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Journal of Organometallic Chemistry 628 (2001) 107–113

Journal of Organometallic Chemistry

www.elsevier.nl/locate/jorganchem

Stereoselectivity of formation of polycyclic ferrocenyl-4,5-dihydropyrazoles based on *E*- and *Z*-*s*-*cis*-α,β-enones

T. Klimova [a,*], E.I. Klimova [a], M. Martínez García [b,1], E.A. Vázquez López [a], C. Alvarez Toledano [b], A.R. Toscano [b], L. Ruíz Ramírez [a]

[a] *Department of Chemistry, National Autonomous University of Mexico, C.P. 04510, Mexico DF, Mexico*
[b] *Institute of Chemistry, National Autonomous University of Mexico, C.P. 04510, Mexico, DF, Mexico*

Received 17 December 2000; accepted 27 February 2001

Abstract

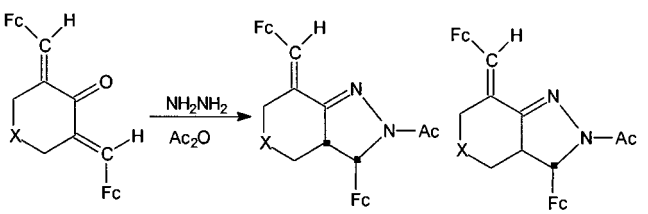
Reaction of *E*- and *Z*-isomeric 2-ferrocenylmethylidene-1-tetralone, 2-ferrocenylmethylidene-3-quinuclidinone, 1-methyl-3-ferrocenylmethylidene-4-piperidone and 2-ferrocenylmethylidenetropinone with hydrazine proceeds stereospecifically with the formation of the same diastereomeric polycyclic ferrocenyldihydropyrazoles independently of the geometric configuration of the starting α,β-unsaturated ketones. X-ray structural analysis is presented for the *trans*-diastereomer of 4-acetyl-3-ferrocenyl-1,4,5-triazatricyclo[5.2.2.0^{2,6}]undec-5-ene. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Ferrocene; Dihydropyrazol; Asymmetric induction; Stereospecificity; X-ray structural analysis

1. Introduction

It is known that the asymmetric synthesis of a chiral fragment of a molecule can occur under the influence of an asymmetry-inducing element in its other part [1,2]. According to the nature of the chiral elements in the molecule of organic compound, nine versions of asymmetric induction are possible [1]. Due to characteristic steric features of the metallocene system of ferrocene, the ferrocenyl substituent in a molecule of an organic compound can induce the following types of asymmetry: chiral plane → chiral center, chiral center → chiral plane, and chiral center → chiral center [1–4].

Stereochemical aspects of the synthesis of heterocyclic systems with a ferrocene fragment in the molecule have been studied with a limited number of examples. Thus asymmetric induction of the chiral plane → chiral center type and vice versa, i.e. of the types 1,1 and 1,3, have been reported [5] in the formation of 4,5-dihydropyrazoles with ferrocenyl and phenylbutadienyliron-tricarbonyl substituents at positions 3 and 5 of the heterocyclic system. High diastereoselectivities of the reaction have been noted in different routes for the synthesis of these compounds. The high 1,2-asymmetric induction of the type chiral center → chiral center have been recently observed in the synthesis of bicyclic ferrocenyl-4,5-dihydropyrazoles based on *E*-,*E*-bis(ferrocenylmethylidene)cycloalkanones [6,7]:



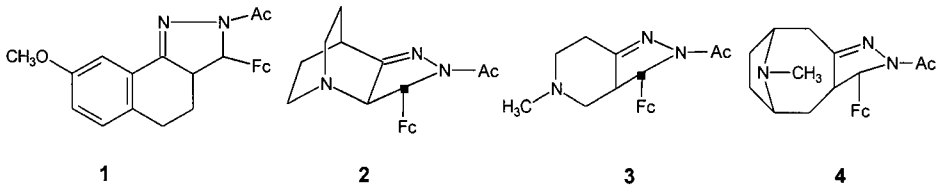
The interest in diastereoselective synthesis is currently associated with demands from pharmacology. Ferrocene-containing compounds often manifest biological activities. Thus ferrocenyl-substituted dihydropyrazoles, cyclopropanes, cyclohexenes, tetrahydrophthalates ex-

* Corresponding author. Fax: +52-5-6225366.
E-mail address: klimova@servidor.unam.mx (T. Klimova).
[1] Fax: +52-5-6162203.

PII: S0022-328X(01)00761-6

hibit antiinflammatory [8–10], analgesic [8–10], and antiviral activities [11]. Diastereomeric forms of the same compound should possess different activities. Thus the study of the ability of a ferrocene substituent to induce asymmetry is a topical task.

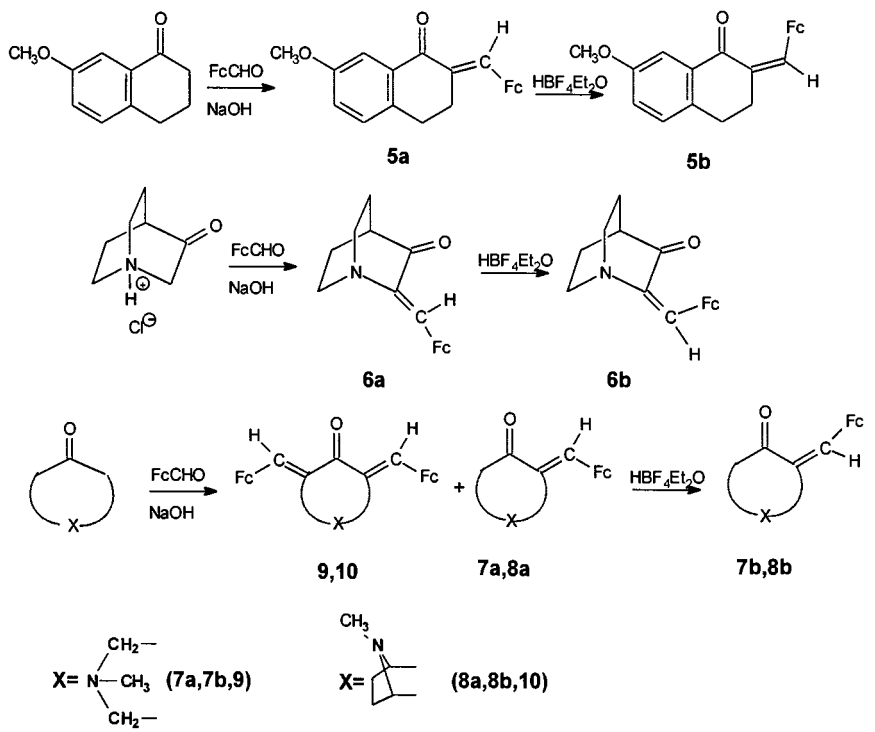
In a continuation of our investigations into chemistry of dihydropyrazoles, we have studied the asymmetric induction of the type 1,2 (chiral center → chiral center) in the synthesis of polycyclic ferrocenyldihydropyrazoles **1**–**4**:



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

2. Results and discussion

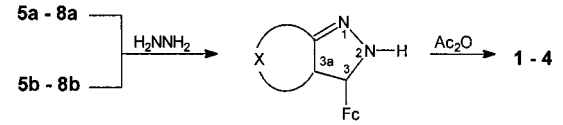
α,β-Enones **5**–**8** served as the starting compounds. They were prepared by condensation of ferrocenecarbaldehyde with the corresponding ketones in the presence of NaOH in aqueous ethanol at ambient temperature [7]:



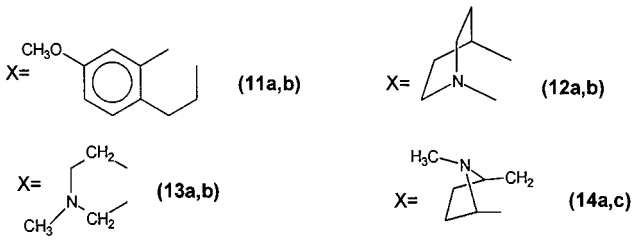
The chalcones **5a**–**8a** were formed as single configurational isomers with the 'outward' arrangement of the bulky ferrocenyl substituents with respect to the *s-cis*-heterodiene systems (^{1}H-NMR data), viz. *E*-**5a**, *Z*-**6a**, *E*-**7a**, and *E*-**8a** [6,12,13]. Their geometrical isomers with the 'inward' arrangement of the ferrocenyl group, viz. *Z*-**5b**, *E*-**6b**, *Z*-**7b**, and *Z*-**8b**, were prepared by the HBF_4-catalyzed isomerization as described previously [14,15].

The addition of hydrazine [16] to the chalcones **5a**–**8a** and **5b**–**8b** yielded relatively unstable *N*-unsubstituted dihydropyrazoles. Those obtained from the former are arbitrarily denoted **11a**–**14a**, while those obtained from the isomeric chalcones are denoted **11b**–**14b**. These compounds are stable in dry state but rapidly decompose in solutions, which precludes their characterization by NMR spectroscopy. The melting points of compounds **11a** and **11b**, **12a** and **12b**, **13a** and **13b**, **14a** and **14b**, respectively, coincide, which allows one to conclude that they are identical pairwise.

N-Acetyldihydropyrazoles prepared by acetylation of each pair of compounds **11a**,**b**, **12a**,**b**, **13a**,**b** and **14a**,**b** (**1**, **2**, **3** and **4**, respectively) have identical melting points and ^{1}H- and ^{13}C-NMR spectral parameters, which confirms the conclusion on the formation of a single diastereomeric form of dihydropyrazloles irrespective of the configuration of the starting α,β-enone.



11a,b - 14a,b



The signals for H-5 of the dihydropyrazole rings in compounds **2** and **3** resonate at δ 4.86 and 5.51 ppm, the spin–spin coupling constants $J_{\text{H-3,H-3a}}$ are equal to 8.6 and 9.9 Hz, respectively. In compounds **1** and **4** the signals for H-3 occurs at δ 4.93 and 4.56 ppm, and its spin–spin coupling constant is smaller ($J_{\text{H-3,H-3a}} = 6.8$ and 5.0 Hz). Ferrocenylmethylidene-substituted bicyclic dihydropyrazoles have been identified by ^{1}H-NMR and X-ray diffraction methods [6,7]. It was shown that the chemical shifts and values of J for the H-3 of the dihydropyrazole rings are diagnostic as regards their

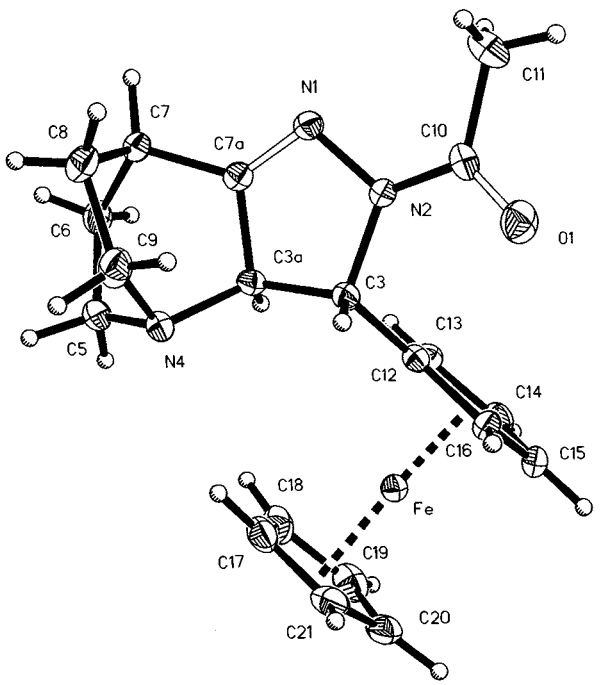


Fig. 1. Crystal structure of **2**. Selected bond lengths (Å): N(1)–N(2) = 1.421(4); N(1)–C(7a) = 1.276(4); C(3a)–C(7a) = 1.500(4); N(2)–C(3) = 1.508(4); C(3)–C(3a) = 1.529(4); C(3a)–N(4) = 1.479(4); N(4)–C(5) = 1.481(5); N(4)–C(9) = 1.494(5); C(5)–C(6) = 1.540(6); C(3)–C(12) = 1.506(5). Selected bond angles (°): C(7a)–N(1)–N(2) = 106.7(3); N(1)–N(2)–C(3) = 112.0(2); N(2)–C(3)–C(3a) = 100.6(2); N(4)–C(3a)–C(7a) = 108.2(3); C(3a)–N(4)–C(5) = 105.1(3); C(9)–N(4)–C(5) = 107.3(3); C(7a)–C(7)–C(8) = 103.3(3); N(1)–C(7a)–C(3a) = 115.8(3); C(7a)–C(3a)–C(3) = 103.0(3).

Table 1
Crystal data, data collection and refinement parameters for **2**

Data	**2**
Molecular formula	$C_{20}H_{23}FeN_3O$
Molecular weight	377.26
Temperature (K)	293
Crystal system	Orthorombic
Space group	*Pbca*
Unit cell dimensions	
a (Å)	18.174(3)
b (Å)	9.034(1)
c (Å)	20.853(2)
α (°)	90.0
β (°)	90.0
γ (°)	90.0
V (Å^3)	3423.7(8)
Z	8
ρ_{calc} (g cm^{-3})	1.464
Absorption coefficient (mm^{-1})	0.894
$F(000)$	1584
λ (Å) (Mo–K$_\alpha$ radiation)	0.71073
Monochromator	Graphite
Θ Scanning range (°)	1.50–25.00
Total number of reflections	3845
Number of independent reflections	3012
R_{int}	0.0434
Number of refinable parameters	296
Goodness-of-fit on F^2	1.023 (full-matrix least-squares refinement on F^2)
Residual electron density (e Å^{-3}) $\rho_{\min}/\rho_{\max}$	−0.327/0.441
Weighting scheme	$w^{-1} = \sigma^2(F_o^2)+(0.0735P)^2$ where $P = (F_o^2+2F_c^2)/3$

trans- or *cis*-arrangement: in the *trans*-isomers, the resonances for H-3 are downfield shifted compared to the *cis*-isomers and the spin–spin coupling constants for the former are larger than those for the latter. Thus, comparison of the ^{1}H-NMR spectral data of compounds **2** and **3** with those of the previously synthesized compounds [6,7] allows attribution of the *trans*-structure to the diasteromers **2** and **3** with the pseudo-axial orientation of the H-3a and H-3 atoms and pseudo-equatorial orientation of the ferrocenyl substituent.

The independent and direct structural elucidation of one of dihydropyrazoles was performed using X-ray diffraction analysis of a single crystal of compound **2**. The general view of this molecule is shown in Fig. 1. The crystallographic data, parameters of the X-ray experiment, and refinements are listed in Table 1.

The central tricyclic skeleton is the key element of the structure of **2**. The quinuclidine bicyclic system is fused to a five-membered dihydropyrazole ring, which exists in a flattened envelope conformation. The ferrocenyl substituent occupies pseudo-equatorial position, the H(3a) and H(3) atoms at C(3a) and C(3), respectively, are in *trans*-arrangement. The N(1)=C(7a) bond in the

dihydropyrazoline ring is somewhat longer, while the N(1)–N(2) bond is somewhat shorter than the standard bond lengths (C=N, 1.23 Å [17]; N–N, 1.45 Å [18]). The C–C and C–N bond lengths in the quinuclidine fragment as well as the Fe–C and C–C bond lengths and geometrical parameters of the ferrocene sandwich are close to the standard values [19].

Thus, X-ray diffraction analysis of a single crystal of compound **2** confirmed the *trans*-orientation of the hydrogen atoms in the dihydropyrazole ring. Comparison of the ^{1}H-NMR spectral data of compound **2** with those of compounds **1**, **3** and **4** allows one to unambiguously ascribe the *trans*-structure to compound **3**. However, no definite conclusion on the spatial structure of compounds **1** and **4** (*trans*- or *cis*-) could be made from the available data.

3. Experimental

^{1}H- and ^{13}C-NMR spectra were registered in $CDCl_3$ on a 'Unity Inova Varian' spectrometer (300 and 75 MHz) using Me_4Si as the internal standard. Column chromatography was carried out on Al_2O_3 (activity III according to Brockmann). The parameters of the unit cell and the X-ray diffraction intensities were recorded on a 'Siemens P4/PC' diffractometer at 293 K. The crystallographic data, parameters of the X-ray diffraction experiment, and refinements are listed in Table 1.

3.1. *E*-2-Ferrocenylmethylidene-7-methoxy-1-tetralone **5a**

E-2-Ferrocenylmethylidene-7-methoxy-1-tetralone **5a** was obtained by a conventional procedure [1] starting from ferrocenecarbaldehyde and 7-methoxy-1-tetralone in the presence of alkali in aqueous EtOH in 70% yield, dark red crystals, m.p. 138–139°C. ^{1}H-NMR (δ ppm): 2.91 (m, 2H, CH_2); 2.97 (m, 2H, CH_2); 3.87 (s, 3H, CH_3); 4.17 (s, 5H, C_5H_5); 4.45 (m, 2H, C_5H_4); 4.57 (m, 2H, C_5H_4); 7.05 (dd, 1H, C_6H_3, $J = 3.0$, 8.4 Hz); 7.16 (d, 1H, C_6H_3, $J = 8.4$ Hz); 7.61 (d, 1H, C_6H_3, $J = 3.0$ Hz); 7.69 (s, 1H, CH=). ^{13}C-NMR (δ ppm): 20.78, 26.45 ($2CH_2$); 56.75 (CH_3); 69.53 (C_5H_5); 70.66, 70.96 (C_5H_4); 79.27 ($C_{ipso\text{Fc}}$); 113.95 (CH=); 119.85, 127.03, 137.13 (C_6H_3); 131.19, 132.11, 134.91 (3C); 156.16 (C_{Ar}–O), 187.10 (C=O). Anal. Found: C, 70.81; H, 5.21; Fe, 15.17. Calc. for $C_{22}H_{20}FeO_2$: C, 70.98; H, 5.42; Fe, 15.00%.

3.2. *Z*-2-Ferrocenylmethylidene-7-methoxy-1-tetralone **5b**

A mixture of the chalcone **5a** (1.12 g, 3 mmol) and HBF_4 etherate (1 ml) in dry CH_2Cl_2 was stirred in an atmosphere of dry argon for 6 h at 30–33°C. The mixture was then cooled to room temperature (r.t.), poured into 10% aqueous Na_2CO_3 (100 ml), and the organic layer was separated. It was washed with water, dried with Na_2SO_4, and concentrated. The residue was chromatographed on alumina to yield 0.48 g (43%) of the starting chalcone **5a** (eluted with hexane), m.p. 138–139°C, and 0.34 g (30%) of the *Z*-isomer **5b** (eluted with benzene), violet crystals, m.p. 143–144°C. ^{1}H-NMR (δ ppm): 2.74 (m, 2H, CH_2); 2.95 (m, 2H, CH_2); 3.79 (s, 3H, CH_3); 4.23 (s, 5H, C_5H_5); 4.36 (m, 2H, C_5H_4); 4.68 (m, 2H, C_5H_4); 7.12 (dd, 1H, C_6H_3, $J = 2.7$, 8.0 Hz); 7.32 (d, 1H, C_6H_3, $J = 8.0$ Hz); 7.65 (d, 1H, C_6H_3, $J = 2.7$ Hz); 7.48 (s, 1H, CH=). ^{13}C-NMR (δ ppm): 21.80, 26.69 (2 CH_2); 58.85 (CH_3); 69.62 (C_5H_5); 71.06, 71.23 (C_5H_4); 79.43 ($C_{ipso\text{Fc}}$); 116.64 (CH=); 119.56, 128.03, 137.93 (C_6H_3); 131.34, 132.61, 136.98 (3C); 156.67 (C_{Ar}–O), 189.20 (C=O). Anal. Found: C, 71.12; H, 5.32; Fe, 14.86. Calc. for $C_{22}H_{20}FeO_2$: C, 70.98; H, 5.42; Fe, 15.00%.

3.3. *Z*-2-Ferrocenylmethylidene-3-quinuclidone **6a**

Z-2-Ferrocenylmethylidene-3-quinuclidone **6a** was obtained analogously starting from ferrocenecarbaldehyde and quinuclidone hydrochloride in 76% yield, dark red crystals, m.p. 122–123°C (literature data: m.p. 122–123°C [1]).

3.4. *E*-2-Ferrocenylmethylidene-3-quinuclidone **6b**

E-2-Ferrocenylmethylidene-3-quinuclidone **6b** was obtained by isomerization of the *Z*-chalcone **6a** (0.96 g, 3 mmol) by HBF_4 etherate as described above to give after chromatography 0.11 g (11%) of the starting **6a** (eluted with hexane), m.p. 122–123°C [1] and *E*-isomer **6b** (0.75 g, 75%) eluted with benzene, violet crystals, m.p. 114–115°C (literature data: m.p. 113–114°C [2]).

3.5. *E*-3-Ferrocenylmethylidene-1-methyl-4-piperidone **7a**

Ferrocenecarbaldehyde (2.14 g, 10 mmol) and 1-methyl-4-piperidone (2.0 ml) were added to a solution of NaOH (1.0 g) in 50% aqueous EtOH (40 ml) and the mixture was stirred at 20°C for 24 h. Then it was mixed with benzene (100 ml), the organic layer was separated, washed with water, and the solvent was removed in vacuo. The residue was chromatographed on alumina (3:1 hexane–benzene) to give 1.98 g (64%) of compound **7a** and 0.5 g (21%) of 3,5-bis(ferrocenylmethylidene)-1-methyl-4-piperidone (**9**).

Compound **7a**, red-violet crystals, m.p. 117–118°C. ^{1}H-NMR (δ ppm): 2.49 (s, 3H, CH_3); 2.60 (t, 2H, CH_2, $J = 6.0$ Hz); 2.78 (t, 2H, CH_2, $J = 6.0$ Hz); 3.49 (d, 2H, CH_2, $J = 2.0$ Hz); 4.16 (s, 5H, C_5H_5); 4.18 (m, 2H, C_5H_4); 4.45 (m, 2H, C_5H_4); 7.46 (t, 1H, CH=, $J = 2.0$

Hz). ^{13}C-NMR (δ ppm): 38.75 (CH_3); 46.34, 52.45, 57.65 (3 CH_2); 69.53 (C_5H_5); 71.20, 71.36 (C_5H_4); 78.61 ($C_{ipso\,Fc}$); 128.52 (CH=); 129.64 (C); 198.37 (C=O). Anal. Found: C, 65.88; H, 6.11; Fe, 18.17; N, 4.39. Calc. for $C_{17}H_{19}FeNO$: C, 66.04; H, 6.19; Fe, 18.06; N, 4.53%.

Compound **9**, violet crystals, m.p. 197–198°C. ^{1}H-NMR (δ ppm): 2.53 (s, 3H, CH_3); 3.61 (t, 4H, 2CH_2, $J = 1.36$ Hz); 4.18 (s, 10H, 2C_5H_5); 4.46 (m, 4H, C_5H_4); 4.49 (m, 4H, C_5H_4); 7.61 (s, 2H, 2CH=). Anal. Found: C, 66.74; H, 5.21; Fe, 22.35; N, 2.58. Calc. for $C_{28}H_{27}Fe_2NO$: C, 66.56; H, 5.39; Fe, 22.11; N, 2.77%.

3.6. *Z*-3-Ferrocenylmethylidene-1-methyl-4-piperidone **7b**

Z-3-Ferrocenylmethylidene-1-methyl-4-piperidone **7b** was obtained by isomerization of the *E*-chalcone **7a** (1.5 g, 5 mmol) by HBF_4 etherate as described above to give after chromatography 0.6 g (40%) of the starting **7a** (eluted with 3:1 hexane–benzene), m.p. 117–118°C, and *Z*-isomer **7b** (0.66 g, 44%, eluted with 2:1 hexane–benzene, violet crystals, m.p. 103–104°C. ^{1}H-NMR (δ ppm): 2.46 (s, 3H, CH_3); 2.73 (t, 2H, CH_2, $J = 5.8$ Hz); 2.94 (t, 2H, CH_2, $J = 5.8$ Hz); 3.69 (d, 2H, CH_2, $J = 1.6$ Hz); 4.19 (s, 5H, C_5H_5); 4.21 (m, 2H, C_5H_4); 4.78 (m, 2H, C_5H_4); 7.35 (t, 1H, CH=, $J = 1.6$ Hz). Anal. Found: C, 66.16; H, 6.03; Fe, 17.93; N, 4.65. Calc. for $C_{17}H_{19}FeNO$: C, 66.04; H, 6.19; Fe, 18.06; N, 4.53%.

3.7. *E*-2-Ferrocenylmethylidenetropinone **8a**

Ferrocenecarbaldehyde (2.14 g, 10 mmol), tropinone (2.19 g, 15 mmol), and NaOH (1.0 g) in 50% aqueous EtOH (40 ml) were stirred at 20°C for 18 h. Then benzene (100 ml) was added, the organic layer was separated, washed with water, and the solvent was removed in vacuo. The residue was chromatographed on alumina (3:1 hexane–chloroform) to give 2.01 g (60%) of monochalcone **8a** and 0.51 g (23%) of 2,7-bis(-ferrocenylmethylidene)tropinone (**10**).

Compound **8a**, violet crystals, m.p. 110–111°C. ^{1}H-NMR (δ ppm): 2.49 (s, 3H, CH_3); 2.60 (t, 2H, CH_2, $J = 6.0$ Hz); 2.78 (t, 2H, CH_2, $J = 6.0$ Hz); 3.49 (d, 2H, CH_2, $J = 2.0$ Hz); 4.16 (s, 5H, C_5H_5); 4.18 (m, 2H, C_5H_4); 4.45 (m, 2H, C_5H_4); 7.46 (t, 1H, CH=, $J = 2.0$ Hz). Anal. Found: C, 67.93; C, 6.44; Fe, 16.71; N, 4.07. Calc. for $C_{19}H_{21}FeNO$: C, 68.07; H, 6.32; Fe, 16.66; N, 4.18%.

Compound **10**, red crystals, m.p. 235–236°C. ^{1}H-NMR (δ ppm): 1.86 (m, 2H, CH_2); 2.39 (s, 3H, CH_3); 2.54 (m, 2H, CH_2); 4.19 (s, 10H, 2 C_5H_5); 4.38 (m, 2H, 2 CH); 4.44 (m, 2H, C_5H_4); 4.49 (m, 4H, C_5H_4); 4.54 (m, 2H, C_5H_4); 7.62 (s, 2H, 2 CH=). ^{13}C-NMR (δ ppm): 30.22 (2CH_2); 35.94 (CH_3); 61.00 (2CH); 69.48 (2C_5H_5); 68.95, 71.04, 71.13, 73.21 (2C_5H_4); 78.48 (2$C_{ipso\,Fc}$); 134.48 (2 C); 137.05 (2CH=); 185.47 (C=O). Anal. Found: C, 67.68; H, 5.73; Fe, 20.93; N, 2.48. Calc. for $C_{30}H_{29}Fe_2NO$: C, 67.82; H, 5.50; Fe, 21.02; N, 2.65%.

3.8. *Z*-2-Ferrocenylmethylidenetropinone **8b**

Z-2-Ferrocenylmethylidenetropinone **8b** was obtained by the isomerization of chalcone **8a** (1.67 g, 5 mmol) using a procedure analogous to that used for the preparation of compound **5b**. Following chromatography (2:1 hexane–benzene), the starting compound **8a** (0.4 g, 24%), m. p. 110–111°C, was recovered, and *Z*-isomer **8b** (1.04 g, 62%) was isolated, violet crystals, m.p. 98–99°C. ^{1}H-NMR (δ ppm): 1.87 (m, 2H, CH_2); 2.34 (s, 3H, CH_3); 2.57 (m, 2H, CH_2); 3.41 (m, 2H, CH_2); 4.15 (s, 5H, C_5H_5); 4.27 (m, 2H, CH); 4.42 (m, 2H, C_5H_4); 4.60 (m, 2H, C_5H_4); 7.30 (s, 1H, CH=). Anal. Found: C, 68.19; H, 6.16; Fe, 16.83; N, 4.25. Calc. for $C_{19}H_{21}FeNO$: C, 68.07; H, 6.32; Fe, 16.66; N, 4.18%.

3.9. 5-Ferrocenyl-12-methoxy-3,4-diazatricyclo-[7.4.3.$0^{2,6}$]trideca-2,9,11,13-tetraene **11**

(A) Hydrazine hydrate (5 ml) was added to a solution of *E*-chalcone **5a** (1.23 g, 3.3 mmol) in EtOH (40 ml) and the mixture was stirred with heating at ca. 70°C for 3 h. The mixture was cooled, the yellow crystals of dihydropyrazole **11a** that sedimented were filtered off, washed with aqueous EtOH, and dried over P_2O_5. Yield 0.89 g (70%), m.p. 283–286°C. Anal. Found: C, 68.22; H, 5.60; Fe, 14.79; N, 7.03. Calc. for $C_{22}H_{22}FeN_2O$: C, 68.41; H, 5.74; Fe, 14.46; N, 7.25%.

(B) Analogously, *Z*-chalcone **5b** (1.07 g, 3.3.mmol) afforded 0.92 g (72%) of dihydropyrazole **11b**, yellow crystals, m.p. 284–286°C. Anal. Found: C, 68.69; H, 6.13; Fe, 14.33; N, 7.48. Calc. for $C_{22}H_{22}FeN_2O$: C, 68.41; H, 5.74; Fe, 14.46; N, 7.25%.

3.10. 3-Ferrocenyl-1,4,5-triazatricyclo[5.2.2.$0^{2,6}$]undec-5-ene **12**

(A) Analogously, compound **12a** (0.80 g, 72%) was obtained from the *Z*-chalcone **6a** (1.07 g, 3.3 mmol). Yellow crystals, m.p. 263–265°C (literature data: m.p. 263–265°C [1]).

(B) Analogously, *E*-chalcone **6b** (1.07 g, 3.3.mmol) afforded 0.84 g (76%) of dihydropyrazole **12b**, yellow crystals, m.p. 264–265°C. Anal. Found: C, 64.74; H, 6.08; Fe, 16.92; N, 12.29. Calc. for $C_{18}H_{21}Fe\,N_3$: C, 64.49; H, 6.32; Fe, 16.66; N, 12.53%.

3.11. 9-Ferrocenyl-3-methyl-3,7,8-triazabicyclo-[4.3.0]non-6(7)-ene **13**

(A) Analogously, compound **13a** (0.81 g, 75%) was obtained from the chalcone **7a** (1.03 g, 3.3 mmol).

Yellow powder, m.p. 188–190°C. Anal. Found: C, 63.32; H, 6.19; Fe, 17.49; N, 12.73. Calc. for $C_{17}H_{21}FeN_3$: C, 63.18; H, 6.43; Fe, 17.28; N, 13.00%.

(B) Analogous reaction of the chalcone **7b** (1.03 g, 3.3 mmol) yielded 0.75 g (70%) of dihydropyrazoline **13b**, yellow powder, m.p. 187–189°C. Anal. Found: C, 62.91; H, 6.57; Fe, 17.52; N, 13.24. Calc. for $C_{17}H_{21}FeN_3$: C, 63.18; H, 6.43; Fe, 17.28; N, 13.00%.

*3.12. 6-Ferrocenyl-11-methyl-4,5,11-triazatricyclo-[6.2.1.0^{3,7}]undec-3-ene **14***

(A) The chalcone **8a** (1.11 g, 3.3 mmol) gave under standard conditions 0.83 g (71%) of compound **14a**, yellow powder, m.p. 239–242°C. Anal. Found: C, 65.15; H, 6.89; Fe, 16.29; N, 11.74. Calc. for $C_{19}H_{23}FeN_3$: C, 65.34; H, 6.64; Fe, 16.00; N, 12.02%.

(B) Analogously, starting from the *E*-chalcone **8b** (1.11 g, 3.3 mmol), dihydropyrazole **14b** (0.84 g, 73%) was obtained, m.p. 240–242°C. Anal. Found: C, 65.49; H, 6.38; Fe, 16.23; N, 12.30. Calc. for $C_{19}H_{23}FeN_3$: C, 65.34; H, 6.64; Fe, 16.00; N, 12.02%.

*3.13. N-Acetyldihydropyrazoles **1**–**4***

N-Acetyldihydropyrazoles **1**–**4** were synthesized using the following general procedure. Dry dihydropyrazoles (**11a**–**14a**) and (**11b**–**14b**) (3.3 mmol) were dissolved in acetic anhydride (2 ml). The reaction mixture was stirred for 1 h at ambient temperature and then treated with 5% aqueous Na_2CO_3. Yellow crystals were filtered off, washed with aqueous EtOH, and dried over P_2O_5.

*3.14. 4-Acetyl-5-ferrocenyl-12-methoxy-3,4-diazatricyclo[7.4.3.0^{2,6}]trideca-2,9,11,13-tetraene **1***

Yield 0.89 g (70%) from compound **11a** (1.15 g), m.p. 163–164°C (from EtOH). ^{1}H-NMR (δ ppm): 2.04 (m, 1H, CH_2); 2.32 (s, 3H, CH_3); 2.43 (m, 1H, CH_2); 3.01 (m, 1H, CH_2); 3.12 (m, 1H, CH_2); 3.69 (m, 1H, CH); 3.86 (s, 3H, CH_3); 4.16 (s, 5H, C_5H_5); 4.13 (m, 1H, C_5H_4); 4.18 (m, 2H, C_5H_4); 4.44 (m, 1H, C_5H_4); 4.93 (d, 1H, CH, $J = 6.8$ Hz); 6.94 (dd, 1H, C_6H_3, $J = 2.7$, 8.4 Hz); 7.14 (d, 1H, C_6H_3, $J = 8.4$ Hz); 7.36 (d, 1H, C_6H_3, $J = 2.7$ Hz). ^{13}C-NMR (δ ppm): 22.37 (CH_3); 28.86, 29.83 ($2CH_2$); 53.31, 61.27 (2CH); 55.50 (OCH_3); 68.25 (C_5H_5); 66.23, 68.02, 68.24, 70.50 (C_5H_4); 88.29 ($C_{ipso\mathrm{Fc}}$); 107.80, 117.86, 130.18 (C_6H_3); 128.83, 131.45 (2C); 155.95 (Ar–O); 158.20 (C=N); 170.21 (C=O). Anal. Found: C, 67.46; H, 5.78; Fe, 12.88; N, 6.35. Calc. for $C_{24}H_{24}FeN_2O_2$: C, 67.30; H, 5.65; Fe, 13.04; N, 6.54%.

Compound **11b** (1.15 g) yielded 0.91 g (72%) of **1**, yellow crystals, m.p. 163–164°C (from EtOH). Mixed m.p. 163–164°C. Anal. Found: C, 67.15; H, 5.51; Fe, 13.20; N, 6.67. Calc. $C_{24}H_{24}FeN_2O_2$: C, 67.30; H, 5.65; Fe, 13.04; N, 6.54%.

*3.15. 4-Acetyl-3-ferrocenyl-1,4,5-triazatricyclo-[5.2.2.0^{2,6}]undec-5-ene **2***

Yield 0.88 g (70%) from compound **12a** (1.12 g), m.p. 201°C (from EtOH) (literature data: m.p. 200–201°C [1]). Compound **12b** (1.12 g) yielded 0.91 g (72%) of **2**, yellow crystals, m.p. 201–201.5°C (from EtOH). Mixed m.p. 200–201°C. ^{1}H-NMR (δ ppm): 1.97 (m, 4H, 2 CH_2); 2.25 (s, 3H, CH_3); 2.85 (m, 2H, CH_2); 3.07 (m, 2H, CH_2); 3.29 (m, 1H, CH); 4.26 (s, 5H, C_5H_5); 4.05 (m, 1H, C_5H_4); 4.16 (m, 2H, C_5H_4); 4.46 (m, 1H, C_5H_4); 4.36 (d, 1H, CH, $J = 8.6$ Hz); 4.86 (d, 1H, CH, $J = 8.6$ Hz). ^{13}C-NMR (δ ppm): 22.56 (CH_3); 28.37 (CH_2); 35.48 (CH_2); 43.26 (CH_2); 48.54(CH_2); 58.88, 65.72, 67.73 (3CH); 68.31 (C_5H_5); 68.10, 68.29, 68.34, 71.77 (C_5H_4); 86.96 ($C_{ipso\mathrm{Fc}}$); 167.33 (C=N); 170.72 (C=O). Anal. Found: C, 63.56; H, 6.27; Fe, 14.99; N, 11.05. Calc. for $C_{20}H_{23}FeN_3O$: C, 63.67; H, 6.15; Fe, 14.81; N, 11.13%.

*3.16. 8-Acetyl-9-ferrocenyl-3-methyl-3,7,8-triazabicyclo[4.3.0]non-6(7)-ene **3***

Compound **13a** (1.08 g) yielded 0.92 g (75%) of **3**, yellow crystals, m.p. 135–136°C (from EtOH). ^{1}H-NMR (δ ppm): 1.80 (m, 1H, CH_2); 2.17 (m, 1H, CH_2); 2.21 (s, 3H, CH_3); 2.36 (s, 3H, CH_3); 2.49 (m, 1H, CH_2); 2.70 (m, 1H, CH_2); 2.90 (m, 1H, CH_2); 3.20 (m, 1H, CH_2); 3.31 (m, 1H, CH); 4.23 (s, 5H, C_5H_5); 3.85 (m, 1H, C_5H_4); 3.96 (m, 1H, C_5H_4); 4.13 (m, 2H, C_5H_4); 5.51 (d, 1H, CH, $J = 9.9$ Hz). ^{13}C-NMR (δ ppm): 22.06 (CH_3); 27.06 (CH_3); 45.71 (CH_2); 48.83 (CH_2); 53.65 (CH_2); 56.13, 56.31 (2CH); 69.43 (C_5H_5); 65.30, 65.81, 66.96, 67.55 (C_5H_4); 86.18 ($C_{ipso\mathrm{Fc}}$); 158.98 (C=N); 168.24 (C=O). Anal. Found: C, 62.57; H, 6.17; Fe, 15.41; N, 11.28. Calc. for $C_{19}H_{23}FeN_3O$: C, 62.48; H, 6.35; Fe, 15.30; N, 11.50%.

Compound **13b** (1.08 g) yielded 0.87 g (71%) of **3**, yellow crystals, m.p. 135–136°C (from EtOH). Mixed m.p. 135–136°C. Anal. Found: C, 62.33; H, 6.46; Fe, 15.22; N, 11.78. Calc. for $C_{19}H_{23}FeN_3O$: C, 62.48; H, 6.35; Fe, 15.30; N, 11.50%.

*3.17. 5-Acetyl-6-ferrocenyl-11-methyl-4,5,11-triazatricyclo[6.2.1.0^{3,7}]undec-3-ene **4***

This compound was obtained from dihydropyrazole **14a** (1.15 g), yield 0.90 g (69%), yellow crystals, m.p. 114–115°C (from benzene). ^{1}H-NMR (δ ppm): 1.44 (m, 1H, CH_2); 1.59 (m, 1H, CH_2); 1.98 (m, 1H, CH_2); 2.10 (m, 1H, CH_2); 2.23 (s, 3H, CH_3); 2.34 (dd, 1H, CH_2, $J = 2.4$, 13.2 Hz); 2.51 (s, 3H, CH_3); 2.79 (dd, 1H, CH_2, $J = 3.6$, 13.2 Hz); 3.41 (dd, 1H, CH_2, $J = 3.6$, 6.0 Hz);

3.51 (t, 1H, CH, $J = 3.6$ Hz); 3.75 (t, 1H, CH, $J = 5.0$ Hz); 4.17 (s, 5H, C_5H_5); 4.02 (m, 1H, C_5H_4); 4.15 (m, 2H, C_5H_4); 4.41 (m, 1H, C_5H_4); 4.76 (d, 1H, CH, $J = 5.0$ Hz). ^{13}C-NMR (δ ppm): 22.21 (CH_3); 23.23 (CH_3); 26.94 (CH_2); 34.57 (CH_2);39.18 (CH_2); 57.14, 58.67, 62.65, 65.96 (4CH); 68.15 (C_5H_5); 66.18, 68.01, 68.22, 70.31 (C_5H_4); 87.72 ($C_{ipso\text{Fc}}$); 157.09 (C=N); 168.72 (C=O). Anal. Found: C, 64.59; H, 6.27; Fe, 14.38; N, 10.68. Calc. for $C_{21}H_{25}FeN_3O$: C, 64.46; H, 6.44; Fe, 14.27; N, 10.73%.

Starting from compound **14b** (1.15 g), the acetyl derivative **4** was obtained, yield 0.91 g (70%), m.p. 114–115°C (from benzene). Mixed m.p. 114–115°C. Anal. Found: C, 64.28; H, 6.59; Fe, 14.11; N, 10.57. Calc. for $C_{21}H_{25}FeN_3O$: C, 64.46; H, 6.44; Fe, 14.27; N, 10.73%.

4. Supplementary material

Crystallographic data for the structural analysis have been deposited with the Cambridge Crystallographic Data Centre, CCDC No. 153621 for compound **2**. Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, Cambrige CB2 1EZ, UK (Fax: +44-1223-336033; e-mail: deposit@ccdc.cam.ac.uk or www: http://www.ccdc.cam.ac.uk).

Acknowledgements

Financial support from DGAPA-UNAM (Mexico, grant IN203599) is gratefully acknowledged. We would like to thank Oscar Salvador Yañez Muñoz for ^{1}H- and ^{13}C-NMR spectra.

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