotonation gave the title compounds as azepine (**11**) and [1,3]oxazepine (**18**).

Scheme 1



The requisite imide ester (**3**) (Scheme 1) was obtained by condensation of tetramethylsuccinimide (**1**)[4] with the known methyl 3-bromomethylthiophene-2-carboxylate (**2**)[5] under PTC conditions (i. e. K_2CO_3, 18-C-6, KI, toluene at reflux).[6] This product (**3**) was isolated as crystalline solid in 79% yield after 24 hours of reaction and then subjected to reduction and carbophilic addition reactions in order to study the influence of steric and electronic effects in both reduction-addition and cyclization steps.

Scheme 2



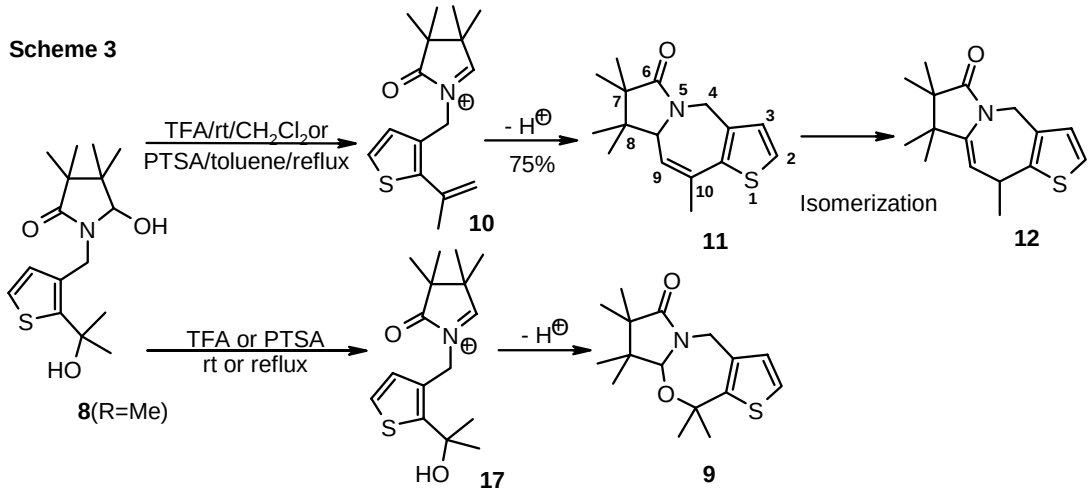
As shown in Scheme 2, reduction reaction of imide ester (**3**) was carried out with sodium borohydride (6 eq) in dry methanol at room temperature for 24 hours (monitored by TLC using silica gel and

dichloromethane as eluent) and afforded, in 86% yield, a 3/7 mixture of two products which was separated by fractional recrystallization (ether) and assigned as components (**4a**) and (**7**) respectively. It is worth of mentioning that the reduction reaction was not alterated when an ethanolic hydrochloric acid solution was added as reported earlier for related compounds.[6,7]

On the other hand, the imide (**3**) was reacted with methylmagnesium iodide (> 3 eq) at room temperature in dichloromethane. It yielded after aqueous ammonium chloride (6 M) hydrolysis a 1/4 mixture of **6** and **7** in 80% yield. Moreover, hydrochloric acid (4 M) hydrolysis gave only olefin (**6**) (79%) while water hydrolysis led exclusively to the expected imide alcohol (**7**) in comparable yield (81%). The relative geometry of olefin part toward the double bond C_2=C_3 of thiophene ring was determined by NOE DIFFERENCE experiments and was assigned as a *s-trans* conformation.

The **4a**/**5** and **6**/**7** proportions are affected by the steric and electronic nature of the nucleophile. Indeed, if the ester function is partially affected during the reduction process, the diol product resulting from Grignard addition onto imide and ester functions was never obtained whatever the quantity of methylmagnesium iodide and experimental conditions used. This result was in contrast to these obtained in phthalimide[3] and succinimide[8] series.

Scheme 3



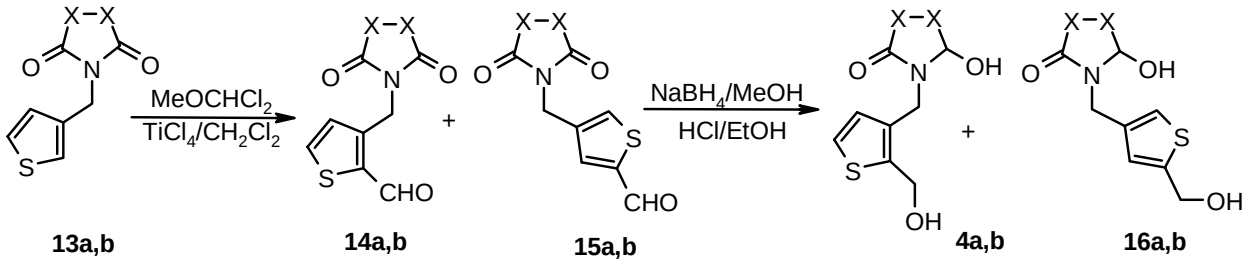
Under similar conditions as above, with methylmagnesium iodide as nucleophile, the α-hydroxy lactam ester (**5**) led after hydrolysis to the expected α-hydroxy lactam alcohol (**8**) (71%). The same product was also obtained in 90% yield by using a borohydride reduction process of **7**. In the latter cases and as mentioned above in Scheme 2, more than 5 equivalents of sodium borohydride were necessary.

The diol (**8**) was treated with trifluoroacetic acid in dry dichloromethane at room temperature for 24 hours, and was led exclusively to thienopyrrolo[2]azepine (**11**) in 75% yield. The latter product was also obtained (73%) by using a catalytic amount of *p*-toluenesulfonic acid in azeotropic conditions and in these conditions only 3 hours were required for complete cyclization. During these process, neither the [1,3]oxazepine (**9**) nor the conjugated azepine (**12**), which could be obtained respectively through an *O*-cationic cyclization of intermadiate (**17**) or isomerization of **11**,[9] were detected. The structure of **11** was supported by NMR (^{1}H, ^{13}C, Dept) spectroscopic analyses. In fact, the spectrum of **11** exhibited an AB

system of methylene protons CH_2-N (J = 15.3 Hz characteristic of *gem* protons) due to the diastereotopic effect while the methyl group at C_{10} appear as a singlet at δ = 1.22 ppm.

From these results, it was interesting to study the reactivity of the diol (**4a**) using *N*-acyliminium ion cyclization. So, taking into account that **4a** was obtained as the minor product from **3** (Scheme 2), another way was explored from imide (**13a**)[6] (Scheme 4).

Scheme 4



13a,b **14a,b** **15a,b** **4a,b** **16a,b**

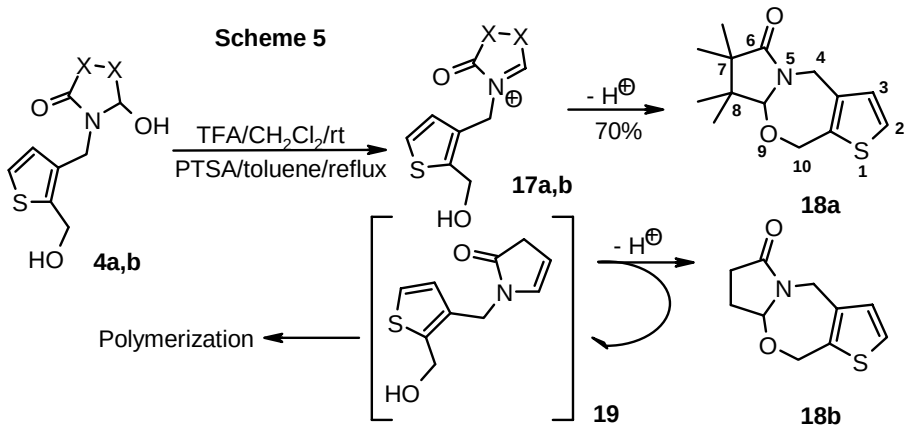
Table 1

X-X	Formyl / J (Hz)	Yield (%)	Ratio*	Alcohol / J (Hz)	Yield (%)	Ratio*
CMe_2-CMe_2	**14a** $J_{2,3}$=5.1 **15a** $J_{3,5}$=1.6	65	5.5 4.5	**4a** $J_{2,3}$=5.2 **16a** $J_{3,5}$=1.3	75	5.7 4.3
CH_2-CH_2	**14b** $J_{2,3}$=5.1 **15b** $J_{3,5}$=1.8	95	7.8 2.2	**4b** $J_{2,3}$=5.3 **16b** $J_{3,5}$=1.5	92	7.7 2.3

* The ratio of products was determined by ^{1}H NMR spectroscopy.

The formylation of **13a** was accomplished with α,α-dichloromethyl methyl ether in the presence of titanium tetrachloride as catalyst (65%) and furnished a 5.5/4.5 mixture of aldehydes (**14a**) and (**15a**) which was identified on the basis on their thiophene ring coupling constants $J_{2,3} \approx 5.0$ Hz and $J_{3,5} \approx 1.5$ Hz. In the same manner, the succinimide derivative (**13b**)[6] furnished formyl derivatives (**14b**) and (**15b**) in 7.8/2.2 ratio (95%). On the other hand, borohydride reduction of the unseparable mixture of **14a**,**15a** and **14b**,**15b** was achieved with yields of 75 and 92% respectively. The expected diol was obtained as a mixture of **4a**/**16a** and **4b**/**16b** in comparable ratios of their aldehyde precursors (See Table 1).

The *N*-acyliminium reaction sequence, exposed above for **8**, was finally applied to the newly model (**4a**). Treatment of **4a** with trifluoroacetic acid (i.e. neat TFA, rt, 2 to 24 h) led after purification by chromatography (i.e. SiO_2, CH_2Cl_2) to **18a** in poor yield (19%) accompanied with considerable tar. When the experimental conditions were changed using *p*-toluenesulfonic acid in azeotrpic conditions, the cyclization proceeded cleanly to provide **18a** in 70% yield. Furthermore, from the mixture of **4a** and **16a** as a starting material, the alcohol (**16a**) was recovered unreacted in the *p*-toluenesulfonic acid cyclization process while **4a** was led to the expected thienopyrrolo[1,3]oxazepine (**18a**) in comparable yield (65%).



In the case of diol (**4b**), no reaction occurred and in all cases the cyclization produced only a polymerization product which could be formed in anionic conditions of the supposed enamide derivative (**19**).

The structure of **18a**, was readily established by analyses of IR, ^{1}H and ^{13}C NMR spectra, MS spectra as well as by microanalyses. The infrared spectra of **18a** indicated the absence of a O-H stretch and the ^{1}H and ^{13}C NMR spectrum revealed an important deshielding of the angular proton H_{8a} (δ = 4.55 ppm) and the angular carbon C_{8a} (δ = 101 ppm). This fact is due to the proximity of oxymethylene (CH_2-O) group compared to the same one in the parent diol (**4a**) precursor (δ_H = 3.87 ppm and δ_C = 87.5 ppm) as a consequence of the capture of *N*-acyliminium ion intermediate (**17a**) by an oxygen atom as intramolecular nucleophile. This process was not very commun and till this date only few report have been done.[10]

In summary, we reported results toward azepine and [1,3]oxazepine ring construction from an imide ester functionality. The sequence was performed in short steps by regioselective reduction and/or carbophilic addition followed by an α-amidoalkylation cyclization in acidic medium.

EXPERIMENTAL

Melting points are uncorrected. The IR spectra of solids (potassium bromide) were recorded on a Perkin Elmer FTIR paragon 1000 spectrophotometer. The ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AC-200 (200 MHz) instrument in deuteriochloroform and chemical shifts (δ) are expressed in ppm relative to TMS as an internal standard. Ascending TLC was performed on precoated plates of silica gel 60 F 254 (Merck) and the spots visualized using an ultraviolet lamp or iodine vapor. E. Merck silica gel 60 F (70-300 mesh) was used for column chromatography. The elemental analyses were carried out by the microanalysis laboratory of INSA at Rouen, F 76130 Mont. Saint. Aignan, France. MS spectral measurements were carried out on a AEI MS 902 S spectrometer (70 eV, electron impact).

1-(2'-Methoxycarbonylthien-3'-ylmethyl)tetramethylsuccinimide (3). To a mixture of imide (**1**) (1.55 g, 10 mmol) and 18-C-6 (15.5 mg, 1% w/w) in dry toluene (50 mL) was added solid potassium carbonate (1.52 g, 11 mmol) and 0.1 eq per mmol of **1** of potassium iodide. After 10 min of reaction, **2** (2.82 g, 12

mmol) was then added and the mixture was refluxed for 24 h. The reaction mixture was cooled, filtered, concentrated and the residue was recrystallized from ethanol to give pure **3** (2.44 g, 79% yield); mp 154°C; IR (KBr): 2952 (CH), 1696 (C=O) cm^{-1}; ^1H NMR: δ 1.10 (s, 12H, $4CH_3$), 3.85 (s, 3H, OCH_3), 5.02 (s, 2H, CH_2-N), 6.77 (d, 1H, *J* = 5.2 Hz, H_4-thiophene), 7.36 (d, 1H, *J* = 5.2 Hz, H_4-thiophene); ^{13}C NMR: δ 21.3 ($4CH_3$), 36.6 (CH_2), 46.8 (2C), 51.9 (CH_3), 127.8 (CH), 127.9 (C), 130.2 (CH), 143.3 (C), 162.4 (CO), 182.3 (2CO); MS: (EI) *m/z* 309 (M^+). *Anal*. Calcd for $C_{15}H_{19}NO_4S$: C, 58.23; H, 6.19; N, 4.52. Found: C, 58.04; H, 6.15; N, 4.45.

General procedure for borohydride reduction of imide ester (3) or imide alcohol (7). To a mixture of imide ester (**3**) or imide alcohol (**7**) (12 mmol) in dry methanol (100 mL) at rt was added sodium borohydride (3 g, 72 mmol) by portions and the mixture was left to react (monitored by TLC; SiO_2 and dichloromethane as eluent). When starting product had disappeared (24 h), the excess of sodium borohydride was decomposed by addition of cold water and 10% HCl. After extractions with dichloromethane, the organic layer was dried over magnesium sulfate, concentrated under reduced pressure, and recrystallization of the residue from ethanol gave **8**. In the case of reduction of **3**, the residue was recrystallized from ether to give pure **4a**. The ether liquor was evaporated and the residue solid was then recrystallized to give pure **5**.

5-Hydroxy-1-(2'-hydroxymethylthien-3'-ylmethyl)-3,3,4,4-tetramethyl-2-pyrrolidinone (4a). This product was obtained in 26% yield; mp 115°C; IR (KBr): 3327 (O-H), 1670 (C=O) cm^{-1}; ^1H NMR: δ 0.8 (s, 3H, CH_3,), 0.88 (s, 6H, $2CH_3$,), 1.07 (s, 3H, CH_3,), 3.82-3.91 (m, 1H, 1H-pyrrolidine), 4.18 (d, 1H, *J* = 14.5 Hz, CH_2-N), 4.41-4.45 (m, 2H, CH_2-O), 4.79 (d, 1H, *J* = 14.5 Hz, CH_2-N), 6.89 (d, 1H, *J* = 5.2 Hz, H_4-thiophene), 7,16 (d, 1H, *J* = 5.2 Hz, H_5-thiophene); ^{13}C NMR: δ 17.5 (CH_3), 19.7 (CH_3), 21.9 (CH_3), 22.6 (CH_3), 36.1 (CH_2), 42.3 (C), 46.2 (C), 56.2 (CH_2), 87.5 (CH), 125.1 (CH), 129.1 (CH), 134.5 (C), 139.2 (C), 179.7 (CO); MS: (EI) *m/z* 283 (M^+). *Anal*. Calcd for $C_{14}H_{21}NO_3S$: C, 59.34; H, 7.47; N, 4.94. Found: C, 59.29; H, 7.36; N, 4.88.

5-Hydroxy-1-(2'-methoxycarbonylthien-3'-ylmethyl)-3,3,4,4-tetramethyl-2-pyrrolidinone (5). This product was obtained in 60% yield; mp 144°C (ether/hexane); IR (KBr): 3300 (O-H), 1707 (C=O), 1655 (C=O) cm^{-1}; ^1H NMR: δ 0.79 (s, 3H, CH_3), 0.88 (s, 3H, CH_3), 0.94 (s, 3H, CH_3), 1.11 (s, 3H, CH_3), 3.88 (s, 3H, O CH_3), 4.36 (s, 1H, 1H-pyrrolidine), 4.69 (d, 1H, *J* = 14.5 Hz, CH_2-N), 4.91 (d, 1H, *J* = 14.5 Hz, CH_2-N), 7.15 (d, 1H, *J* = 5.4 Hz, H_4-thiophene), 7.43 (d, 1H, *J* = 5.4 Hz, H_5-thiophene); ^{13}C NMR: δ 17.3 (CH_3), 19.4 (CH_3), 22.5 (CH_3), 23.3 (CH_3), 36.3 (CH_2), 42.1 (C), 46.1 (C), 52.5 (CH_3), 87.4 (CH), 128.7 (C), 131.3 (CH), 131.5 (CH), 144.9 (C), 179.6 (CO), 179.6 (CO); MS: (EI) *m/z* 311 (M^+). *Anal*. Calcd for $C_{15}H_{21}NO_4S$: C, 57.86; H, 6.80; N, 4.50. Found: C, 57.77; H, 6.68; N, 4.36.

5-Hydroxy-1'-(2'-(1"-hydroxy-1"-methylethyl)thien-3'-ylmethyl)-3,3,4,4-tetramethyl-2-pyrrolidinone (8). This product was obtained in 90% yield; mp 166°C; IR (KBr): 3397 (O-H), 3283 (O-H), 1655 (C=O) cm^{-1}; ^1H NMR: δ 0.84 (s, 3H, CH_3), 0.92 (s, 6H, $2CH_3$), 1.10 (s, 3H, CH_3), 1.66 (s, 3H, CH_3-alcohol), 1.73 (s, 3H, CH_3-alcohol), 4.57 (d, 1H, *J* = 14.5 Hz, CH_2-N), 4.87 (d, 1H, *J* = 14.5 Hz, CH_2-N),

6.85 (d, 1H, *J* = 5.4 Hz, H_4-thiophene), 7.03 (d, 1H, *J* = 5.4 Hz, H_5-thiophene); ^{13}C NMR: δ 17.3 (CH_3), 19.5 (CH_3), 22.7 (CH_3), 33.2 (CH_3), 33.6 ($2CH_3$), 37.5 (CH_2), 42.1 (C), 46.2 (C), 72.6 (C), 87.9 (CH), 122.3 (CH), 130.3 (CH), 132.4 (C), 147.4 (C), 179.6 (CO); MS: (EI) *m/z* 311 (M^+). *Anal*. Calcd for $C_{16}H_{25}NO_3S$: C, 61.70; H, 8.09; N, 4.50. Found: C, 61.62; H, 8.01; N, 4.44.

General procedure for Grignard addition onto imide ester (3) or α-hydroxy lactam ester (5). To a stirred and cold imide ester (**3**) or α-hydroxy lactam ester (**5**) (10 mmol) in dichloromethane (25 mL) was added in dropwise a 0.5 M solution of methylmagnesium iodide (35 to 40 mmol) prepared according to the classical procedure in dry ether. After 1 h of reaction at 0-5°C, the reaction was allowed to stir for an additional 2 h at rt. After hydrolysis under stirring with water (6 M NH_4Cl or 4 M HCl solution) (30 mL), the solution was passed through celite. After separation, the organic layer was washed with brine, dried over magnesium sulfate and concentrated under reduced pressure. Recrystallization of the residue from ethanol gave pure products (**6**) and/or (**7**) or (**8**) in good yields.

1-(2'-(1"-Methylvinyl)thien-3'-ylmethyl)-3,3,4,4-tetramethylsuccinimide (6). This product was obtained as a solid (79%); mp 110°C; IR (KBr): 1692 (C=O) cm^{-1}; ^{1}H NMR: δ 1.12 (s, 12H, $4CH_3$), 2.14 (s, 3H, CH_3), 4.67 (s, 2H, CH_2-N), 5,15 (d, 1H, *J* = 2.4 Hz, 1H-vinyl), 5.29 (d, 1H, *J* = 2.4 Hz, 1H-vinyl), 6.76 (d, 1H, *J* = 5.4 Hz, H_4-thiophene), 7.07 (d, 1H, *J* = 5.4 Hz, H_5-thiophene); ^{13}C NMR: δ 21.3 ($4CH_3$), 25.3 (CH_3), 36.2 (CH_2), 46.8 (2C), 117.1 (CH_2), 123.4 (CH), 127.4 (CH), 131.5 (C), 137.4 (C), 142.9 (C), 182.5 (2CO); MS: (EI) *m/z* 291 (M^+). *Anal*. Calcd for $C_{16}H_{21}NO_2S$: C, 65.94; H, 7.26; N, 4.80. Found: C, 65.81; H, 7.16; N, 4.67.

1-(2'-(1"-Hydroxy-1"-methylethyl)thien-3'-ylmethyl)-3,3,4,4-tetramethylsuccinimide (7). This product was obtained as a solid (81%); mp 96°C; IR (KBr): 3105 (OH), 1694 (C=O) cm^{-1}; ^{1}H NMR: δ 1.10 (s, 12H, $4CH_3$), 1.64 (s, 6H, $2CH_3$-alcohol), 4.98 (s, 2H, CH_2-N), 6.71 (d, 1H, *J* = 5.1 Hz, H_4-thiophene), 7.01 (d, 1H, *J* = 5.1 Hz, H_5-thiophene); ^{13}C NMR: δ 18.2 ($4CH_3$), 32.3 ($2CH_3$), 42.5 (CH_2), 49.7 (2C), 62.8 (C), 110.2 (C), 124.3 (CH), 133.9 (C), 144.2 (CH), 176.5 (2CO); MS: (EI) *m/z* 309 (M^+). *Anal*. Calcd for $C_{16}H_{23}NO_3S$: C, 62.10; H, 7.49; N, 4.52. Found: C, 62.01; H, 7.36; N, 4.48.

5-Hydroxy-1-(2'-(1"-hydroxy-1"-methylethyl)thien-3'-ylmethyl)-3,3,4,4-tetramethyl-2-pyrrolidin-one (8). The characteristic of this product, obtained in 71% yield, were identical to these described above.

General procedure for cyclization of hydroxy lactams (4a) and (8). ***Procedure A:*** To a well stirred solution of hydroxy lactam (**4a**) or (**8**) (10 mmol) in dry dichloromethane (20 mL) was added trifluoroacetic acid (4 mL). After stirring at rt for 24 h, the solvent was evaporated. Chromatography purification of the residue (SiO_2, CH_2Cl_2) afforded pure compounds (**18a**) (19%) and (**11**) (75%). ***Procedure B:*** To a well stirred solution of hydroxy lactam (**4a**) or (**8**) (20 mmol) and PTSA (crystal) in dry toluene (35 mL) was refluxed in Dean-Stark apparatus. After 3 h of reaction, the solvent was evaporated. Recrystallization of the residue from ethanol afforded pure **18a** (70%). Azepine (**11**) was obtained as an orange oil in 73% yield after a flash chromatography (SiO_2, CH_2Cl_2).

4,7,8,8a-Tetrahydro-7,7,8,8,10-pentamethylpyrrolo[1,2-*a*]thieno[2,3-*e*][2]azepin-6-one (11). This compound was obtained as an orange oil; IR (neat): 1677 (C=O) cm^{-1}; ^1H NMR: δ 0.76 (s, 3H, CH_3), 0.94 (s, 3H, CH_3), 0.97 (s, 6H, $2CH_3$), 1.22 (s, 3H, CH_3), 4.08 (d, 1H, *J* = 15.3 Hz, CH_2-N), 4.15 (d "bad resolved", 1H, 1H-pyrrolidinone), 4.76 (d, 1H, *J* = 15.3 Hz, CH_2-N), 5.54 (d "bad resolved", 1H, H_9), 6.95 (d, 1H, *J* = 5.1 Hz, H_4-thiophene), 7.12 (d, 1H, *J* = 5.1 Hz, H_5-thiophene); ^{13}C NMR: δ 18.8 (CH_3), 20.1 ($2CH_3$), 20.4 (CH_3), 25.6 (CH_3), 40.1 (C), 43.3 (C), 47.4 (CH_2), 66.2 (CH), 122.6 (CH), 123.5 (CH), 128.4 (CH), 131.5 (C), 136.4 (C), 140.3 (C), 177.7 (CO); MS: (EI) *m/z* 275 (M^+). *Anal*. Calcd for $C_{16}H_{21}NOS$: C, 69.77; H, 7.68; N, 5.08. Found: C, 69.62; H, 7.65; N, 4.99.

4,6,7,8,8a,10-Hexahydro-7,7,8,8-tetramethylpyrrolo[2,1-*b*]thieno[3,2-*e*][1,3]oxazepin-6-one (18a). This compound was obtained as a white solid; mp 90°C; IR (KBr): 1668 (C=O) cm^{-1}; ^1H NMR: δ 0.96 (s, 3H, CH_3), 0.99 (s, 3H, CH_3), 1.01 (s, 3H, CH_3), 1.05 (s, 3H, CH_3), 4.03 (d, 1H, *J* = 15.6 Hz, CH_2-N), 4.55 (s, 1H, 1H-pyrrolidinone), 4.74 (d, 1H, *J* = 15.0 Hz, CH_2-O), 4.94 (d, 1H, *J* = 15.0 Hz, CH_2-O), 5.21 (d, 1H, *J* = 15.6 Hz, CH_2-N), 6.91 (d, 1H, *J* = 5.1 Hz, H_4-thiophene), 7.03 (d, 1H, *J* = 5.1 Hz, H_5-thiophene); ^{13}C NMR: δ 17.0 (CH_3), 18.4 (CH_3), 24.0 (CH_3), 25.6 (CH_3), 41.0 (CH_2), 42.8 (C), 45.3 (C), 67.2 (CH_2), 101.0 (CH), 122.7 (CH), 128.6 (CH), 136.4 (C), 137.7 (C), 179.2 (CO); MS: (EI) *m/z* 265 (M^+). *Anal*. Calcd for $C_{14}H_{19}NO_2S$: C, 63.36; H, 7.21; N, 5.28. Found: C, 63.28; H, 7.14; N, 5.09.

REFERENCES

1. For reviews see: (a) W. N. Speckamp, *Rec. Trav. Chim. Pays-Bas*, 1981, **100**, 345. (b) W. N. Speckamp and H. Hiemstra, *Tetrahedron*, 1985, **41**, 4367. (c) H. Hiemstra and W. N. Speckamp, In The Alkaloids, ed. by A. Brossi, *Academic Press*, New York, 1988, Vol. 32, pp. 271-339. (d) H. Hiemstra and W. N. Speckamp, In Comprehensive Organic Synthesis, ed. by B. M. Trost and I. Fleming, *Pergamon Press*, Oxford, 1991, Vol. 2, pp. 1047-1082. (e) B. E. Maryanoff and M. C. Rebarchak, *Synthesis*, 1992, 1245.
2. N. Hucher, A. Daïch, and B. Decroix, *Tetrahedron Lett.*, 1999, **40**, 3363.
3. A. Daïch, S. Marchalin, P. Pigeon, and B. Decroix, *Tetrahedron Lett.*, 1998, **39**, 9187.
4. A. F. Bickel and W. A. Waters, *Rec. Trav. Chim. Pays-Bas*, 1950, **69**, 1490.
5. V. N. Gogte, B. D. Tilak, K. N. Godekar, and M. B. Sahasrabudhe, *Tetrahedron*, 1967, **23**, 2443.
6. (a) A. Mamouni, A. Daïch, and B. Decroix, *J. Heterocycl. Chem.*, 1996, **33**, 1251. (b) A. Mamouni, A. Daïch, and B. Decroix, *Synth. Commun.*, 1997, **27**, 2241.
7. (a) A. Mamouni, P. Pigeon, A. Daïch, and B. Decroix, *J. Heterocycl. Chem.*, 1997, **34**, 1495. (b) J. C. Hubert, J. B. P. A. Wijnberg, and W. N. Speckamp, *Tetrahedron*, 1975, **31**, 1437. (c) J. B. P. A. Wijnberg, H. E. Schoemaker, and W. N. Speckamp, *Tetrahedron*, 1978, **34**, 179.
8. I. Manteca, N. Sotomayor, M. J. Villa, and E. Lete, *Tetrahedron Lett.*, 1996, **37**, 7841.
9. P. Pigeon, M. Othman, P. Netchitaïlo, and B. Decroix, *J. Heterocycl. Chem.*, 1999, **36**, 691.
10. S. Bienz, C. Busacca, and A. I. Meyers, *J. Am. Chem. Soc.*, 1989, **111**, 1905.