STEREOSPECIFIC SYNTHESIS OF 2-ACYL-4-ALKYL-3-ARYL-2,3,3a,4-TETRAHYDROINDENO[1,2-*c*]PYRAZOLES

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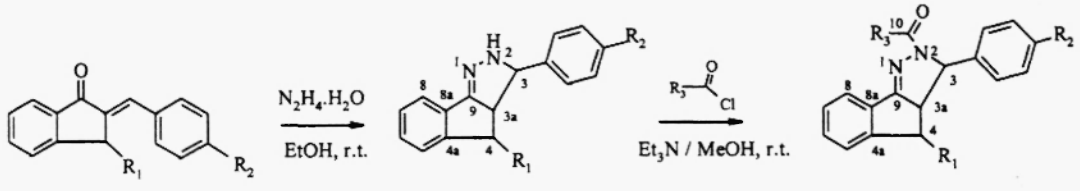
Abstract: Stereospecific synthesis of trans-2-acyl-4-alkyl-3-aryl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazoles **3** has been performed by the two-steps reaction between 3-alkyl-2-arylidene-1-indanones **1** and hydrazine followed by acylation of the pyrazolenic intermediate **2**. Structure and stereochemistry of compounds **3** have been elucidated by IR measurements and NMR techniques : monodimensional : ^{1}H, ^{13}C; two-dimensional homonuclear ^{1}H-^{1}H (COSY, NOESY) and two-dimensional heteronuclear ^{1}H-^{13}C (HMQC, HMBC).

Introduction

The reaction of hydrazines with different chalcones as a route to pyrazoles was investigated and several publications have been devoted to this method (1-3). Particularly, the condensation of hydrazines with exocyclic α,β-unsaturated benzo-condensed cyclic ketones presents a useful way in the synthesis of tricyclic pyrazolines (4-6). Owing to the interesting bioactivities of this type of heterocyclic compounds, an increasing attention has been focused on this molecules (7-9). In this paper, we report the synthesis of tricyclic pyrazolines from hydrazine and both, 2-arylidene-1-indanones **1a-c** and 2-arylidene-3-methyl-1-indanones **1d-f**. We also devoted a particular interest for the structural elucidation of such heterocyclic compounds. Their relative configuration and ^{1}H and ^{13}C NMR assignments are discussed

Results and discussion

The two-steps reaction we describe uses as starting material 2-arylidene-1-indanones **1a-c** and 2-arylidene-3-methyl-1-indanones **1d-f**. Condensed with an excess of hydrazine hydrate in ethanol at room temperature, this chalcones lead to the formation of 4-alkyl-3-aryl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazoles **2a-f**. Intermediates **2**, sufficiently stables for isolation, were further treated with acid chloride in methanol at room temperature in the presence of triethylamine to give in good yields the corresponding colorless crystalline 2-acyl-3-aryl-4-methyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazoles **3a-k** (scheme 1). The reaction was rapid, and we did not observe any competition from the ester formation between the acid chloride and methanol.



Scheme 1 : Synthetic pathway for compounds **2** and **3**

Earlier, Sinha *et al.*(10) showed that refluxing hydrazine with 2-anisylidene-1-indanones in glacial acetic acid gives stereospecifically the 3,3a-cis isomer of the 2-acetyl-3-anisyltetrahydro-indeno[1,2-c]pyrazole as an oil in 32 % yield. However and in spite of our attempts, we could not reproduce this reaction and isolate the isomer described above.

Thus, and according to the results we found, it appears, that the proceeding we reported above, can be considered as a more efficient route to the preparation of such tricyclic pyrazolines in good yield, using mild conditions (table 1).

Table 1 : Synthesis of pyrazolines **3**

Compound	R_1	R_2	R_3	Yield(%)[a]	Yield(%)[b]
3a	H	H	Ph	80	71
3b	H	Me	Ph	90	82
3c	H	OMe	Ph	85	75
3d	Me	H	Ph	81	71
3e	Me	Me	Ph	75	69
3f	Me	OMe	Ph	80	75
3g	H	Me	Me	76	68
3h	H	OMe	Me	75	65
3i	Me	H	Me	82	73
3j	Me	Me	Me	78	72
3k	Me	OMe	Me	71	67

(a) : Determined from pyrazolines **2a-f**.
(b) : Determined from chalcones **1a-f**.

A particular attention was devoted to the stereochemistry of compounds **3**. Therefore, the creation of two new centers of chirality may, logically, give rises to the formation of diastereoisomeric mixtures of tricyclic pyrazolines **3**. Thus, unambiguous ^{1}H and ^{13}C assignments of the sole isomer obtained and its relative configuration drew our interest and was accomplished by inverse two-dimensional chemical shift correlation methods and by NOESY experiments.

Table 2 : ^{1}H and ^{13}C NMR chemical shifts (ppm), multiplicity, coupling constants, HMBC and NOESY correlations for the pyrazoline **3f**

Atom	$\delta^{1}H$ (ppm)		J (Hz)	$\delta^{13}C$ (ppm)	HMBC	NOESY
3	5.24	d	11.3	69.5	3a,4,10,1'	4,2',6'
3a	3.34	dd	7.4	68.1	3,4,9,1',Me-4	2',6',Me-4
4	3.19	q		41.6	3,3a,4a,Me-4	5,Me-4
4a				154.2		
5	7.32	d	7.0	124.5	4,7,8a	Me-4
6	7.41	dd		131.3	4a,8	
7	7.29	dd		127.8	5,8a	8
8	7.78	d	7.0	122.9	4a,6,9	
8a				130.5		
9				165.2		
10				169.4		
1'				133.4		
2',6'	7.42	m		127.2	3,4'	3',5'
3',5'	6.89	m		114.4	1'	MeO-4'
4'				158.9		
1''				134.4		
2'',6''	7.97	m		130.2	10,4''	3'',5''
3'',5''	7.40	m		127.8	1''	
4''	7.47	m		131.3	2'',6''	
Me-4	1.34	d	6.9	17.9	3a,4,4a	
MeO-4'	3.79	s		55.3	4'	

As expected, the ^1H NMR spectrum of the derivative **3f**, chosen as illustration example, shows the presence of characteristic signals which can be, according to their multiplicity, readily assigned to H_3 (d, 5.24 ppm), H_{3a} (dd, 3.34 ppm), H_4 (m, 3.19 ppm), Me-4 (d, 1.34 ppm) and OMe-4' (s, 3.79 ppm). Thus, the location of the carbons C_3 (69.5 ppm), C_{3a} (68.0 ppm) and C_4 (41.6 ppm), can be easily deduced from the HMQC spectrum. The HMBC spectrum, shows that both H_3 and H_4 correlate with C_{3a}, whereas H_{3a} presents correlations with C_3, C_4 and C_9 at 165.1 ppm, thereby suggesting C_4-C_{3a}-C_3 and C_{3a}-C_9 linkages. In the same way, a whole set of linkages confirming the structure was established and are reported in table 2. Having established the two-dimensional structure of **3f**, the relative positions of H_3, H_4 and H_{3a} was investigated from a NOESY map.

As shown in table 2, the observed cross peaks between the indane methyl group and H_{3a}, on the one hand and H_3 and H_{3a} on the other hand, placed the methyl group, H_{3a} and the aromatic disubstitued ring on the same side of average plane of the tricyclic ring system. Moreover, the existence of a NOESY cross peak between H_3 and H_4 indicates that they are both on a same side, trans from H_{3a} (see figure 1).

The stereochemistry we attributed to the derivative **3f** is in accordance to the modeling structure shown in figure 2. So that the preferred thermodynamically stable conformation of **3f**, places the 3-aryl and acyl groups in a suitable spatial arrangement with least steric interaction and ring strain.

Similarly, going through the NOESY spectrum of compound **3c** (R_1=H, R_2=OCH_3, R_3=CH_3) reveals exactly the same stereochemistry as that we found for **3f**. Hence, the cis-stereochemistry given by Sinha *et al.* (10) for compound **3c** may not be correct and, in all likelihood, can not be established on the sole basis of the chemical shifts and the coupling constant $J_{3\,3a}$.

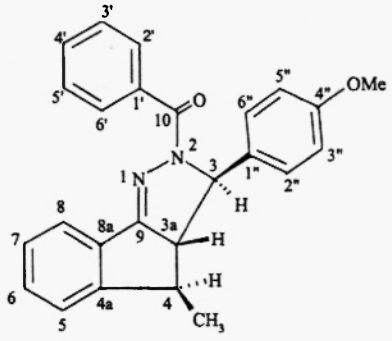


Figure 1 : Structural formula for **3f**

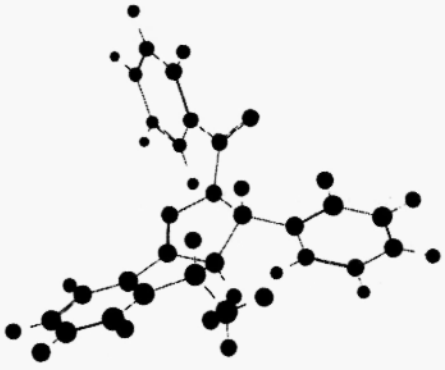


Figure 2 : Modeling structure for **3f**

Depending on the NMR data determined for derivative **3f**, assignements for the hole serie of pyrazolines **3** was easily established from their ^1H and ^{13}C NMR spectra, ^{13}C chemical shifts are summarized in table 3.

Table 3 : ^{13}C NMR chemical shifts (ppm), for the pyrazolines **3**

	compound									
Atom	**3a**	**3b**	**3c**	**3d**	**3e**	**3g**	**3h**	**3h**	**3j**	**3k**
3	70.6	70.6	70.2	69.5	69.7	69.4	69.2	68.7	68.4	68.1
3a	59.8	59.9	59.7	67.5	68.0	61.1	61.0	69.2	69.1	69.1
4	33.5	33.6	33.5	41.5	41.6	33.6	33.7	41.6	41.3	41.5
4a	149.8	150.0	149.9	154.0	154.2	149.7	149.7	153.8	153.8	153.8
5	126.4	126.5	126.4	124.4	124.5	126.6	126.6	124.5	124.4	124.4
6	131.2°	131.3°	131.2	131.5	131.3	131.2	131.3	131.3	131.1	131.1
7	128.8	127.8	127.7	127.5	127.7	128.0	128.1	127.3	127.8	127.8
8	123.1	123.3	123.1	123.0	122.8	122.9	122.9	122.5	122.4	122.4
8a	130.8	131.0	130.9	130.3	130.4	129.6	131.3	130.5	130.5	130.5
9	166.4	166.7	166.4	165.0	165.2	165.8	165.7	164.3	164.3	164.2
10	169.7	169.8	169.7	169.0	169.4	171.2	171.5	171.3	171.2	171.3
1'	140.7	137.8	132.6	141.5	138.4	138.3	133.4	141.9	138.8	133.8
2',6'	126.1	126.2	127.4	126.0	125.8	126.0	127.4	125.7	125.5	126.8
3',5'	127.8	129.6	114.2	129.0	129.6	129.6	114.3	128.8	129.4	114.2
4'	127.7	137.3	158.9	128.0	137.0	137.1	160.0	127.9	136.7	158.6
1''	134.2	134.4	134.3	134.4	134.4	*	*	*	*	*
2'',6''	130.1	130.3	130.2	130.0	130.1	*	*	*	*	*
3'',5''	127.7	127.8	127.7	128.0	127.7	*	*	*	*	*
4''	131.3°	131.4°	131.3	131.5	131.3	*	*	*	*	*
Me-4	*	*	*	18.0	17.9	*	*	17.7	17.7	17.7
Me-4'	*	21.2	*	*	21.1	21.2	*	*	21.1	*
MeO-4'	*	*	55.3	*	*	*	55.4	*	*	55.1
MeCO	*	*	*	*	*	22.8	22.9	22.6	22.	22.6

° May be reversed within the same column.

Conclusion

We have developed in this work a simple method for the stereospecific synthesis, in good yields, of trans-2-acyl-4-alkyl-3-aryl-2,3,3a,4-tetrahydroindeno[1,2-c]pyrazoles **3**. Total NMR spectral assignments for this compounds were performed using 2D NMR spectroscopic methods and permits an unambiguous elucidation of the molecular skeleton and stereochemistry of pyrazolines **3**.

Experimental

Melting points were taken on a Buchi-510 capillary melting point apparatus. Infrared spectra (potassium bromide) were run on a Perkin-elmer IR-197 infrared spectrometer. ^{1}H and ^{13}C nmr spectra were recorded on a Brüker spectrometer AC-300 using C_5D_5N as solvent for compounds **2** and $CDCl_3$ for compounds **3**. 2D experiments were performed on an AM-400 Brüker spectrometer.

2-Arylidene-1-indanones **1a-c** (11) and 2-arylidene-3-methyl-1-indanones **1d-f** (12) were prepared as previously reported. Molecular modelling calculations were performed using the MM2 force field implemented in the Chem3D program V6.0 (CambridgeSoft Corporation, Cambridge, USA). A conformational search was carried out by minimising energy using standard MM2 constants.

General procedure for the preparation of 4-alkyl-3-aryl-2,3,3a,4-tetrahydroindeno[1,2-c]pyrazoles 2a-f

An excess of hydrazine hydrate (10 ml) was added, at room temperature, to a stirred solution of enone **1** (10 mmol) in 3 ml of absolute ethanol. The reaction was followed by thin layer chromatography, (eluent = chloroform/ethyl acetate, 8/2), after 30 minutes stirring pyrazolines **2** have generally precipitated at room temperature or on cooling, the crude was poured into ice and hydrochloric acid, filtered and washed with water then stored at –20 °C.

3-phenyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2a** (R_1=H, R_2=H), colourless crystals, m.p. 103 °C. IR : $\nu_{C=N}$=1601 cm^{-1}, ν_{NH}=3267cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 2.80 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\alpha,3a}$=3.0 Hz), 3.32 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\beta,3a}$=8.0 Hz), 3.51 (m, 1H, H_{3a}), 4.14 (d, 1H, H_3, $J_{3,3a}$=7.0 Hz), 7.2-7.6 (m, 6H, H_5, H_6, H_7, $H_{3'}$, $H_{4'}$, $H_{5'}$), 7.7 (d, 2H, $H_{2'}$, $H_{6'}$), 7.8 (m, 1H, H_8).

3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2b** (R_1=H, R_2=Me), colourless crystals, m.p. 119 °C. IR : $\nu_{C=N}$=1624 cm^{-1}, ν_{NH}=3261cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 2.22 (s, 3H, Me-4'), 2.80 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.5 Hz), 3.32 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\beta,3a}$=7.5 Hz), 3.51 (m, 1H, H_{3a}), 4.14 (d, 1H, H_3, $J_{3,3a}$=5.0 Hz), 7.1-7.5 (m, 6H, H_5, H_6, H_7, $H_{3'}$, $H_{4'}$, $H_{5'}$), 7.7 (d, 2H, $H_{2'}$, $H_{6'}$), 7.8 (m, 1H, H_8).

3-anisyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2c** (R_1=H, R_2=OMe), colourless crystals, m.p. 109 °C. IR : $\nu_{C=N}$=1604 cm^{-1}, ν_{NH}=3273cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 2.79 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.5 Hz), 3.30 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\beta,3a}$=6.0 Hz), 3.49 (m, 1H, H_{3a}), 3.97 (s, 3H, OMe-4'), 4.15 (s, 1H, H_3), 7.1-7.5 (m, 3H, H_5, H_6, H_7), 7.6 (d, 2H, $H_{2'}$, $H_{6'}$), 7.7 (m, 1H, H_8).

4-methyl-3-phenyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2d** (R_1=Me, R_2=H), colourless crystals, m.p. 123 °C. IR : $\nu_{C=N}$=1615 cm^{-1}; ν_{NH}=3275cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 1.31 (d, 3H, Me-4, $J_{Me-4,4}$= 7.4 Hz), 3.18 (m, 2H, H_{3a}, H_4), 4.35 (d, 1H, H_3, $J_{3,3a}$=6.5 Hz), 7.25-7.84 (m, 9H, H_{arom}).

4-methyl-3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2e** (R_1=Me, R_2=Me), colourless crystals, m.p. 129°C. IR: $\nu_{C=N}$=1622 cm^{-1}, ν_{NH}=3289cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 1.28 (d, 3H, Me-4, $J_{Me-4,4}$= 7.8 Hz), 2.42 (s, 3H, Me-4'), 3.22 (m, 1H, H_{3a}, H_4), 2.42 (s, 3H, Me-4'), 4.31 (d, 1H, H_3, $J_{3,3a}$=6.5 Hz), 7.19-7.81 (m, 8H, H_{arom}).

4-methyl-3-anisyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **2f** (R_1=Me, R_2=OMe), colourless crystals, m.p. 137 °C. IR: $\nu_{C=N}$=1601 cm^{-1}, ν_{NH}=3267cm^{-1}. ^1H NMR (C_5D_5N), δ(ppm): 1.42 (d, 3H, Me, $J_{Me-4,4}$=7.8 Hz), 2.20 (m, 2H, H_{3a}, H_4), 3.95 (s, 3H, OMe-4'), 4.15 (d, 1H, H_3, $J_{3,3a}$=6.5 Hz), 7.1 (m, 2H, $H_{3'}$, $H_{5'}$), 7.3-7.6 (m, 3H, H_5, H_6, H_7), 7.6 (m, 2H, $H_{2'}$, $H_{6'}$), 7.9 (m, 1H, H_8).

General procedure for the preparation of 2-acyl-3-aryl-4-methyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazoles 3a-k

To a solution of pyrazoline **2** (5 mmol) and triethylamine (0.4 g) in 10 ml of dry methanol was added dropwise the acid chloride (12.5 mmol). The solution was stirred at room temperature for 1 hour and the reaction was followed by thin layer chromatography, (eluent = chloroform/ethyl acetate, 4/1). The precipitate generally formed while stirring, was filtered, washed with ether then recristallized in ethanol.

2-benzoyl-3-phenyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3a**, colourless crystals, m.p. 188 °C. ^1H NMR ($CDCl_3$), δ(ppm) : 2.93 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\alpha,3a}$=7.5 Hz), 3.22 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\beta,3a}$=8.5 Hz), 3.73 (m, 1H, H_{3a}), 5.21 (d, 1H, H_3, $J_{3,3a}$=11.9 Hz), 7.27-7.51 (m, 11H, H_5, H_6, H_7, $H_{2'}$, $H_{3'}$, $H_{4'}$, $H_{5'}$, $H_{6'}$, $H_{3''}$, $H_{4''}$, $H_{5''}$), 7.71 (m, 1H, H_8), 7.97 (m, 2H, $H_{2''}$, $H_{6''}$).

2-benzoyl-3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3b**, colourless crystals, m.p. 169 °C. ^1H NMR ($CDCl_3$), δ(ppm) : 2.35 (s, 3H, Me-4'), 2.91 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\alpha,3a}$=7.5 Hz), 3.19 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.5 Hz, $J_{4\alpha,3a}$=8.5 Hz), 3.72 (m, 1H, H_{3a}), 5.18 (d, 1H, H_3, $J_{3,3a}$=11.3 Hz), 7.18 (m, 2H, $H_{3'}$, $H_{5'}$), 7.29-7.49 (m, 8H, H_5, H_6, H_7, $H_{2'}$, $H_{6'}$, $H_{3''}$, $H_{4''}$, $H_{5''}$), 7.70 (m, 1H, H_8), 7.96 (m, 2H, $H_{2''}$, $H_{6''}$).

3-anisyl-2-benzoyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3c**, colourless crystals, m.p. 221 °C. ^1H NMR ($CDCl_3$), δ(ppm) : 2.91 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.0 Hz, $J_{4\alpha,3a}$=7.5 Hz), 3.23 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.0 Hz, $J_{4\alpha,3a}$=8.5 Hz), 3.73 (m, 1H, H_{3a}), 3.78 (s, 3H, OMe-4'), 5.17 (d, 1H, H_3, $J_{3,3a}$=12,0 Hz), 6.90 (m, 2H, $H_{3'}$, $H_{5'}$), 7.30-7.50 (m, 8H, H_5, H_6, H_7, $H_{2'}$, $H_{6'}$, $H_{3''}$, $H_{4''}$, $H_{5''}$), 7.71 (m, 1H, H_8), 7.97 (m, 2H, $H_{2''}$, $H_{6''}$).

2-benzoyl-4-methyl-3-phenyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3d**, colourless crystals, m.p. 189 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 1.41 (d, 3H, Me-4, $J_{Me\text{-}4,4}$=6.6 Hz), 3.20 (m, 1H, H_4), 3.35 (m, 1H, H_{3a}), 5.17 (d, 1H, H_3, $J_{3,3a}$=11.7 Hz), 7.20-7.60 (m, 11H, H_5, H_6, H_7, $H_{2'}$, $H_{3'}$, $H_{4'}$, $H_{5'}$, $H_{6'}$, $H_{3''}$, $H_{4''}$, $H_{5''}$), 7.65 (m, 1H, H_8), 7.98 (m, 2H, $H_{2''}$, $H_{6''}$).

2-benzoyl-4-methyl-3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3e**, colourless crystals, m.p. 177 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 1.34 (d, 3H, Me-4, $J_{Me\text{-}4,4}$=6.6 Hz), 2.33 (s, 3H, Me-4'), 3.20 (m, 1H, H_4), 3.32 (m, 1H, H_{3a}), 5.25 (d, 1H, H_3, $J_{3,3a}$=11 5 Hz), 7.20 (m, 2H, $H_{3'}$, $H_{5'}$), 7.35 (m, 2H, H_5, H_7), 7.40-7.60 (m, 6H, H_6, $H_{2'}$, $H_{6'}$, $H_{3''}$, $H_{4''}$, $H_{5'}$), 7.71 (m, 1H, H_8), 7.98 (m, 2H, $H_{2''}$, $H_{6''}$).

2-acetyl-3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3g**, colourless crystals, m.p. 123 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 2.23 (s, 6H, MeCO, Me-4'), 2.89 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=14.0 Hz, $J_{4\alpha,3a}$=7.5 Hz), 3.20 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=14.0 Hz, $J_{4\alpha,3a}$=8.5 Hz), 3.64 (m, 1H, H_{3a}), 4.95 (d, 1H, H_3, $J_{3,3a}$=11.6 Hz), 7.19 (m, 2H, $H_{3'}$, $H_{5'}$), 7.30 (m, 2H, $H_{2'}$, $H_{6'}$), 7.35-7.50 (m, 3H, H_5, H_6, H_7), 7.70 (m, 1H, H_8).

2-acetyl-3-anisyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3h**, colourless crystals, m.p. 149 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 2.34 (s, 3H, MeCO), 2.86 (dd, 1H, $H_{4\alpha}$, $J_{4\alpha,4\beta}$=15.3 Hz, $J_{4\alpha,3a}$=7.7 Hz), 3.17 (dd, 1H, $H_{4\beta}$, $J_{4\alpha,4\beta}$=15.3 Hz, $J_{3a,4\beta}$=8.6 Hz), 3.63 (m, 1H, H_{3a}), 3.78 (s, 3H, OMe-4'), 4.93 (d, 1H, H_3, $J_{3,3a}$=11.5 Hz), 6.88 (m, 2H, $H_{3'}$, $H_{5'}$), 7.30 (m, 2H, $H_{2'}$, $H_{6'}$), 7.33-740 (m, 3H, H_5, H_6, H_7), 7.74 (m, 1H, H_8).

2-acetyl-4-methyl-3-phenyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3i**, colourless crystals, m.p. 154 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 1.31 (d, 3H, Me-4, $J_{Me\text{-}4,4}$=6.7 Hz), 2.31 (s, 3H, MeCO), 3.10-3.25 (m, 2H, $H_{3a}H_4$), 5.05 (d, 1H, H_3, $J_{3,3a}$=11.6 Hz), 7.20-7.50 (m, 8H, H_5, H_6, H_7, $H_{2'}$, $H_{3'}$, $H_{4'}$, $H_{5'}$, $H_{6'}$), 7.72 (m, 1H, H_8).

2-acetyl-4-methyl-3-tolyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3j**, colourless crystals, m.p. 143 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 1.32 (d, 3H, Me-4, $J_{Me\text{-}4,4}$=6.7 Hz), 2.33 (s, 3H, Me-4'), 2.36 (s, 3H, MeCO), 3.16 (m, 1H, H_4), 3.20 (m, 1H, H_{3a}), 5.01 (d, 1H, H_3, $J_{3,3a}$=10.8 Hz), 7.14 (m, 2H, $H_{3'}$, $H_{5'}$), 7.35 (m, 2H, $H_{2'}$, $H_{6'}$), 7.37 (m, 2H, H_6, H_7), 7.45 (d, 1H, H_5), 7.73 (m, 1H, H_8).

2-acetyl-3-anisyl-4-methyl-2,3,3a,4-tetrahydroindeno[1,2-*c*]pyrazole **3k**, colourless crystals, m.p. 157 °C. ^{1}H NMR ($CDCl_3$), δ(ppm) : 1.32 (d, 3H, Me-4, $J_{Me\text{-}4,4}$=7.0 Hz), 2.36 (s, 3H, MeCO), 3.13 (m, 1H, H_4), 3.23 (m, 1H, H_{3a}), 3.79 (s, 3H, MeO-4'), 5.01 (d, 1H, H_3, $J_{3,3a}$=11.6 Hz), 6.89 (m, 2H, $H_{3'}$, $H_{5'}$), 7.30 (m, 2H, $H_{2'}$, $H_{6'}$), 7.33 (d, 1H, H_5), 7.38 (m, 1H, H_7), 7.44 (m, 1H, H_6), 7.73 (m, 1H, H_8).

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