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REARRANGEMENTS OF 3-HETEROBICYCLO[3.2.0]HEPT-6-ENES

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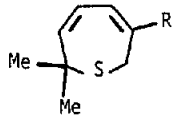
Abstract—Studies directed at a synthesis of dihydrothiepin **1b** have resulted in the elucidation of several factors which effect cyclobutene ring opening in the 3-heterobicyclo[3.2.0]hept-6-ene ring system. We report the unexpected rearrangement of **4a**, **4b**, **13b** and **13c** to the synthetically useful α-vinyl-2,5-dihydrothiophenes **7a**, **7b**, **15a** and **15b**, respectively. Conversion of **4a** to **6** is suggested to occur by a 1,3-rearrangement of **4a** to isomeric 3-thiabicyclo[3.2.0]hept-6-ene **19** followed by cyclobutene ring opening in **19**.

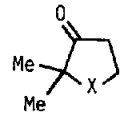
In connection with a proposed alkaloid total synthesis, we desired a practical preparation of dihydrothiepin **1b**. A well traveled route to heteropins involves cycloaddition of enamines derived from heterocyclopentanones to electron deficient acetylenes followed by ring expansion of the cycloadduct.[1] Herein we describe several unusual rearrangements which occur in sterically congested 3-heterobicyclo[3.2.0]hept-6-enes, thereby delineating limitations with regard to the flexibility of this two atom ring expansion process.



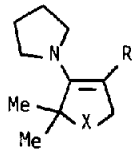
1a, R = H
b, R = $CH_2CH_2CO_2Me$

RESULTS

Initial studies directed at **1a** commenced with the conversion of readily available ketone **2a**[2] to enamine **3a**. Whereas standard enamine preparation[3] failed, treatment of ketone **2a** with pyrrolidine and titanium tetrachloride[4] in benzene solution at room temperature produced enamine **3a** in quantitative yield. Cycloaddition of methyl propiolate to **3a** in ether solution at room temperature gave 3-thiabicyclo[3.2.0]hept-6-ene **4a**.

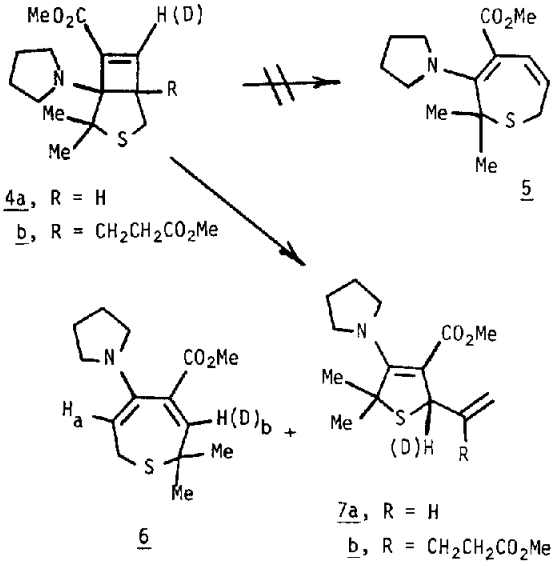


2a, X = S
b, X = NMe
c, X = NCO_2Me



3a, X = S; R = H
b, X = S; R = $CH_2CH_2CO_2Me$
c, X = NMe; R = H
d, X = NCO_2Me; R = H

Thermolysis of **4a** in refluxing dioxane solution failed to produce any of the desired dihydrothiepin **5**. Instead, rearranged dihydrothiepin **6** and 2,5-dihydrothiophene **7a** were formed in as high as 80% combined yield (Scheme 1). Varying the solvent from refluxing dioxane to ethanol to dimethylformamide (DMF) had no observable effect on product distribution, and **6** and **7a** did not interconvert under these reaction conditions.



4a, R = H
b, R = $CH_2CH_2CO_2Me$

5

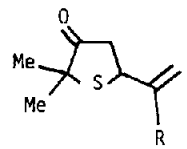
6

7a, R = H
b, R = $CH_2CH_2CO_2Me$

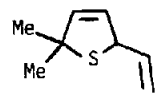
Scheme 1.

The structure assignment for **6** is supported by strong IR absorption at 1675 and 1600 cm^{-1} along with clearly defined ^1H NMR resonances, especially for H_a appearing as a triplet (J = 3 Hz) at 5.55 and H_b appearing as a singlet at 7.75 ppm. Clearly, structure **5** is not compatible with these NMR data.

The major reaction product **7a** (67% chromatographically isolated yield) could be converted to ketone **8a** in 83% overall yield by enamine hydrolysis and decarbomethoxylation in refluxing aqueous sulfuric acid. Borohydride reduction of **8a** in methanol produced an alcohol, which was converted to the α-vinyl-2,5-dihydrothiophene **9** on treatment with methanesulfonyl chloride in 10% SO_2-DMF-pyridine.



8a, R = H
b, R = $CH_2CH_2CO_2Me$



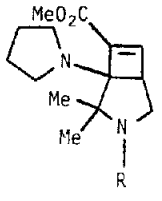
9

Michael addition of **3a** to methyl acrylate in refluxing methanol gave **3b** (99%); however, attempted cycload-

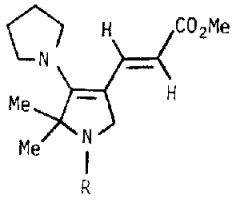
dition of **3b** to methyl propiolate using the mild conditions for preparation of **4a** resulted in no reaction. In DMF solution at 100° **3b** and methyl propiolate reacted to give only the rearranged α-vinyl-2,5-dihydrothiophene **7b** in 80% isolated yield. No intermediate 3-thiabicyclo[3.2.0]-hept-6-ene nor dihydrothiepins corresponding to **5** or **6** were detected. Conversion of **7b** to ketone **8b** was accomplished by enamine hydrolysis (68%), followed by decarbomethoxylation (86%) with sodium chloride in refluxing wet DMSO.

In order to obtain information concerning the mechanism for the unexpected rearrangements of **4a**, monodeutero-methyl propiolate was prepared (97% D–C≡C incorporation)[5] and added to **3a** to give vinyldeutero-**4a**; thermolysis gave the indicated monodeutero-**6** and **7a** (^{1}H NMR analysis).

The conversion of **4** to **7** was thought to occur by an initial ring fragmentation via a retro-5-endo-trigonal-like process.[6] Accordingly, 3-azabicyclo-[3.2.0]hept-6-enes **10a** and **10b** were prepared in order to test the effect of a first row element on α-vinyl heterocycle production. As expected, thermolysis of **10a** and **10b** in refluxing dioxane solution did not produce α-vinyl-2,5-dihydropyrroles analogous to **7**. However, dihydroazepins also were not formed; instead, cyclobutene ring opening occurred to give the 2,5-dihydropyrroles **11a** (60% yield) and **11b** (73%), respectively.



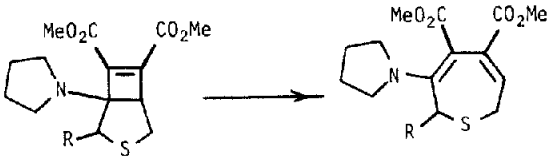
10a, R = Me
b, R = CO_2Me



11a, R = Me
b, R = CO_2Me

Reinhoudt and Kowenhoven have developed a method for synthesis of thiepins by cycloaddition of enamines derived from tetrahydrothiopen-3-ones with electron deficient acetylenes followed by thermal ring opening of the resulting 3-thiabicyclo[3.2.0]hept-6-ene.[1] For example, enamine **12a** was converted to **13a** and on thermolysis, **13a** gave 2,7-dihydrothiepin **14** in moderate yield.

Likewise, both **12a** and **12b** are reported ty cycloadd to dimethyl acetylenedicarboxylate (DMAD) to give **16a** and **16b**, respectively and these were converted to **17a** and **17b** on thermolysis.



16a, R = H
b, R = Me

17a, R = H
b, R = Me

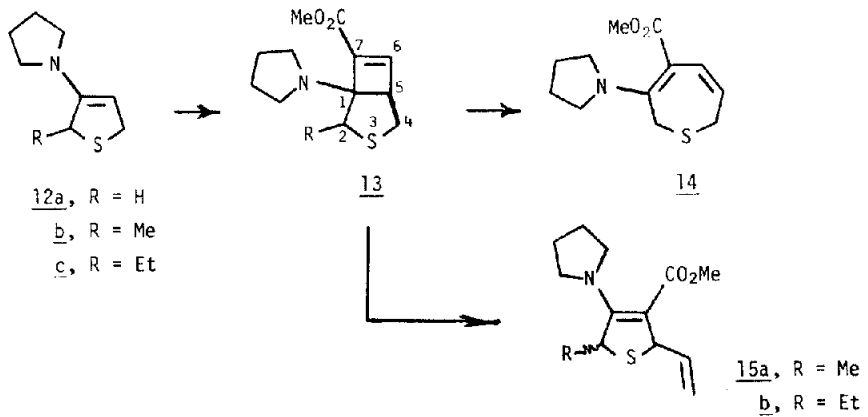
We have prepared **16b** and find that on thermolysis, **17b** is indeed formed. However, attempts to apply the cyclobutene ring isomerization to the methyl propiolate adduct **13b** and **13c** failed; thermolysis did not lead to dihydrothiepins, but rather gave α-vinyl-2,5-dihydrothiophenes **15a** and **15b**, respectively.

DISCUSSION

We are able to identify several factors that effect cyclobutene ring opening in the 3-heterobicyclo[3.2.0]hept-6-ene ring system. Substitution at C(2) in the methyl propiolate adducts **13** and **4** is highly detrimental with regard to 2,7-dihydrothiepin production. Thus, **13a** (R=H) rearranges to thiepin **14**, but **13b** (R=Me), **13c** (R=Et), **4a** and **4b** all rearrange instead to the respective α-vinyl-2,5-dihydrothiophenes **15a**, **15b**, **7a** and **7b**. In the case of **4a**, a small amount of the skeletally-rearranged 2,7-dihydrothiepin **6** also is formed. The unfavorable effect of C(2) substitution can be offset by incorporation of a C(6) carbomethoxy group as demonstrated by the conversion of the C(2) Me group substituted DMAD adduct **16b** to the expected 2,7-dihydrothiepin **17b** in moderate yield.

Formation of α-vinyl-2,5-dihydrothiophenes may occur by a pyrrolidine nitrogen atom initiated retro 5-endo-trigonal-like process to give, for example, **18a** (Scheme 2); 5-endo-trigonal cyclization of **18a** would give **7**. Presumably, incorporation of a carbomethoxy group at C(6) as in **16a** retards 3-thiabicyclo[3.2.0]-hept-6-ene ring fragmentation by destabilization of an iminium ion intermediate; e.g. **18b**.

The retro 5-endo-trigonal process should be relatively disfavored when first row heteroatoms are incorporated



12a, R = H
b, R = Me
c, R = Et

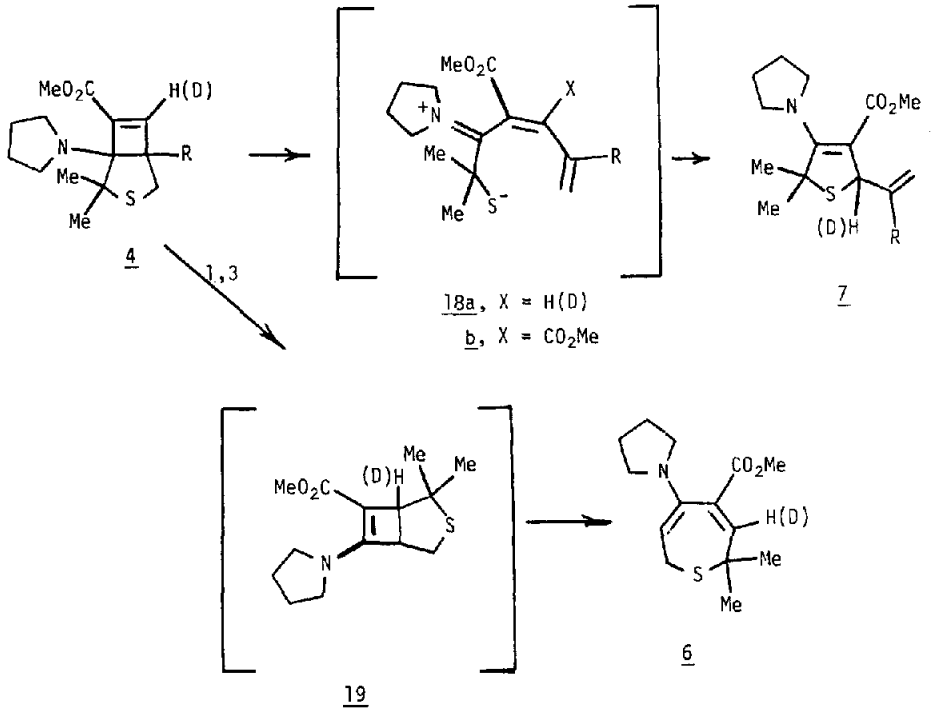
13

14

15a, R = Me
b, R = Et

into the 3-heterbicyclo ring system. This supposition was supported by experiment with the 3-azabicyclo[3.2.0]hept-6-enes **10a** and **10b**, from which no α-vinyldihydropyrroles could be detected on thermolysis.

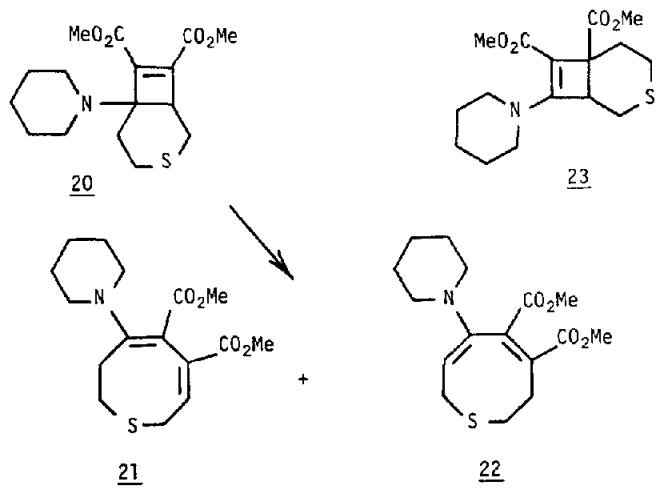
With regard to formation of rearranged 2,7-dihydrothiepin **6**, we suggest that **4a** experiences a 1,3-rearrangement to give the isomeric 3-thiabicyclo[3.2.0]hept-6-ene **19** and that this undergoes cyclobutene ring opening



Scheme 2. Mechanisms for formation of **6** and **7** compatible with deuterium labeling studies.

to give **6** (Scheme 2). It is noteworthy that this type of rearrangment does not occur with the 3-azabicyclo system **10**; instead C(1)–C(7) bond cleavages produces the "Michael adduct" **11**.

In their fused cyclobutene ring expansion study, Reinhoudt and Kouwenhoven described the isolation of a by-product analogous to **6**.[1] Thermolysis of 3-thiabicyclo[4.2.0]oct-7-ene **20** gives the "normal" cyclodienamine **21** and the "abnormal" isomer **22**. Compounds **21** and **22** did not interconvert under the reaction conditions employed. The duality of product formation was explained by a "transition state in which a 1,5-hydrogen shift can occur to give isomer **22**." However, it is possible that a 1,3-sketetal rearrangement in **20** occurs to give the isomeric 3-thiabicyclooctene **23**, from which cyclobutane ring opening would generate **22**. Appropriate labeling studies would be required to differentiate between these two mechanisms.



Finally, it should be noted that ylides derived from α-vinyltetrahydrothiophenes rearrange to 8-membered heterocycles and these have been used to advantage in macrolide synthesis studies.[7] The preparation of α-vinylthiophene derivatives by methods outlined here may be of value in related studies.

EXPERIMENTAL

General. M.ps. were determined using a Thomas–Hoover apparatus in open capillary tubes and are corrected. IR spectra were recorded on a Perkin–Elmer 137B or Perkin–Elmer 680 spectrophotometer. ^{1}H NMR spectra were determined on a Varian Associates T-60 or Perkin–Elmer R600 spectrometer using TMS as an internal standard. The low resolution electron-impact mass spectra were obtained on a Hitachi Perkin–Elmer RMU-6E mass spectrometer. ^{13} NMR spectra were obtained at the Cornell NMR Facility. Elemental microanalyses were performed by Galbraith Laboratories, Knoxville, Tennessee.

Analytical tlc was conducted on precoated tlc sheets (silica gel 60 F-254, layer thickness 0.25 mm) manufactured by E. Merck and Co. Preparative tlc was performed on 20 × 20 cm glass plates coated with E. Merck silica gel 60 GF_{254} (layer thickness 0.25 cm). Silica gel columns for chromatography utilized dry column chromatography Woelm silica gel Activity III/30 mm manufactured by Woelm Pharma, West Germany. Analytical and preparative liquid chromatography separations were performed using an analytical Waters HPLC (using a 3.9 mm i.d. × 30 cm μ Porasil column) and a Waters Prep LC/system 500 (using Prep PAK-500 silica cartridges), respectively.

2,2 - *Dimethyl* - 3 - *pyrrolidino* - 3 - *thiophene* (**3a**). A soln of **2a** (0.260 g, 2.0 mmol)[2] and pyrrolidine (1.0 mL, 6.0 mmol) in dry benzene (15 ml) was stirred and cooled to 0° (ice–water bath). Titanium tetrachloride (0.18 mL, 1.5 mmol) in dry benzene (2 mL) was added dropwise and after 15 min at 0°, the soln was allowed to warm to room temp. After 6 hr, the soln was filtered and concentrated under reduced pressure. EtOAc–hexane (1:3, 10 mL) was added after which filtration and concentration gave **3a** (yellow oil, 0.460 g, 99%); IR (neat) 2900, 2800, and 1610 cm^{-1}; NMR ($CDCl_3$) δ 1.60 [s, 6H, $C(CH_3)_2$], 1.85 [m, 4H, $(CH_2)_2$], 3.05 [m, 4H, $(N–CH_2)_2$], 3.60 [d, 2H, $S–CH_2$, J = 3 Hz], 4.30 [t, 1H, vinyl CH, J = 3 Hz].

1 - *Pyrrolidino* - 2,2 - *dimethyl* - 7 - *carbomethoxy* - 3 - *thiabicyclo*[3.2.0]*hept* - 3 - *ene* (**4a**). To a soln of **3a** (0.460 g, 2.00 mmol) in dry ether (15 mL) was added methy propiolate (0.2 mL, 2.25 mmol). The soln was stirred at room temp for 12 hr. A soln of HCl (15 mL) was added and the soln was stirred for 1 hr. The layers were separated and the aqueous layer was washed with ether (2 × 20 mL). The aqueous soln was made basic with solid $NaHCO_3$ and extracted with ether (3 × 20 mL). The combined ether extract was dried over $MgSO_4$ and concentrated to yield **4a** (0.452 g, 85%); mp 54–54.4° (hexane); IR (neat) 2900, 2820, 1700 and 1610 cm^{-1}; NMR ($CDCl_3$) δ 1.50 [s, 3H, CH_3), 1.55 [s, 3H, CH_3], 1.75 [m, 4H, $(CH_2)_2$], 3.00 [m, 7H, $(N–CH_2)_2$, SCH_2, CH], 3.70 [s, 3H, OCH_3], 6.90 [s, 1H, vinyl proton]; electron impact mass spectrum *m/e* 267 (M+). (Found: C, 62.97; H, 7.95; N, 5.23; S, 11.89. Calc. for $C_{14}H_{21}SNO_2$: C, 62.88; H, 7.92; N, 5.24; S, 11.99%).

Thermal rearrangement of 3 - *thiabicyclo*[3.2.0]*heptane* **4a**. A soln of **4a** (1.89 g, 7.00 mmol) in dry DMF (50 mL) was heated at 100°–110° for 25 hr. After cooling to room temp the solvent was removed under reduced pressure to give a brown oil. Purification using the Waters Prep LC 500 (5:1 hexane/EtOAc) gave **7a** (pale yellow oil, 1.266 g, 67%) and **6** (yellow oil, 0.215 g, 12%). For **7a**, IR (neat 2900, 1675, 1600, and 1530 cm^{-1}; NMR ($CDCl_3$) δ 1.62 [s, 3H, CH_3], 1.68 [s, 3H, CH_3], 1.82 [m, 4H, $(CH_2)_2$], 3.20 [m, 4H, $(NCH_2)_2$], 3.60 [s, 3H, OCH_3], 4.62 [d, 1H, SCH, J = 8 Hz], 4.90 [d of d, 1H, vinyl proton, J = 12, 2 Hz], 5.00 [d of d, 1H, vinyl proton, J = 16, 2 Hz], 5.90 [d of d of d, 1H, vinyl proton, J = 16, 12, 8 Hz]; electron impact mass spectrum *m/e* 267 (M+). (Found: C, 62,79; H, 8.06; N, 5.11; S, 12.09. Calc. for $C_{14}H_{21}SNO_2$: C, 62.88; H, 7.92; N, 5.24; S, 11.99%).

For **6**, IR (neat) 2900, 1675, and 1600 cm^{-1}; NMR ($CDCl_3$) δ 1.45 [s, 6H, $(CH_3)_2$], 1.90 [m, 4H, $(CH_2)_2$], 3.45 [m, 4H, $(NCH_2)_2$], 3.65 [5H, OCH_3 and SCH_2], 5.55 [t, 1H, vinyl proton, J = 3 Hz], 7.75 [s, 1H, vinyl proton]; electron impact mass spectrum *m/e* 267 (M+).

Conversion of **7a** *to* 5 - *vinyl* - 2,2 - *dimethylthiophan* - 3 - *one* (**8a**)

Method A. A soln of **7a** (0.605 g, 2.25 mmol), conc HCl (2 mL), and THF (10 mL) was refluxed for 10 m, water (20 mL) was added, and reflux continued for 30 m. The soln was extracted with ether (3 × 30 mL); the ether extract was washed with water (30 mL), dried over $MgSO_4$, and concentrated to give crude keto ester. Purification using Prep LC 500 (9:1 hexane/EtOAc) gave pure keto ester (clear oil, 0.340 g, 71%); IR (neat) 3250, 2950, 1720, 1650, and 1620 cm^{-1}; NMR ($CDCl_3$) δ 1.45, 1.50, 1.55, 1.60 [s, 6H, $(CH_3)_2$], 3.50 [d, $\frac{1}{2}$H, SCH (keto tautomer), J = 10 Hz], 3.80 [s, 3H, OCH_3], 4.6 [d, $\frac{1}{2}$H, SCH (enol tautomer), J = 8 Hz], 4.9 to 6.1 [m, 3H, vinyl protons], 11.50 [br.s, $\frac{1}{2}$H, OH (enol tautomer)]. (Found: C, 56.13; H, 6.59; S, 15.02. Calc. for $C_{10}H_{14}O_3S$: C, 56.05; H, 6.58; S, 14.97%).

A soln of the keto ester (54 mg; 0.25 mmol), NaCl (30 mg, 0.5 mmol), water (20 mL), and DMSO (5 mL) was heated at 140°–150° for 3 hr. After cooling to room temp water (20 mL) and sat. NaCl (5 mL) were added and the soln was extracted with ether (4 × 15 mL). The ether extract was washed with water (3 × 20 mL), dried over $MgSO_4$, and concentrated to give **8a** (clear oil, 46 mg, quantitative); IR (neat) 2900, 1725, and 1630 cm^{-1}; NMR ($CDCl_3$) δ 1.50 [s, 6H, $(CH_3)_2$], 2.90 [d of d, 2H, $CO–CH_2$, J = 9, 8 Hz], 4.00 [m, 1H, CH], 5.0 to 6.1 [m, 3H, vinyl protons]. (Found: C, 61.39; H, 7.91; S, 20.10. Calc. for $C_8H_{12}SO$: C, 61.49; H, 7.74; S, 20.52%).

Method B. A soln of **7a** (1.21 g, 5.7 mmol) and 10% H_2SO_4 (50 mL) was refluxed for 24 hr. The soln was extracted with ether (3 × 40 mL) and the ether extract washed with water (50 mL), dried over $MgSO_4$ and concentrated. Short path distillation afforded **8a** (clear liquid, 0.740 g, 83%).

Preparation of Michael adduct **3b**. A soln of **3a** (22 mol, 0.366 g), methyl acrylate (0.3 mL, 3 mmol), and dry MeOH (15 mL) was refluxed for 24 hr. The solvent and excess methyl acrylate were removed under reduced pressure to give **3b** (yellow oil, 0.530 g, 99%); IR (neat) 2900, 2800, 2750, 1725, and 1600 cm^{-1}; NMR ($CDCl_3$) δ 1.50 [s, 6H, $(CH_3)_2$], 1.90 [m, 4H, $(CH_2)_2$], 2.45 [s, 4H, $CO–CH_2–CH_2$], 3.10 [m, 4H, $(N–CH_2)_2$], 3.50 [s, 2H, SCH_2], 3.65 [s, 3H, OCH_3].

Reaction of enamine **3b** *with methyl propiolate.* A soln of **3b** (2.00 mmol, 0.530 g), methyl propiolate (0.25 mL, 0.275 mmol), and dry DMF (15 mL) was heated at 100°–105° for 24 hr. The solvent was removed under reduced pressure to give crude **7b**. Purification using the prep LC 500 (6:1 hexane/EtOAc) gave **7b** (pale yellow oil, 0.568 g, 80%); IR (neat) 2950, 1720, 1675, 1610, and 1550 cm^{-1}; NMR ($CDCl_3$) δ 1.60 [s, 6H, $(CH_3)_2$], 1.85 [m, 4H, $(CH_2)_2$], 2.42 [s, 4H, $CO–CH_2–CH_2$], 3.25 [m, 4H, $(N–CH_2)_2$], 3.56 [s, 3H, OCH_3], 3.64 [s, 3H, OCH_3], 3.75 [d, 2H, vinyl protons, J = 12 Hz]. (Found: C, 60.87; H, 7.72; N, 3.68; S, 9.30. Calc. for $C_{18}H_{27}SNO_4$: C, 61.16; H, 7.70; N, 3.96; S, 9.07%).

Conversion of **7b** *to* 5 - *vinyl* - 2,2 - *dimethylthiophan* - 3 - *one* **8b**. A soln of **7b** (0.353 g, 1.00 mmol), conc. HCl (1 mL), and THF (5 mL) was refluxed for 5 m, water was added (10 mL), and reflux continued for 30 m. After cooling to room temp, water was added (20 mL) and the soln extracted with ether (3 × 30 mL). The combined ether extract was dried over $MgSO_4$ and concentrated to give crude keto ester (yellow oil). Purification using prep LC 500 (6:1 hexane/EtOAc) gave pure keto ester (clear oil, 0.204 g, 68%); IR (neat) 3300, 2950, 1740, 1660, and 1620 cm^{-1}; NMR ($CDCl_3$) δ 1.50, 1.55, 1.60, 1.66 [s, 6H, $(CH_3)_2$], 2.45 [m, 4H, $CO–CH_2–CH_2$], 3.60 [m, 1H, SCH (keto tautomer)], 3.63 [s, 3H, OCH_3], 3.70 [s, 3H, OCH_3], 5.00 [m, $2\frac{1}{2}$H, vinyl proton and SCH (enol tautomer)], 11.50 [br.s, $\frac{1}{2}$H, OH (enol tautomer)]. (Found: C, 56.15; H, 6.87; S, 10.62. Calc. for $C_{14}H_{20}SO_5$: C, 55.98; H, 6.71; S, 10.68%).

A soln of the keto ester (30 mg, 0.1 mmol), NaCl (15 mg, 0.25 mmol), water (20 mL) and DMSO (3 mL) was heated at 140°–150° for 3 hr. The soln was cooled to room temp, and water

(20 mL) and sat. NaCl of (5 mL) was added. The soln was extracted with ether (3 × 15 mL), and the ether extracts washed with water (3 × 15 mL) dried over $MgSO_4$, and concentrated to give **8b** (oil, 23 mg, 96%); IR (neat) 2950, 2900, 1730, and 1640 cm^{-1}; NMR ($CDCl_3$) δ 1.45 [s, 6H, $(CH_3)_2$], 2.55 [s, 4H, MeO_2C–$\underline{CH_2}$–$\underline{CH_2}$], 2.90 [d of d, 2H, CO–CH_2, J = 8, 9 Hz], 3.65 [s, 3H, OCH_3], 4.00 [m, 1H, CH], 5.02 [s, 1H, vinyl proton], 5.18 [s, 1H, vinyl proton]. (Found: C, 59.46; H, 7.36; S, 13.08. Calc. for $C_{12}H_{18}SO_3$: C, 59.47; H, 7.49; S, 13.23%).

1,2,2 - *Trimethyl* - 3 - *pyrrolidino* - 3 - *pyrrolidine* (**3c**). Prepared from **2b** by the method used for preparation of **3a** (yellow oil, 0.348 g, 99%); IR (neat) 2900 and 1630 cm^{-1}; NMR ($CDCl_3$) δ 1.10 [s, 6H, $(CH_3)_2$], 1.85 [m, 4H, $(CH_2)_2$], 2.30 [s, 3H, NCH_3], 3.10 [m, 4H, $(N–CH_2)_2$], 3.40 [d, 2H, H–CH_2, J = 2 Hz], 4.15 [t, 1H, vinyl proton, J = 2 Hz].

1 - *Pyrrolidino* - 2,2, - *dimethyl* - 7 - *carbomethoxy* - (N - *methyl*) - 3 - *azabicyclo*[3.2.0]*hept* - 6 - *ene* (**10a**). Prepared from **3c** by the method used for preparation of **4a** (yellow oil, 0.439 g, 70%); IR (neat) 2900, 2750, 1710, and 1600 cm^{-1}; NMR ($CDCl_3$) δ 0.90 [s, 3H, CH_3], 1.21 [s, 3H, CH_3], 1.68 [m, 4H, $(CH_2)_2$], 2.19 [s, 3H, N–CH_3], 2.60 [m, 3H, NCH_2 and CH], 2.89 [m, 4H, $(N–CH_2)_2$], 3.66 [s, 3H, OCH_3], 6.97 [s, 1H, vinyl proton].

Thermal rearrangement of azabicycloheptene **10a**. A soln of **10a** (1.185 g, 7 mmol) in dry dioxane (50 mL) was refluxed for 24 hr. After cooling to room temp the solvent was removed under reduced pressure to give a brown oil. Purification using prep LC 500 (5:1 hexane/EtOAc) gave **11a** (yellow oil, 1.109 g, 60%); IR (neat) 2900, 2850, 1670, 1600, and 1520 cm^{-1}; NMR ($CDCl_3$) δ 1.11 [s, 6H, $(CH_3)_2$], 1.86 [m, 4H, $(CH_2)_2$], 2.56 [s, 5H, N–CH_3 and N–CH_2], 3.19 [m, 4H, $(NCH_2)_2$], 3.66 [s, 3H, OCH_3], 4.45 [d, 1H, vinyl, J = 9.5 Hz], 7.26 [d, 1H, vinyl, J = 9.5 Hz]; ^{13}C-NMR ($CDCl_3$) δ 25.3 [q, N–CH_3], 48.2 [t, $(NCH_2)_2$], 5.10 [q, OCH_3], 53.1 [s, N–C], 85.2 [d, vinyl C atom], 110.9 [s, vinyl C atom], 136.5 [d, vinyl C atom], 158.7 [s, vinyl C atom], 169.9 [s, CO]; electron impact mass spectrum *m/e* 254 (M+). (Found: C, 68.21; H, 9.18; N, 10.64. Calc for $C_{15}H_{24}N_2O_2$: C, 68.15, H, 9.15; N, 10.68%).

1 - *Carbomethoxy* - 2,2 - *dimethyl* - 3 - *pyrrolidino* - 3 - *pyrrolidine* (**3d**). Prepared from **2c** by the method used for preparation of **3a** (yellow oil, 0.446 g, 99%); IR (neat) 2900, 2800, 1680, and 1615 cm^{-1}; NMR ($CDCl_3$) δ 1.38 [s, 6H, $(CH_3)_2$], 1.89 [m, 4H, $(CH_2)_2$], 3.05 [m, 4H, $(N–CH_2)_2$], 3.62 [overlapping s and d, 5H, OCH_3 and N–CH_2], 4.55 [t, 1H, vinyl proton, J = 2 Hz].

1 - *pyrrolidino* - 2,2 - *dimethyl* - 7 - *carbomethoxy* - 3 - (N - *carbomethoxy*) - *azabicyclo* - [3.2.0] - *hept* - 6 - *ene* (**10b**). Prepared from **3d** by the method used for preparation of **4a** (yellow oil, 0.388 g, 62%); IR (neat) 2900, 2850, 1720, 1650, and 1600 cm^{-1}; NMR ($CDCl_3$) δ 0.95 [s, 3H, CH_3], 1.25 [s, 3H, CH_3], 1.67 [m, 4H, $(CH_2)_2$], 2.60 [m, 3H, NCH_2 and CH], 2.90 [m, 4H, $(N–CH_2)_2$], 3.58 [s, 3H, OCH_3], 3.68 [s, 3H, OCH_3], 6.95 [S, 1H, vinyl proton]. (Found: C, 62.52; H, 8.01; N, 8.98. Calc. for $C_{16}H_{24}N_2O_4$: C, 62.31; H, 7.84; N, 9.09%).

Thermal rearrangement of azabicycloheptene **10b**. A soln of **10b** (1.892 g, 6.00 mmol) in dry dioxane (50 mL) was refluxed for 70 hr. After cooling to room temp the solvent was removed under reduced pressure to give a brown oil. Purification using prep LC 500 (5:1 hexane/EtOAc) gave **11b** (yellow oil, 0.912 g, 48%) and unrearranged **10b** (0.642 g, 34%). For **11b** IR (neat) 2900, 1690, 1610, and 1550 cm^{-1}; NMR ($CDCl_3$) δ 1.35 [bs, 6H, $(CH_3)_2$], 1.90 [m, 4H, $(CH_2)_2$], 3.00 [bs, 2H, NCH_2], 3.24 [m, 4H, $(NCH_2)_2$], 3.58 [s, 3H, OCH_3], 3.66 [s, 3H, OCH_3], 4.54 [d, 1H, vinyl proton, J = 8.5 Hz], 7.20 [d of t, 1H, vinyl proton, J = 8.5, 1.5 Hz]. (Found: C, 62.61; H, 7.94; N, 8.99. Calc. for $C_{16}H_{24}N_2O_2$: C, 62.31; H, 7.84; N, 9.09%).

Thermal rearrangements of 3 - *thiabicyclo*[3.2.0]*heptenes* **13b** *and* **13c**. The preparation and thermolysis of **13b** was the same as that described for **4a**; this produced an unresolved mixture of diastereoisomers of **15a** (~60:40 based on NMR analysis), which gave characteristic NMR resonance for the Me group as an overlapping pair of doublets (J = 7 Hz) centered at δ 1.50 (minor component) and 1.61 (major component). The OMe group appeared as a pair of singlets at δ 3.60 (major component and 3.66 (minor component) and the vinyl group gave a complicated multiplet in the expected region of δ 4.8–6.1. Similar results were obtained with **13c**, except that the NMR of **15b** showed an overlapping pair of triplets (J = 7 Hz) in the region δ 1.0–1.4. As reactions of **13b** and **13c** were explored only for purposes of mechanistic insight, no further reaction characterization was carried out.

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