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On the reactivity of some 2-methyleneindolines with β-nitroenamines, α-nitroalkenes, and 1,2-diaza-1,3-butadienes

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Abstract—A study of the behaviour of some electron-rich 2-methyleneindolines (**1**–**3**) with different electron-poor reagents (formation of new carbon–carbon and nitrogen–carbon bonds) has furnished interesting results from both synthetic and the mechanistic viewpoints. Enamines **1**–**3** have been reacted with the β-nitroenamines **4**–**7** (reaction $CeCl_3 \cdot 7H_2O$ promoted), giving the polymethine dyes **14**–**23**. The same bases **1**–**3** have been nitroalkylated with the nitroolefins **8**–**10**, furnishing the indolines **24**–**32**, and the diastereoselectivity of the reaction has been thoroughly investigated. The most unexpected results derived from the first example of reaction of Fischer's bases with 1,2-diaza-1,3-butadienes. In fact, with **11**–**13**, the 'unknown' indoline spirodihydropyrroles **33**–**40** were formed. Their structures were unambiguously assigned, and we determined, as an example, that of **33** by X-ray analysis.

1. Introduction

Fischer's base[1] **1** (1,3,3-trimethyl-2-methyleneindoline) has been frequently used in dye chemistry for the synthesis of polymethine dyes, a class of compounds that contain an electron donor and an electron acceptor at the opposite ends of the methine chain.[2] Thus, chiral monomethine cyanine dyes,[3] chiral arylazomethyleneindoline dyes[4] and chiral trimethine cyanine dyes[2c] were synthesized using chiral 2-methyleneindolines as key intermediates.

Also interesting are the reactions of Fischer's base with 2-hydroxybenzaldehyde derivatives[5] and 1-nitroso-2-hydroxyaryl derivatives,[6] which afford spiropyran and [1,4]-spirooxazine derivatives, respectively, whereas [1,2]-spirooxazine derivatives can be obtained using nonaromatic nitrosohydroxy compounds.[7] These spirocompounds are a class of photochromic organic compounds that have been extensively studied since the first report by Fischer and Hirshberg.[8] The photochromism of spiropyran[9] and spirooxazine[6,9c,10] is based on the reversible colour change between the closed spiro-structure and the open planar merocyanine structure. Permanent open forms of spirooxazines can be also synthesized.[11]

In accordance with previous considerations and in the framework of our interest on the use of nitroalkenylation reactions in organic synthesis, we have addressed our attention to the behaviour of bases **1**–**3** (electron-rich substrates) with the β-nitroenamines **4**–**7**[12–16] (electron-poor reagents) (Fig. 1) with the aim of obtaining new polymethine dyes. For the sake of comparison and continuing our studies on nitroalkylation reactions[16] of 2-methyleneindolines, we investigated the reactivity of bases **1**–**3** with the α-nitroalkenes **8**–**10**,[17–18] also to verify the diastereoselectivity of this reaction on the chiral racemic substrates **2** and **3**. Furthermore, for the first time, the study of the reactivity study of nucleophiles such as **1**–**3** has been extended to the 1,2-diaza-1,3-butadienes **11**–**13**,[19] electrophiles that, because of their polyfunctionalized structure, could show unexpected development in the reaction.

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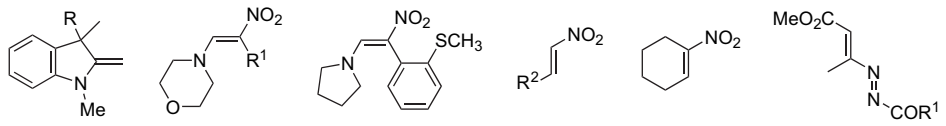


1: R = Me
2: R = Et
3: R = Ph

4: R^1 = H
5: R^1 = Me
6: R^1 = Ph

7

8: R^2 = Me
9: R^2 = Ph

10

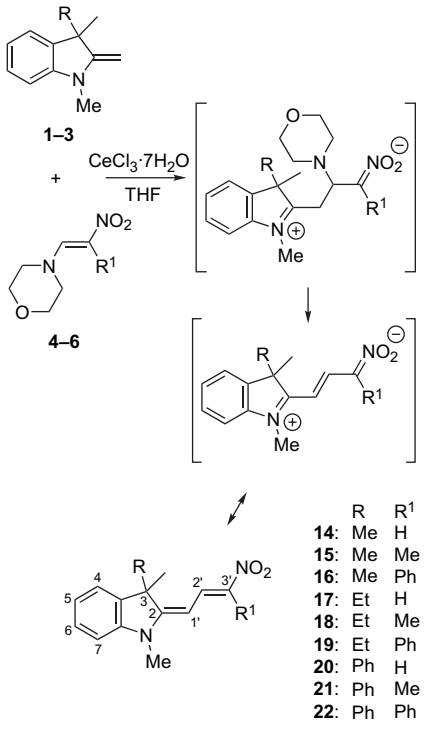
11: R^1 = NH_2
12: R^1 = OMe
13: R^1 = O-*t*-Bu

Figure 1. 2-Methyleneindolines **1**–**3**, β-nitroenamines **4**–**7**, nitroolefins **8**–**10** and 1,2-diaza-1,3-butadienes **11**–**13**.

2. Results and discussion

2.1. Reactivity of indolines with β-nitroenamines

2.1.1. Nitroalkenylation reactions of 2-methyleneindolines 1–3 with nitroenamines 4–6. The enamines **1**–**3** (2 equiv) reacted with the nitroenamines **4**–**6** (1 equiv) in dichloromethane, in the presence of 1 equiv of $CeCl_3 \cdot 7H_2O$,[20] to yield the corresponding nitroalkenylated products **14**–**22** (Scheme 1), with formation of a new carbon–carbon bond between two sp^2-hybridized carbon atoms, showing nucleophilic (in **1**–**3**) and electrophilic (in **4**–**6** or in **7**, see subsequently) characters, respectively. In such a way compounds containing the interesting diene system having at the two ends an electron-donating and an electron-withdrawing group have been built-up, that is, polymethine dye systems.



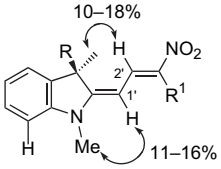
	R	R^1
14:	Me	H
15:	Me	Me
16:	Me	Ph
17:	Et	H
18:	Et	Me
19:	Et	Ph
20:	Ph	H
21:	Ph	Me
22:	Ph	Ph

Scheme 1. Nitroalkenylation products of 2-methyleneindolines **1**–**3**.

The presence of Ce(III) chloride promotes the reaction, with time varying from 4 to 15 days. Yields of purified products ranged between 26% and 56% (Table 2). The geometry of the two conjugated double bonds in the products **16**–**22** (compounds **14** and **15** were already known[16]) was established as (1′*E*,2′*E*) by difference NOE measurements performed on **16**, **19**, **20**, **21** and **22** (Table 1) and by comparison of the resonances of their vinyl protons (Table 2). In all compounds examined, irradiation of the methyl group on nitrogen caused the enhancement of the H-1′ vinyl proton signal, whereas by irradiating the H-2′ vinyl proton either the methyl group (in **16**, **19**, **20**, **21**, and **22**) or the methylene group of the ethyl chain (in **19**) was enhanced, thus demonstrating the *s*-trans geometry of the butadiene moiety.

2.1.2. Nitroalkenylation reaction of Fischer's base 1 with nitroenamine 7. In this case, $CeCl_3 \cdot 7H_2O$ alone was not able to promote the reaction. On the contrary, when a mixture of $CeCl_3 \cdot 7H_2O$ (0.2 equiv) and NaI (0.1 equiv)[21] was used, the nitroalkenylated product **23** was isolated in 10% yield. The lower yield found in this case, in which the nitroolefin phenyl ring bears a methylthio group, when compared with that found for the nitroolefin **6** with the same substrate (Table 2) would suggest a preferred coordination of cerium with sulfur, owing to its known great affinity for oxygen and sulfur. $InCl_3$ was also used as a Lewis acid, however, after 7 days only traces of the product **23** could be detected in the ^{1}H NMR spectrum of the crude reaction mixture (Fig. 2). This result is difficult to explain, as in some cases $InCl_3$ has been found to be more efficient than $CeCl_3 \cdot 7H_2O$.[22] When $Zn(CF_3SO_3)_2$ was used, the same product **23** was isolated in 30% yield. The ability of zinc triflate to promote carbon–carbon bond formation in the indole chemistry has

Table 1. Difference NOE data for compounds **16**, **19**, **20**, **21**, and **22**

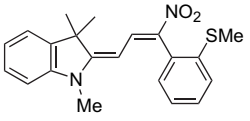
	Compound	Irradiated nucleus: CH_3 at N c.s. (ppm)	Enhanced nucleus: H-1′ c.s. (ppm)	η	Irradiated nucleus: H-2′ c.s. (ppm)	Enhanced nucleus: CH_3 at C-3 c.s. (ppm)	η
	**16**	3.09	5.23	0.14	8.74	1.71	0.18
	19	3.09	5.30	0.15	8.71	1.69	0.12
						2.31[a]	0.14
	20	3.40	5.41	0.11	7.70	1.93	0.10
	21	3.40	5.25	0.13	7.82	1.93	0.13
	22	3.20	5.20	0.16	8.07	1.99	0.18

16, 19, 20, 21, 22

[a] Enhancement of the methylene of the ethyl group.

Table 2. Reaction times, reaction yields and the most meaningful ^{1}H NMR data for the nitrodiene derivatives **14–23**

Product	Reaction time (d)	Yield (%)	^{1}H NMR	
			H-1′ ppm, mult., *J* (Hz)	H-2′ ppm, mult., *J* (Hz)
14	14	56	5.46, d, 13.2	8.38, dd, 13.2, 12.1
15	14	53	5.30, d, 13.2	8.50, d, 13.2
16	6	45	5.23, d, 13.5	8.74, d, 13.5
17	15	38	5.51, d, 13.1	8.34, t, 13.1
18	4	42	5.34, d, 13.5	8.46, d, 13.5
19	7	44	5.30, d, 13.5	8.71, d, 13.5
20	8	31	5.41, d, 12.9	7.70, t, 12.9
21	4	42	5.25, d, 13.0	7.82, d, 13.0
22	15	26	5.20, d, 13.2	8.07, d, 13.2
23	12	30	4.93, d, 13.5	8.74, d, 13.5



23

Figure 2. Compound **23**.

already been evidenced to be superior to other heavy-metal salts and lanthanide salts as well.[23]

2.1.3. UV spectra of trimethines 16–23. All the nitrodiene derivatives **16–23** exhibited an intense absorption band in the visible region. Their electronic spectra were recorded (see data in Table 3) in three solvents with very different properties. In fact, cyclohexane, acetonitrile and methanol were different from one another, as shown by the values of their empirical parameters of solvent polarity. They differed not only in their dielectric properties, evaluated by using the E_T^N (that is, the normalized parameter of solvatochromic solvent polarity: 0.006, 0.460 and 0.762, respectively) values,[24] but also for their different aptitude to participate in hydrogen bond formation, as evaluated by the (A_j+B_j) parameter[25] (0.09, 1.22 and 1.25, respectively).

It is noteworthy that the position of band 4 was particularly affected by solvent polarity, being significantly shifted from 434–452 nm in cyclohexane to longer wavelengths (bathochromic shift) in acetonitrile (473–489 nm) and in methanol (477–491 nm). Moreover, for all compounds, in the apolar solvent cyclohexane, a further intense absorption band (band 3) appeared around 417–436 nm.

2.2. Reactivity of indolines with α-nitroolefins

2.2.1. Nitroalkylation reactions of 2-methyleneindolines 1–3 with α-nitroolefins 8–10. The nitroalkylation reactions of 2-methyleneindolines **1–3** with the α-nitroolefins **8–10** were performed in diethyl ether and furnished the corresponding products **24–32** (Scheme 2) in good yields, with the exception of the products derived from **3**, which were obtained in a much lower yield. Evidently, the steric hindrance of the phenyl group greatly affected the approach of the reagents. Compound **26** had already been synthesized,[16] and it is included only for comparison.

Once more a new carbon–carbon bond between carbon atoms initially sp^2-hybridized is formed, but, in this case, the absence of a leaving group in **8–10** causes the formation of an alkenic instead of an alkadienic system.

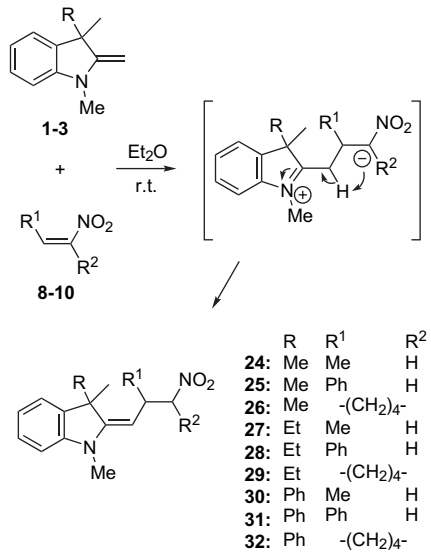
Moreover the higher electrophilic character of **8–10**, caused by the absence of the amino moiety, makes unnecessary the presence of the Lewis acid promoters.

2.2.2. Reactions of 2-methyleneindolines 1–3 with 1-nitropropene 8 and β-nitrostyrene 9. The reaction of Fischer's base **1** with (*E*)-1-nitropropene **8** gave compound **24** as a single diastereomer. By contrast, in the reaction of

Table 3. Electronic absorption spectra of compounds **16–23**: λ_{max} [nm] (log ε)

	Solvent	Band 1	Band 2	Band 3	Band 4
16	CH_3OH	208 (4.29)	275 (4.12)		490 (4.42)
	CH_3CN	193 (4.76)	277 (4.05)		485 (4.46)
	CyH[a]	195 (4.65)	251 (3.71), 279 (4.09)	434 (3.93)	450 (3.94)
17	CH_3OH	209 (3.97)	277 (3.90)		483 (4.41)
	CH_3CN	195 (4.60)	280 (4.13)		477 (4.59)
	CyH[a]	212 (4.01)	247 (3.68), 276 (3.94)	420 (4.22)	440 (4.26)
18	CH_3OH	209 (4.01)	283 (3.99)		490 (4.48)
	CH_3CN	192 (4.94)	280 (4.35)		480 (4.65)
	CyH[a]	216 (4.15)	248 (4.06), 280 (4.20)	428 (4.51)	448 (4.53)
19	CH_3OH	208 (4.25)	284 (3.95)		491 (4.57)
	CH_3CN	193 (3.91)	276 (4.16)		488 (4.56)
	CyH[a]	195 (4.68)	279 (4.21)	436 (4.45)	452 (4.46)
20	CH_3OH	208 (4.41)	275 (3.94)		477 (4.15)
	CH_3CN	194 (5.02)	277 (4.24)		473 (4.55)
	CyH[a]	197 (4.66)	271 (4.11)	417 (4.43)	434 (4.45)
21	CH_3OH	207 (4.29)	276 (4.28)		483 (4.46)
	CH_3CN	194 (4.72)	280 (4.07)		477 (4.49)
	CyH[a]	210 (4.21)	248 (3.77)	421 (3.86)	440 (3.85)
22	CH_3OH	209 (4.60)	263 (4.12)		487 (4.35)
	CH_3CN	193 (4.98)	260 (4.17)		484 (4.40)
	CyH[a]	210 (4.49)	254 (3.98)	429 (4.15)	443 (4.13)
23	CH_3OH	209 (4.50)	254 (4.08), 281 (3.97)		489 (4.42)
	CH_3CN	203 (4.46), 209 (4.47)	259 (4.10), 288 (3.99)		489 (4.48)
	CyH[a]	201 (4.24), 210 (4.41)	259 (4.09), 281 (3.99)	432 (4.35)	451 (4.36)

[a] CyH, cyclohexane.



Scheme 2. Nitroalkylation products of 2-methyleneindolines **1**–**3** with nitroalkenes **8**–**10**.

1 with (*E*)-β-nitrostyrene **9**, two isomers, **25a** and **25b**, were obtained in a 9:1 ratio. The *E* geometry was assigned to compounds **24** and **25a** on the basis of NOE measurements. In fact, irradiation of the respective vinyl protons (3.96 ppm for **24** and 4.39 ppm for **25a**) enhanced the signal of the singlet relative to the methyl group at nitrogen (2.95 ppm for **24** and 3.00 ppm for **25a**) for 6% and 13%, respectively. As a consequence, **25b** was assigned the *Z* configuration.

The reactions of 2-methyleneindolines **2** and **3** with 1-nitropropene **8** and β-nitrostyrene **9** gave pairs of inseparable diastereomers **27a**,**b**, **28a**,**b**, **30a**,**b** and **31a**,**b** at ratios of 9:1, 3:2, 3:1 and 1:1, respectively (Table 4). The **a** and **b** isomers were assigned the *E* configuration because the chemical shifts of their vinyl proton H-1′ were practically the same, differing by 0.01–0.04 ppm. In Table 4 we also report the chemical shifts of (*E*)-**24**, (*E*)-**25a** and (*Z*)-**25b**. NOE experiments were performed on compounds **24**–**28, 30** and **31**, in order to confirm their geometries. Irradiation of the nitrogen methyl group caused enhancement of the respective vinyl proton signal for amounts ranging from 5% to 13%.

It is interesting to point out that only in the reactions of **2** and **3** with 1-nitropropene **8** it was possible to envisage a 1,4-asymmetric induction for the formation of the new stereocentre. In fact, the diastereomeric excess (de) was 80% for the reaction of enamine **2**, and it was only 50% for the reaction of the 2-methyleneindoline **3** with the same α-nitroolefin. The relative stereochemistry of the nitroalkyl chain was tentatively assigned as 2′*R** and 2′*S** by analysis of the ^{1}H NMR data for compounds **30a** and **30b** (Fig. 3).

Table 4. Relative yields and chemical shift values of vinyl proton signals for compounds **24**, **25**, **27**, **28**, **30** and **31**

Entry	Product	Yield (%)	H-1′ (ppm)
1	(*E*)-**24**	100	3.96
2	(*E*)-**25a**	90	4.39
	(*Z*)-**25b**	10	4.25
3	(*E*)-**27a**	90	4.02
	(*E*)-**27b**	10	4.03
4	(*E*)-**28a**	60	4.46
	(*E*)-**28b**	40	4.47
5	(*E*)-**30a**	75	3.99
	(*E*)-**30b**	25	3.95
6	(*E*)-**31a**	50	4.40
	(*E*)-**31b**	50	4.36

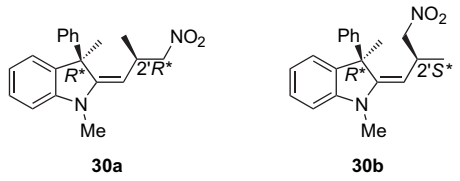


Figure 3. Structures of compounds **30a** and **30b**.

Although a rotation around the C1′–C2′ single bond is possible, the average positions of the methyl group and the nitromethylenic group are influenced differently by the presence of the phenyl group. Thus, the methyl doublet at C-2′ resonated at 0.50 ppm for the major component **30a** and at 1.04 ppm for the minor component **30b**, whereas the resonances of the respective nitromethylenic protons appeared at 4.19 ppm for **30a**, as an AB part of an ABXY3 system, and at higher field (3.64 and 3.36 ppm, two double doublets) for **30b**. Therefore, the (3*R**,2′*R**) configuration was assigned to **30a**, for which the methyl group at C-2′ is more shielded by the phenyl group, and the (3*R**,2′*S**) configuration to **30b**, for which the nitromethylenic protons are more shielded. These assignments agree with the *R**,*Si** topological approach of α-nitroolefins to the enamines, and is similar to that proposed by Seebach et al.[26] (Fig. 4). In a similar manner, the diastereomers **27a** and **27b** were assigned the (3*R**,2′*R**) and (3*R**,2′*S**) configurations.

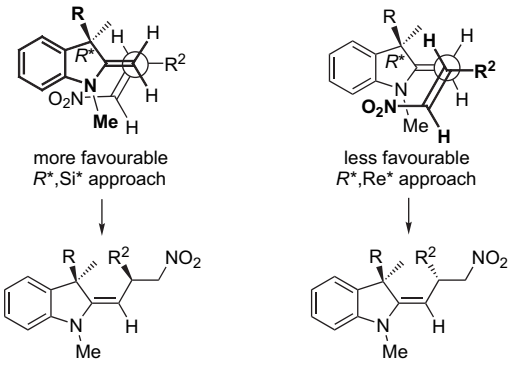


Figure 4. The proposed topological approach.

In the reaction of 2-methyleneindoline **3** with β-nitrostyrene **9**, the isomers **31a** and **31b** were formed in a 1:1 ratio. Since the nitromethylenic protons resonated as two double doublets at 4.56 and 4.48 ppm for **31a** and at 4.14 and 3.60 ppm for **31b**, owing to the C.I.P. configurational rules, in this case the (3*R**,2′*S**) configuration was assigned to **31a** and the (3*R**,2′*R**) configuration to **31b**, the former being generated by an *R**,*Si** approach and the latter by an *R**,*Re** approach. In this case the two approaches were equally probable.

2.2.3. Reactions of 2-methyleneindolines 1–3 with nitrocyclohexene 10. The reaction of Fischer's base **1** with nitrocyclohexene **10** gave two diastereomeric Michael-type adducts **26a** and **26b**, both of which were in *E* geometry and differed in the orientation of the nitro group.[16]

In the reaction of 2-methyleneindoline **2** with nitrocyclohexene **10**, two isomers, **29a** and **29b**, were formed in a 3:1 ratio. The same *E* geometry was assigned to both diastereomers by comparison of their ^{1}H NMR data with those of the known compounds **26**.[16] Since the axial and equatorial orientations of the nitro group were easily recognizable from the positions and patterns of the respective nitromethine proton signals, the *cis* and *trans* geometries were assigned to **29a** and **29b**, respectively. In fact, in the *cis* isomer **29a**, the equatorial nitromethine proton resonated at lower field than the same proton in the *trans* isomer **29b** (4.62 ppm vs 4.22 ppm). The two signals also exhibited different patterns: a double triplet with J_1=J_2=4.3, J_3=8.8 Hz and W_H=16 Hz for **29a** and a multiplet with W_H=26 Hz for **29b**, in accordance with equatorial and axial orientations, respectively, of the nitromethine protons. On standing, the *cis* diastereomer **29a** slowly converted into the more stable *trans* isomer **29b**, thus confirming the assignments made.

The ^{1}H NMR analysis of the crude reaction mixture obtained from the enamine **3** and nitrocyclohexene **10** indicated the presence of three diastereomers of *E* configuration: *cis*-**32a**, *trans*-**32b** and *cis*-**32c** in 60%, 25% and 15% yields, respectively. Unfortunately, purification by column chromatography did not allow a complete separation of the products. In fact, *cis*-**32a** transformed in large amount into *trans*-**32b**, whereas *cis*-**32c** converted completely into *trans*-**32d**.

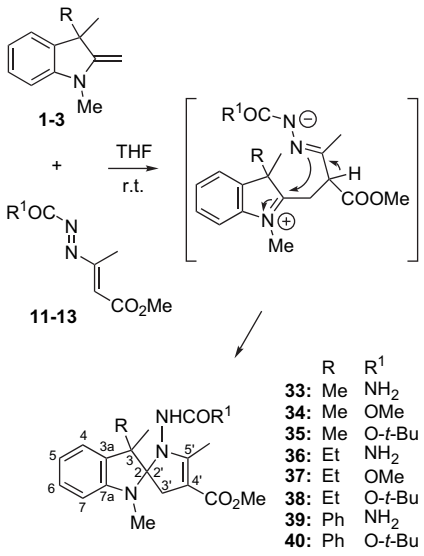
The *cis* configuration assigned to **32a** and **32c** on the basis of their lower thermodynamic stability was confirmed by an analysis of the signals of their respective nitromethine protons when they were compared with those of the corresponding *trans* isomers **32b** and **32d**. In fact, the nitromethine protons resonated at 4.48 ppm (W_H=18.4 Hz) for **32a** and at 4.48 ppm (W_H=18.4 Hz) for **32c**, whereas the same signal appeared at 4.10 ppm (W_H=30.0 Hz) for **32b** and at 3.94 ppm (W_H=29.0 Hz) for **32d**.

In accordance with the above stereochemical considerations and the type of proposed topological approach described in Figure 4, the same (3*R**,2′*R**) configuration was assigned to **32a** and **32b**, whereas the (3*R**,2′*S**) configuration was assigned to **32c** and **32d**.

2.3. Reactions of 2-methyleneindolines 1–3 with 1,2-diaza-1,3-butadienes 11–13

The reactions between the indolines **1–3** and the 1,2-diaza-1,3-butadienes **11–13**[19a,b] were performed in THF at room temperature, which produced the tricyclic addition compounds **33–40** in good yields (81–96%) (Scheme 3) with formation of two new bonds (carbon–carbon and nitrogen–carbon, respectively).

The interesting spiro-structure of compound **33** has been unambiguously determined by X-ray diffraction study



Scheme 3. The spirocompounds **33–40**.

(Fig. 5).[27] Indoline spirodihydropyrroles have not been reported in the literature, and only few cases of spiroindolepyrrolidinones are known.[28] Interestingly, whereas the ^{1}H and ^{13}C NMR spectra of **33** in $CDCl_3$ showed the presence of a single product, in DMSO-d_6 each peak was split into two signals, thus indicating the presence of two conformers **a** and **b** in a 60:40 ratio. They remained stable even when the temperature was increased. The relative signals did not coalesce even at 110 °C. However, after recovering the product from DMSO-d_6, its spectrum again in $CDCl_3$ showed the signals of the parent isomer. DIFNOE measurements were performed on the two conformers **33a** and **33b** with the aim of understanding the origin of this isomerism. Irradiating the methyl group linked to nitrogen in the major component **33a** at 2.60 ppm an enhancement was observed for the signal of the NH group at 6.94 ppm (4%), whereas, in the minor component **33b**, the same signal (at 7.22 ppm) was enhanced by irradiating the methyl group at C-3 at 1.23 ppm. These results suggest that, in the major isomer **33a**, the NH group of the chain pointed towards the nitrogen of the indole moiety, as shown by the X-ray structure, whereas, in the minor isomer, the same group pointed towards C-3 of the indole moiety. This could be consistent with an inversion (flip-flap) at the pyrroline nitrogen.

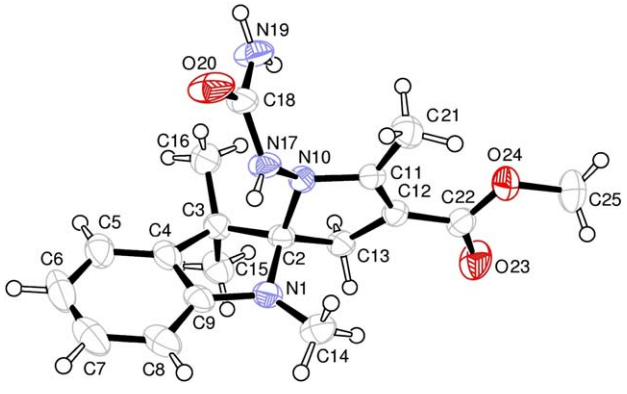


Figure 5. X-ray structure of compound **33**.

The structure of the minor isomer **33b** was optimized with the Cornell version of the Amber force field,[29] which showed a relative energy difference of 4 kcal/mol with respect to **33a**. In the invertomer **33b**, the proximity of the NH group to the methyl group at C-3 is evident. No other rotamer of **33a** would account for the NOE effect observed for **33b**. Figure 6 presents a better representation of the two isomers showing the distance between the protons involved in the NOE effects observed.

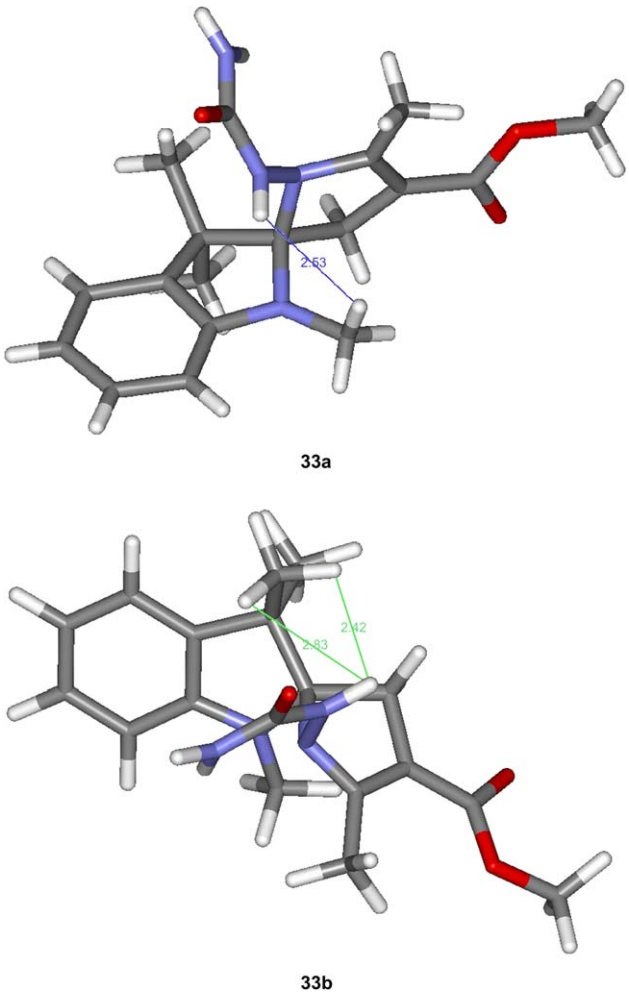


Figure 6. Optimized geometries of **33a** and **33b**.

NMR analysis of all the other products **34–40** showed that they were mixtures of isomers **a** and **b** even in $CDCl_3$. If this result can be attributed to the presence of conformers for compounds **34** and **35**, which possess a single stereocentre, the same conclusion cannot be drawn immediately for compounds **36–40**, which possess two stereocentres. However, a comparison between the spectra of the same spirocompounds in $CDCl_3$ and in DMSO-d_6 revealed that they simply differed in the composition of **a** and **b**, as shown in Table 5. This could suggest that **a** and **b** are conformers and not diastereomers. In that case the preferred approach of the enamines **2** and **3** onto the 1,2-diaza-1,3-butadienes would occur from the less sterically demanding side namely the one that contains the methyl group at C-3.

Table 5. Chemical compositions of compounds **33–40**

Compound	*a*:*b* $CDCl_3$	*a*:*b* DMSO-d_6
33	100:0	60:40
34	60:40	55:45
35	60:40	50:50
36	75:25	60:40
37	55:45	50:50
38	60:40	50:50
39	40:60	65:35
40	40:60	55:45

3. Conclusion

By reaction of 2-methyleneindoline derivatives **1–3** with β-nitroenamines **4–7**, new deeply coloured trimethine dyes containing the nitro function as the electron-acceptor group were obtained. These syntheses were promoted by $CeCl_3 \cdot 7H_2O$, although in most cases long reaction times were required. Studies on the optical properties of these dyes are under investigation.

In the nitroalkylation reactions of **1** and **2**, (*E*)-1-nitropropene **8** proved more diastereoselective than (*E*)-β-nitrostyrene **9**, as it has already been observed for enolates,[14a] whereas the nitrocyclohexene **10** was the most diastereoselective. The nitroalkylation reactions of the 2-methyleneindoline **3** were less satisfactory as far as yields and diastereoselectivity are concerned. This was probably due to the severe steric hindrance carried on both sides of the enamine system by the phenyl group.

The reactions of 2-methyleneindolines with 1,2-diaza-1,3-butadienes **11–13** gave rise to unknown indoline spiropyrrolines. It is noteworthy that neither spirotetrahydropyridazines deriving from the possible [4+2] cycloaddition, nor the simple Michael addition products were detected. The new reaction observed provides a route to interesting, partially reduced benzocondensed pyrrole derivatives that are intermediates in natural product synthesis.[28,30] Experiments of ring opening under thermal and photochemical conditions are in progress, to verify whether a ring open-chain equilibration is possible to modulate the absorption wavelength of the molecules.

4. Experimental

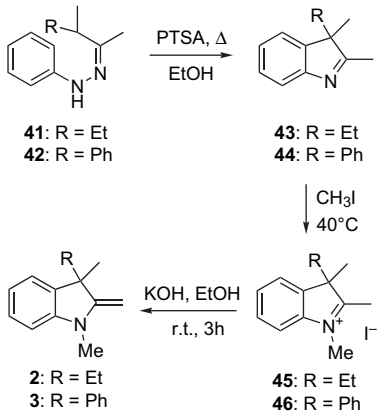
4.1. General

IR spectra were recorded on a Jasco FT/IR 200 spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were run on a Jeol EX-400 spectrometer (400 MHz for proton, 100 MHz for carbon) and a Jeol EX-270 spectrometer (270 MHz for proton, 68 MHz for carbon), using deuteriochloroform as a solvent and tetramethylsilane as the internal standard. Coupling constants are given in Hertz. GLC analyses were run on a Carlo Erba GC 8000 instrument, the capillary column being OV 1701 (25 m×0.32 mm) (carrier gas He, 40 kPa, split 1:50). Mass spectra were recorded on an ion trap FINNIGAN GCQ (70 eV) spectrometer, HRMS were recorded on a FINNIGAN MAT95XP apparatus. UV spectra were recorded on a HELIOS β-UNICAM spectrophotometer. TLCs were performed on Polygram® Sil G/UV254

silica gel pre-coated plastic sheets (eluant: light petroleum–ethyl acetate). Flash chromatography was run on silica gel 230–400 mesh ASTM (Kieselgel 60, Merck). Light petroleum refers to the fraction with bp 40–70 °C. All solvents were distilled over appropriate drying agents and maintained over molecular sieves. 2,3-Dihydro-2-methylene-1,3,3-trimethyl-1*H*-indole **1**, 3-methyl-2-pentanone and *trans*-β-nitrostyrene **9** were purchased from Sigma–Aldrich. Phenylhydrazine was purchased from Carlo Erba; 4-(2-nitroethenyl)morpholine **4**,[12] 4-(2-nitro-1-propenyl)morpholine **5**,[13] 4-(2-phenylethenyl-2-nitro)morpholine **6**,[14] 1-[(1*E*)-2-[2-(methylthio)phenyl]-2-nitroethenylpyrrolidine **7**,[15] 3-phenyl-2-butanone,[31a] 1-nitropropene,[17] 1-nitrocyclohexene[18] and 1,2-diaza-1,3-butadienes **11**–**13**[19,32] were synthesized according to the literature.

4.2. Synthesis of 2-methyleneindoline derivatives 2 and 3

2-Methyleneindoline derivatives **2** and **3** were prepared according to the procedure of Brunner[33] and Ferratini,[34] as indicated in Scheme 4. Fischer's indolization[35] of 3-methyl-2-pentanone phenylhydrazone **41** and 3-phenyl-2-butanone phenylhydrazone **42**[31b] furnished the corresponding 3*H*-indoles **43**[36] and **44**[37] that were alkylated with iodomethane providing salts **45**[2c] and **46**, respectively. Their treatment with KOH afforded 3-ethyl-1,3-dimethyl-2-methyleneindoline **2** and 2-methylene-1,3-dimethyl-3-phenylindoline **3**, respectively.



Scheme 4. Synthesis of 2-methyleneindolines **2** and **3**.

4.3. Synthesis of substrates

4.3.1. 3-Methyl-2-pentanone phenylhydrazone (41). To a solution of phenylhydrazine (7.8 ml, 80 mmol) in ethanol (28.8 ml) 3-methyl-2-pentanone (9.8 ml, 80.0 mmol) was added. After refluxing the solution for 5 h and evaporation of the solvent the phenylhydrazone **41** was obtained as a yellow oil (99% yield). IR (cm^{-1}, film) 3350 (NH), 1602 (C═N), 1502 (Ph); ^1H NMR (δ, ppm, $CDCl_3$) 7.23 (2H, t, Ph-H, J=7.9 Hz), 7.05 (2H, d, Ph-H, J=8.4 Hz), 6.81 (1H, t, Ph-H, J=7.3 Hz), 2.43 (1H, m, $CHCH_3$), 2.13 (1H, s, NH), 1.82 (3H, s, CH_3C), 1.57 (1H, m, *H*$CHCH_3$), 1.44 (1H, m, *H*$CHCH_3$), 1.10 (3H, d, C*H*$_3$CH, J=7.0 Hz), 0.89 (3H, t, C*H*$_3$CH$_2$, J=7.3 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 146.0 (s, C═N), 129.2 (2d, Ph), 119.7 (d, Ph), 113.2 (2d, Ph), 43.8 (d, *C*HCH_3), 27.3 (t, *C*H_2CH_3), 17.8 (q, CH_3), 12.1 (q, CH_3), 12.0 (q, CH_3).

4.3.2. 3-Phenyl-2-butanone phenylhydrazone (42).[31a] To a solution of phenylhydrazine (2.5 ml, 25 mmol) in ethanol (9 ml) 3-phenyl-2-butanone[31a] (3.70 g, 25 mmol) was added. The orange solution obtained was refluxed for 7 h and after removal of the solvent the phenylhydrazone **42** was obtained in 91% yield. Mp 70–72 °C; IR (cm^{-1}, Nujol) 3350 (NH), 1601 (C═N), 1498 (Ph); ^1H NMR (δ, ppm, $CDCl_3$) 7.40–7.12 (9H, m, Ar-H), 6.84 (1H, t, Ar-H, J=7.3 Hz), 3.70 (1H, m, CH), 2.05 (1H, s, NH), 1.68 (3H, s, CH_3C), 1.51 (3H, d, CH_3CH, J=7.0 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 148.0 (s), 146.1 (s), 143.8 (s), 129.3 (d), 128.6 (d), 127.8 (d), 126.6 (d), 119.7 (d), 113.1 (d), 48.3 (d, C-3), 18.9 (q, CH_3), 13.6 (q, CH_3).

4.3.3. 3-Ethyl-2,3-dimethyl-3*H*-indole (43).[36] To a solution of **41** (15.02 g, 79.0 mmol) in ethanol (28.8 ml) *p*-toluenesulfonic acid monohydrate (PTSA, 30.43 g, 160.0 mmol) was added and the mixture refluxed for 5 h. After evaporation of the solvent the oil obtained was dissolved in CH_2Cl_2, washed with a saturated solution of $NaHCO_3$, brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave compound **16** as a brown oil in 85% yield. IR (cm^{-1}, film) 1577 (C═N); ^1H NMR (δ, ppm, $CDCl_3$) 7.53 (1H, d, Ar-H, J=7.7 Hz), 7.29 (1H, t, Ar-H, J=7.5 Hz), 7.21 (2H, m, Ar-H), 2.23 (3H, s, CH_3C═N), 1.90 (1H, m, *H*$CHCH_3$), 1.79 (1H, m, *H*$CHCH_3$), 1.28 (3H, s, CH_3C), 0.39 (3H, t, C*H*$_3$CH$_2$, J=7.5 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 187.0 (s, C═N), 154.5 (s), 143.4 (s), 127.4 (d), 125.0 (d), 121.4 (d), 119.6 (d), 58.3 (s, C-3), 30.0 (t, *C*H_2CH_3), 22.3 (q, *C*H_3C═N), 15.6 (q, *C*H_3C), 8.4 (q, *C*H_3CH_2); HRGC (OV1701) t_R=13.72 (10 min at 100 °C, 3 °C/min up to 200 °C).

4.3.4. 2,3-Dimethyl-3-phenyl-3*H*-indole (44).[37] Compound **44** was obtained in 94% yield following the same procedure described for the synthesis of **43**. Mp, IR and ^1H NMR are in accordance with those reported in the literature.[37] ^{13}C NMR (δ, ppm, $CDCl_3$) 187.1 (s), 154.5 (s), 146.9 (s), 139.2 (s), 128.9 (d), 128.0 (d), 127.3 (d), 126.1 (d), 125.9 (d), 122.6 (d), 120.1 (d), 61.8 (s), 20.4 (q, CH_3), 15.9 (q, CH_3).

4.3.5. 3-Ethyl-1,2,3-trimethyl-3*H*-indolium iodide (45).[2c] Methyl iodide (12.6 ml, 0.20 mol) was added to compound **43** (11.72 g, 68.0 mmol), and the solution was warmed at 40 °C until a precipitate was formed. The white solid was filtered and washed with diethyl ether. Compound **45** was obtained in 72% yield (15.33 g, 49.0 mmol). Mp 240–242 °C. All spectroscopic data were identical to those reported in the literature.[2c]

4.3.6. 1,2,3-Trimethyl-3-phenyl-3*H*-indolium iodide (46). Compound **46** was obtained in 34% yield by the same procedure described for the synthesis of **45**. Mp 227–229 °C; IR (cm^{-1}, Nujol) 1633, 1610, 1590; ^1H NMR (δ, ppm, $CDCl_3$) 7.78 (1H, d, Ar-H, J=8.0 Hz), 7.64 (1H, t, Ar-H, J=7.7 Hz), 7.57 (1H, t, Ar-H, J=7.5 Hz), 7.41–7.33 (4H, m, Ar-H), 7.10–7.06 (2H, m, Ar-H), 4.42 (3H, s, CH_3N^+), 2.94 (3H, s, CH_3C═N), 1.25 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 194.6 (s, C-2), 142.3 (s), 142.2 (s), 133.8 (s), 130.6 (d), 129.9 (2d), 129.7 (d), 129.4 (d), 126.5 (2d), 124.1 (d), 115.7 (d), 62.0 (s, C-3), 38.1 (q, CH_3N^+), 20.6 (q, CH_3), 17.5 (q, CH_3).

4.3.7. 3-Ethyl-2,3-dihydro-1,3-dimethyl-2-methylene-1*H*-indole (2).[2c] Compound **45** (9.48 g, 30.1 mmol) in anhydrous ethanol (150 ml) was treated with KOH (3.38 g, 60.2 mmol). The solution was stirred for 3 h at room temperature. After removal of the solvent, water was added and the aqueous solution was extracted four times with diethyl ether. The combined organic phases were dried over anhydrous Na_2SO_4 and after evaporation of the solvent compound **2** was obtained as a yellowish oil in 92% yield. ^{1}H NMR and ^{13}C NMR spectra were reported in the literature.[2c] IR (cm^{-1}, film) 1649, 1608, 1492, 1462; EIMS (*m/z*) 187 (M^+, 64), 158 (100); HRGC (OV1701) t_R=15.17 (10 min at 100 °C, 3 °C/min up to 200 °C).

4.3.8. 2,3-Dihydro-1,3-dimethyl-2-methylene-3-phenyl-1*H*-indole (3).[38] 2-Methyleneindoline **3** was obtained as an orange oil in 92% yield by the same procedure described for the synthesis of **2**. IR (cm^{-1}, film) 1650, 1606, 1495, 1460; ^{1}H NMR (δ, ppm, $CDCl_3$) 7.29–7.17 (5H, m, Ar-H), 7.15 (1H, t, H-6, *J*=7.3 Hz), 6.91 (1H, d, H-4, *J*=7.3 Hz), 6.71 (1H, t, H-5, *J*=7.3 Hz), 6.61 (1H, d, H-7, *J*=7.7 Hz), 3.93 (1H, d, H-1′, *J*=1.8 Hz), 3.73 (1H, d, H-1′, *J*=1.8 Hz), 3.09 (3H, s, CH_3N), 1.74 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 162.5 (s, C-2), 146.7 (s), 146.6 (s), 137.5 (s), 128.1 (d), 127.7 (d), 126.4 (d), 126.1 (d), 123.3 (d), 118.7 (d), 105.1 (d, C-7), 76.2 (d, C-1′), 52.0 (s, C-3), 28.8 (q, CH_3), 28.0 (q, CH_3).

4.4. Nitroalkenylation reactions

4.4.1. General procedure. To a solution of the nitroenamines **4–6** (0.29 mmol) in CH_2Cl_2 (1.8 ml), a solution of 2-methyleneindolines **1–3** (0.58 mmol) in CH_2Cl_2 (0.9 ml) and $CeCl_3\cdot 7H_2O$ (0.108 g, 0.29 mmol) was added. The reaction mixture was stirred at room temperature monitoring the course of the reaction by ^{1}H NMR. At the end of the reaction, water was added, and the organic phase was dried over anhydrous Na_2SO_4. After evaporation of the solvent the crude reaction mixture was purified by flash chromatography (light petroleum–ethyl acetate, 85:15) and products **14–22** were isolated.

4.4.2. 2,3-Dihydro-1,3,3-trimethyl-2-[(3-nitro) propenylidene]-1*H*-indole (14). After 14 days, compound **14** was obtained in 56% yield. All spectroscopic data are in accordance with those reported in the literature.[16] Mp 161–162 °C. ^{1}H NMR (δ, ppm, $CDCl_3$) 8.38 (1H, dd, H-2′, J_1=13.2 Hz, J_1=12.1 Hz), 7.27 (2H, t+d, H-6 and H-4), 7.10 (1H, d, H-3′, *J*=12.1 Hz), 7.06 (1H, t, H-5), 6.85 (1H, d, H-7), 5.46 (1H, d, N–C=CH, *J*=13.2 Hz), 3.30 (3H, s, NCH_3), 1.64 (6H, s, *gem*-CH_3).

4.4.3. 2,3-Dihydro-1,3,3-trimethyl-2-[(3-nitro) but-2-enylidene]-1*H*-indole (15). After 14 days, compound **15** was obtained as a purple solid in 53% yield. All spectroscopic data are in accordance with those reported in the literature.[16] Mp 191–192 °C. ^{1}H NMR (δ, ppm, $CDCl_3$) 8.50 (1H, d, H-2′, *J*=13.2 Hz), 7.27 (1H, t, H-6), 7.24 (1H, d, H-4), 7.03 (1H, t, H-5), 6.84 (1H, d, H-7), 5.30 (1H, d, H-1′, *J*=13.2 Hz), 3.32 (3H, s, NCH_3), 2.25 (3H, s, CH_3), 1.64 (6H, s, *gem*-CH_3).

4.4.4. 2,3-Dihydro-1,3,3-trimethyl-2-[(3-nitro-3-phenyl)-propenylidene]-1*H*-indole (16). After 6 days, compound **16** was obtained in 45% yield. Reddish solid; mp 188–190 °C, IR (cm^{-1}, Nujol) 1616, 1568, 1489; UV (nm, CH_3OH) (log ε) 208 (4.29), 275 (4.12), 490 (4.42); UV (nm, CH_3CN) (log ε) 193 (4.76), 277 (4.05), 485 (4.46); UV (nm, cyclohexane) (log ε) 195 (4.65), 251 (3.71), 279 (4.09), 434 (3.93), 450 (3.94); ^{1}H NMR (δ, ppm, $CDCl_3$) 8.74 (1H, d, H-2′, *J*=13.5 Hz), 7.50–7.36 (5H, m, Ph), 7.27–7.22 (2H, m, H-6 and H-4) 7.04 (1H, t, H-5, *J*=7.4 Hz), 6.77 (1H, d, H-7, *J*=8.2 Hz), 5.23 (1H, d, H-1′, *J*=13.5 Hz), 3.09 (3H, s, CH_3N), 1.71 (6H, s, *gem*-CH_3). ^{13}C NMR (δ, ppm, $CDCl_3$) 168.6 (s, C-2), 143.5 (s, C-7a), 139.6 (s), 139.5 (s), 135.5 (d, C-2′), 131.4 (s), 130.9 (2d, Ph), 128.4 (2d, Ph), 128.1 (d), 122.4 (d), 121.9 (d), 107.8 (d, C-7), 90.8 (d, C-1′), 47.4 (s, C-3), 29.5 (q, CH_3N), 28.7 (2q, CH_3C); EIMS (*m/z*) 320 ($M^{+\bullet}$, 100); HRMS calcd for $C_{20}H_{20}N_2O_2$ 320.1525, found 320.1522.

4.4.5. (1′*E*,2′*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(3′-nitro)propenylidene]-1*H*-indole (17). After 15 days, compound **17** was obtained in 38% yield. Orange-brown solid; mp 110–113 °C. IR (cm^{-1}, Nujol) 1618, 1579, 1491; UV (nm, CH_3OH) (log ε) 209 (3.97), 277 (3.90), 483 (4.41); UV (nm, CH_3CN) (log ε) 195 (4.60), 280 (4.13), 477 (4.59); UV (nm, cyclohexane) (log ε) 212 (4.01), 247 (3.68), 276 (3.94), 420 (4.22), 440 (4.26); ^{1}H NMR (δ, ppm, $CDCl_3$) 8.34 (1H, t, H-2′, *J*=13.1 Hz), 7.25 (2H, m, H-6 and H-4), 7.08 (1H, d, H-3′, *J*=12.1 Hz), 7.06 (1H, t, H-5, *J*=7.5 Hz), 6.83 (1H, d, H-7, *J*=8.05 Hz), 5.51 (1H, d, H-1′, *J*=13.1 Hz), 3.30 (3H, s, CH_3N), 1.92 (1H, m, *H*CHCH$_3$), 1.80 (1H, m, *H*CHCH$_3$), 1.30 (3H, s, CH_3C), 0.47 (3H, t, C*H*$_3$CH$_2$, *J*=7.3 Hz). ^{13}C NMR (δ, ppm, $CDCl_3$) 167.8 (s, C-2), 144.4 (s, C-7a), 138.3 (d, C-2′), 137.4 (s, C-3a), 129.1 (d), 128.1 (d), 122.5 (d), 121.9 (d), 107.7 (d, C-7), 90.1 (d, C-1′), 52.5 (s, C-3), 35.0 (t, CH_2CH_3), 29.6 (q), 28.1 (q), 8.8 (q, *C*H$_3$CH$_2$); EIMS (*m/z*) 258 ($M^{+\bullet}$, 100); HRMS calcd for $C_{15}H_{18}N_2O_2$ 258.1368, found 258.1363.

4.4.6. (1′*E*,2′*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(3′-nitro)but-2-enylidene]-1*H*-indole (18). After 4 days compound **18** was obtained in 42% yield. Purple solid; mp 168–169 °C. IR (cm^{-1}, Nujol) 1620, 1595, 1572, 1489; UV (nm, CH_3OH) (log ε) 209 (4.01), 283 (3.99), 490 (4.48); UV (nm, CH_3CN) (log ε) 192 (4.94), 280 (4.35), 480 (4.65); UV (nm, cyclohexane) (log ε) 216 (4.15), 248 (4.06), 280 (4.20), 428 (4.51), 448 (4.53); ^{1}H NMR (δ, ppm, $CDCl_3$) 8.46 (1H, d, H-2′, *J*=13.5 Hz), 7.26 (1H, t, H-6, *J*=7.7 Hz), 7.20 (1H, d, H-4, *J*=7.3 Hz), 7.04 (1H, t, H-5, *J*=7.3 Hz), 6.81 (1H, d, H-7, *J*=8.0 Hz), 5.34 (1H, d, H-1′, *J*=13.5 Hz), 3.31 (3H, s, CH_3N), 2.26 (3H, s, CH_3CNO_2), 2.22 (1H, m, *H*CHCH$_3$), 2.05 (1H, m, *H*CHCH$_3$), 1.64 (3H, s, CH_3C), 0.47 (3H, t, C*H*$_3$CH$_2$, *J*=7.3 Hz). ^{13}C NMR (δ, ppm, $CDCl_3$) 165.9 (s, C-2), 144.6 (s, C-7a), 137.3 (s), 136.0 (s), 133.3 (d, C-2′), 128.0 (d, C-6), 122.1 (d, Ar), 121.9 (d, Ar), 107.3 (d, C-7), 90.8 (d, C-1′), 52.2 (s, C-3), 34.9 (t, *C*H$_2$CH$_3$), 29.5 (q), 28.1 (q), 12.0 (q, C-4′), 8.9 (q, CH$_3$CH$_2$); EIMS (*m/z*) 272 ($M^{+\bullet}$, 100); HRMS calcd for $C_{16}H_{20}N_2O_2$ 272.1525, found 272.1520.

4.4.7. (1′*E*,2′*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(3′-nitro-3′-phenyl)propenylidene]-1*H*-indole (19). After 7

days compound **19** was obtained in 44% yield. Red solid; mp 126–128 °C. IR (cm^{-1}, Nujol) 1616, 1586, 1570, 1491; UV (nm, CH_3OH) (log ε) 208 (4.25), 284 (3.95), 491 (4.57); UV (nm, CH_3CN) (log ε) 193 (3.91), 276 (4.16), 488 (4.56); UV (nm, cyclohexane) (log ε) 195 (4.68), 279 (4.21), 436 (4.45), 452 (4.46); ^1H NMR (δ, ppm, $CDCl_3$) 8.71 (1H, d, H-2′, J=13.5 Hz), 7.60–7.40 (6H, m, Ph and H-6), 7.23 (1H, m, H-4), 7.04 (1H, t, H-5, J=7.3 Hz), 6.77 (1H, d, H-7, J=7.9 Hz), 5.30 (1H, d, H-1′, J=13.5 Hz), 3.09 (3H, s, CH_3N), 2.31 (1H, m, *H*$CHCH_3$), 2.09 (1H, m, *H*$CHCH_3$), 1.69 (3H, s, CH_3C), 0.49 (3H, t, CH_3CH_2, J=7.3 Hz). ^{13}C NMR (δ, ppm, $CDCl_3$) 167.0 (s, C-2), 144.5 (s, C-7a), 139.3 (s), 137.5 (s), 135.2 (d, C-2′), 131.5 (s), 131.0 (2d), 128.4 (2d), 128.1 (d), 122.4 (d), 121.9 (d), 107.6 (d, C-7), 91.3 (d, C-1′), 52.5 (s, C-3), 35.1 (t, *C*H_2CH_3), 29.5 (q), 28.2 (q), 9.0 (q, *C*H_3CH_2); EIMS (*m*/*z*) 334 ($M^{+\bullet}$, 53), 273 (31), 260 (100); HRMS calcd for $C_{21}H_{22}N_2O_2$ 334.1681, found 334.1680.

4.4.8. (1′*E*,2′*E*)-2,3-Dihydro-1,3-dimethyl-2-[(3′-nitro)-propenylidene]-3-phenyl-1*H*-indole (20). After 8 days compound **20** was obtained in 31% yield. Red solid; mp 152–159 °C. IR (cm^{-1}, film) 1620, 1574, 1491; UV (nm, CH_3OH) (log ε) 208 (4.41), 275 (3.94), 477 (4.15); UV (nm, CH_3CN) (log ε) 194 (5.02), 277 (4.24), 473 (4.55); UV (nm, cyclohexane) (log ε) 197 (4.66), 271 (4.11), 417 (4.43), 434 (4.45); ^1H NMR (δ, ppm, $CDCl_3$) 7.70 (1H, t, H-2′, J=12.9 Hz), 7.46–7.22 (6H, m), 6.94–6.88 (4H, m), 5.41 (1H, d, H-1′, J=12.9 Hz), 3.40 (3H, s, CH_3N), 1.93 (3H, s, CH_3C). ^{13}C NMR (δ, ppm, $CDCl_3$) 169.2 (s, C-2), 143.5 (s), 142.8 (s), 140.0 (s), 138.7 (d), 129.9 (d), 129.0 (2d), 128.1 (d), 127.4 (d), 126.0 (2d), 123.2 (d), 122.6 (d), 107.9 (d, C-7), 89.3 (d, C-1′), 54.5 (s, C-3), 29.7 (q), 27.1 (q); EIMS (*m*/*z*) 306 ($M^{+\bullet}$, 25), 259 (49), 244 (13), 237 (70), 235 (30), 234 (22), 222 (100); HRMS calcd for $C_{19}H_{18}N_2O_2$ 306.1368, found 306.1365.

4.4.9. (1′*E*,2′*E*)-2,3-Dihydro-1,3-dimethyl-3-phenyl-2-[(3′-nitro)but-2-enylidene]-1*H*-indole (21). After 4 days compound **21** was obtained in 42% yield. Red solid; mp 174–176 °C. IR (cm^{-1}, Nujol) 1616, 1597, 1574, 1487; UV (nm, CH_3OH) (log ε) 207 (4.29), 276 (4.28), 483 (4.46); UV (nm, CH_3CN) (log ε) 194 (4.72), 280 (4.07), 477 (4.49); UV (nm, cyclohexane) (log ε) 210 (4.21), 248 (3.77), 421 (3.86), 440 (3.85); ^1H NMR (δ, ppm, $CDCl_3$) 7.82 (1H, d, H-2′, J=13.0 Hz), 7.33–7.20 (5H, m), 6.92–6.86 (4H, m), 5.25 (1H, d, H-1′, J=13.0 Hz), 3.40 (3H, s, CH_3N), 2.12 (3H, s, CH_3CNO_2), 1.93 (3H, s, CH_3C). ^{13}C NMR (δ, ppm, $CDCl_3$) 167.4 (s, C-2), 143.7 (s), 143.0 (s), 139.9 (s), 136.7 (s), 133.6 (d, C-2′), 128.8 (2d), 128.0 (d), 127.2 (d), 126.1 (2d), 123.2 (d), 122.2 (d), 107.5 (d, C-7), 89.9 (d, C-1′), 54.3 (s, C-3), 29.7 (q), 26.9 (q), 12.0 (q); EIMS (*m*/*z*) 320 ($M^{+\bullet}$, 88), 303 (15), 289 (14), 273 (56), 272 (20), 258 (41), 243 (22), 241 (16), 237 (29), 234 (33), 231 (16), 221 (100); HRMS calcd for $C_{20}H_{20}N_2O_2$ 320.1525, found 320.1523.

4.4.10. (1′*E*,2′*E*)-2,3-Dihydro-1,3-dimethyl-3-phenyl-2-[(3′-nitro-3′-phenyl)propenylidene]-1*H*-indole (22). After 15 days compound **22** was obtained in 26% yield. Red solid; mp 179–180 °C. IR (cm^{-1}, Nujol) 1618, 1572, 1491; UV (nm, CH_3OH) (log ε) 209 (4.60), 263 (4.12), 487 (4.35); UV (nm, CH_3CN) (log ε) 193 (4.98), 260 (4.17), 484 (4.40); UV (nm, cyclohexane) (log ε) 210 (4.49), 254 (3.98), 429 (4.15), 443 (4.13); ^1H NMR (δ, ppm, $CDCl_3$) 8.07 (1H, d, H-2′, J=13.2 Hz), 7.66–6.82 (14H, m), 5.20 (1H, d, H-1′, J=13.2 Hz), 3.20 (3H, s, CH_3N), 1.99 (3H, s, CH_3C). ^{13}C NMR (δ, ppm, $CDCl_3$) 168.4 (s, C-2), 143.6 (s), 143.0 (s), 140.1 (s), 135.6 (d, C-2′), 131.4 (s), 130.9 (2d), 129.0 (2d), 128.4 (d), 128.3 (2d), 128.1 (d), 127.4 (d), 126.1 (2d), 123.2 (d), 122.5 (d), 107.7 (d, C-7), 90.4 (d, C-1′), 54.5 (s, C-3), 29.6 (q), 27.1 (q); an aromatic singlet was hidden under other signals; EIMS (*m*/*z*) 382 ($M^{+\bullet}$, 75), 335 (54), 334 (24), 320 (20), 273 (23), 262 (53), 258 (16), 247 (56), 246 (40), 244 (27), 232 (47), 231 (31), 230 (23), 221 (100); HRMS calcd for $C_{25}H_{22}N_2O_2$ 382.1681, found 382.1686.

4.4.11. (1′*E*,2′*E*)-2,3-Dihydro-2-[(3′-(2-methylthiophenyl)-3′-nitro)propenylidene]-1,3,3-trimethyl-1*H*-indole (23). To a solution of the nitroenamine **7** (0.038 g, 0.14 mmol) and 2-methyleneindoline **1** (0.05 g, 0.29 mmol) in CH_2Cl_2 (2 ml), $Zn(OTf)_2$ (0.105 g, 0.29 mmol) was added. The reaction mixture was stirred at room temperature. After 12 days water was added, and the organic phase was dried over Na_2SO_4 anhydrous. After evaporation of the solvent the crude reaction mixture was purified by flash chromatography (light petroleum–ethyl acetate, 85:15) to give compound **23** (0.015 g, 30% yield). Red oil; IR (cm^{-1}, Nujol) 1580; UV (nm, CH_3OH) (log ε) 209 (4.50), 254 (4.08), 281 (3.97), 489 (4.42); UV (nm, CH_3CN) (log ε) 203 (4.46), 209 (4.47), 259 (4.10), 288 (3.99), 489 (4.48); UV (nm, cyclohexane) (log ε) 201 (4.24), 210 (4.41), 259 (4.09), 281 (3.99), 432 (4.35), 451 (4.36); ^1H NMR (δ, ppm, $CDCl_3$), 8.74 (1H, d, H-2′, J=13.5 Hz), 7.45–7.15 (6H, m), 7.04, (1H, t, J=7.7 Hz), 6.77 (1H, d, H-7, J=8.0 Hz), 4.93 (1H, d, H-1′, J=13.5 Hz), 3.06 (3H, s, CH_3N), 2.42 (3H, s, CH_3S), 1.72 (3H, s, *gem*-CH_3), 1.70 (3H, s, *gem*-CH_3); ^{13}C NMR (δ, ppm, $CDCl_3$) 168.8 (s, C-2), 143.5 (s), 140.4 (s), 139.6 (s), 138.0 (s), 136.6 (d), 131.7 (d), 130.3 (s), 129.6 (d), 128.0 (d), 126.0 (d), 125.1 (d), 122.4 (d), 121.8 (d), 107.8 (d, C-7), 90.7 (d, C-1′), 47.5 (s, C-3), 29.6 (q, *C*H_3N), 28.8 (q, *gem*-CH_3), 28.7 (q, *gem*-CH_3), 15.8 (q, SCH_3); EIMS (*m*/*z*) 366 ($M^{+\bullet}$, 100); HRMS calcd for $C_{21}H_{22}N_2O_2S$ 366.1402, found 366.1405.

4.5. Nitroalkylation reactions

4.5.1. General procedure. To a solution of 2-methylenindolines **1–3** (3 mmol) in diethyl ether (7 ml), a solution of nitroolefins **8–10** (3 mmol) in diethyl ether (3.5 ml) was added at −15/−5 °C. The solution was allowed to warm to room temperature and the course of the reaction was monitored by ^1H NMR. After 2–3 days the products obtained **24–32** were purified by flash chromatography (light petroleum–ethyl acetate, 95:5).

4.5.2. (*E*)-2,3-Dihydro-1,3,3-trimethyl-2-[(2-methyl-3-nitro)propylidene]-1*H*-indole (24). 62% Yield; yellow oil; IR (cm^{-1}, film) 1658, 1604, 1547, 1496, 1454; UV (nm, CH_3OH) (log ε) 210 (4.29), 280 (4.13); UV (nm, CH_3CN) (log ε) 195 (4.58), 204 (4.54), 282 (4.26); UV (nm, cyclohexane) (log ε) 194 (4.73), 207 (4.61), 281 (4.42); ^1H NMR (δ, ppm, $CDCl_3$) 7.10 (1H, t, H-6, J=7.7 Hz), 7.04 (1H, d, H-4,

J=7.0 Hz), 6.73 (1H, t, H-5, J=7.3 Hz), 6.47 (1H, d, H-7, J=7.7 Hz), 4.30 (2H, m, CH_2NO_2), 3.96 (1H, d, H-1′, J=11.0 Hz), 3.61 (1H, m, H-2′), 2.95 (3H, s, CH_3N), 1.50 (3H, s, CH_3C), 1.49 (3H, s, CH_3C), 1.17 (3H, d, CH_3CH, J=6.6 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 155.0 (s, C-2), 145.5 (s, C-7a), 137.4 (s, C-3a), 127.4 (d, C-6), 121.0 (d, C-4), 118.0 (d, C-5), 104.5 (d, C-7), 93.5 (d, C-1′), 82.3 (t, C-3′), 44.2 (s, C-3), 31.2 (d, C-2′), 28.5 (q, CH$_3$N), 28.0 (q, CH$_3$C), 27.8 (q, CH$_3$C), 20.3 (q, CH$_3$CH); EIMS (*m*/*z*) 260 ($M^{+\bullet}$, 90), 230 (13), 214 (15), 200 (35), 198 (15), 185 (24), 184 (22), 175 (50), 160 (100); HRMS calcd for $C_{15}H_{20}N_2O_2$ 260.1525, found 260.1524.

4.5.3. (*E*) and (*Z*)-2,3-Dihydro-1,3,3-trimethyl-2-[(3-nitro-2-phenyl)propylidene]-1*H*-indole (25a,b). The two compounds (*E*)-**25a** and (*Z*)-**25b** in ratio 9:1, respectively, were inseparable by flash chromatography. 75% Yield; yellow oil; IR (cm^{-1}, film) 1653, 1604, 1550, 1491, 1456; UV (nm, CH_3OH) (log ε) 210 (4.48), 283 (4.47); UV (nm, CH_3CN) (log ε) 193 (5.02), 206 (4.62), 285 (4.54). UV (nm, cyclohexane) (log ε) 197 (4.42), 210 (4.50), 284 (4.38). EIMS (*m*/*z*) 322 ($M^{+\bullet}$, 22), 276 (16), 262 (100); HRMS calcd for $C_{20}H_{22}N_2O_2$ 322.1681, found 322.1682. For clarity sake the NMR values are given separately for each isomer. Compound (*E*)-**25a**: ^{1}H NMR (δ, ppm, $CDCl_3$) 7.41 (5H, m, Ph), 7.09 (1H, t, H-6, J=7.7 Hz), 7.03 (1H, d, H-4, J=7.0 Hz), 6.73 (1H, t, H-5, J=7.3 Hz), 6.47 (1H, d, H-7, J=8.1 Hz), 4.77 (1H, m, CHPh), 4.68 (1H, dd, $CHNO_2$, J_1=7.7 Hz, J_2=11.2 Hz), 4.51 (1H, dd, $CHNO_2$, J_1=7.8 Hz, J_2=11.2 Hz), 4.39 (1H, d, H-1′, J=10.6 Hz), 3.00 (3H, s, CH_3N), 1.59 (3H, s, CH_3C), 1.41 (3H, s, CH_3C). ^{13}C NMR (δ, ppm, $CDCl_3$) 156.2 (s, C-2), 145.8 (s), 141.8 (s), 138.0 (s), 129.2 (2d), 127.7 (d, C-6), 127.4 (d), 127.1 (2d), 121.4 (d, C-4), 118.5 (d, C-5), 105.0 (d, C-7), 90.8 (d, C-1′), 82.3 (t, C-3′), 44.7 (s, C-3), 41.7 (d, CHPh), 29.2 (q, CH_3N), 28.3 (q, CH$_3$C), 28.1 (q, CH$_3$C). Compound (*Z*)-**25b**, only a few signals were identified. ^{1}H NMR (δ, ppm, $CDCl_3$) 6.56 (1H, d, H-7), 4.98 (1H, m, CHPh), 4.65 (1H, dd, $CHNO_2$, J_1=6.2 Hz, J_2=11.3 Hz), 4.50 (1H, m, CHNO$_2$), 4.25 (1H, d, H-1′, J=9.9 Hz), 3.32 (3H, s, CH_3N), 1.31 (3H, s, CH_3), 1.30 (3H, s, CH_3); ^{13}C NMR (δ, ppm, $CDCl_3$) 121.8 (d, C-4), 119.2 (d, C-5), 105.5 (d, C-7), 88.6 (d, C-1′), 41.2 (d, CHPh) 33.0 (q, CH_3N).

4.5.4. (*E*)-2,3-Dihydro-1,3,3-trimethyl-2-[(2-nitrocyclohexyl)methylidene]-1*H*-indole (26a,b). Compounds **26a**,**b** were reported in the literature.[16] Compound **26a**. ^{1}H NMR (δ, ppm, $CDCl_3$) 7.08 (1H, t, H-6), 7.01 (1H, d, H-4), 6.71 (1H, t, H-5), 6.45 (1H, d, H-7), 4.76 (1H, dt, $CHNO_2$, J_1=J_2=4.8 Hz, J_3=9.5 Hz, W_H=16.5 Hz), 4.34 (1H, d, H-1′, J=11.4 Hz), 3.51 (1H, m, CHCHNO$_2$, W_H=21.5 Hz), 2.95 (3H, s, NCH_3), 2.26 (1H, m, annular H), 2.0 (3H, m, annular H), 1.78 (1H, m, annular H), 1.45 (3H, s, CH_3 at C-3), 1.41 (3H, s, CH_3 at C-3), 1.40 (1H, m, annular H), 1.20 (1H, m, annular H). Compound **26b**. ^{1}H NMR (δ, ppm, $CDCl_3$) 7.07 (1H, t, H-6), 7.01 (1H, d, H-4), 6.70 (1H, t, H-5), 6.43 (1H, d, H-7), 4.25 (1H, ddd, $CHNO_2$, J_1=11.7 Hz, J_2=10.6 Hz, J_3=3.7 Hz, W_H=27.5 Hz), 4.05 (1H, d, H-1′, J=10.6 Hz), 3.05 (1H, dq, CHCHNO$_2$, J_1=J_2=J_3=10.6 Hz, J_4=10.6 Hz, J_3=3.7 Hz), 2.92 (3H, s, NCH_3), 2.26 (1H, m, annular H), 2.01 (1H, dq, annular H), 1.96 (3H, m, annular H), 1.76 (2H, m, annular H), 1.50 (1H, m, annular H), 1.46 (4H, s+m, CH_3 at C-3, annular H), 1.42 (3H, s, CH_3 at C-3).

4.5.5. (*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(2-methyl-3-nitro)propylidene]-1*H*-indole (27a,b). The isomers **27a** and **27b** (80% yield) were obtained in 9:1 ratio (determined by HRGC) and were not separable by flash chromatography. Yellow oil; IR (cm^{-1}, film) 1655, 1606, 1551, 1496, 1460; UV (nm, CH_3OH) (log ε) 211 (4.34), 282 (4.37); UV (nm, CH_3CN) (log ε) 192 (4.53), 204 (4.46), 282 (4.30). UV (nm, cyclohexane) (log ε) 216 (4.00), 280 (4.30); EIMS (*m*/*z*) 274 ($M^{+\bullet}$, 56), 245 (13), 228 (21), 214 (40), 198 (80), 184 (33), 183 (21), 182 (16), 174 (100); HRMS calcd for $C_{16}H_{22}N_2O_2$ 274.1681, found 274.1683; HRGC (OV1701) t_R=45.00 min for **27b**; t_R=45.44 min for **27a** (10 min at 100 °C, 3 °C/min up to 200 °C). For clarity sake the NMR values are given separately for each isomer. Compound **27a**: ^{1}H NMR (δ, ppm, $CDCl_3$) 7.10 (1H, t, H-6, J=7.5 Hz), 6.99 (1H, d, H-4, J=7.3 Hz), 6.73 (1H, t, H-5, J=7.3 Hz), 6.46 (1H, d, H-7, J=7.5 Hz), 4.30 (2H, m, CH_2NO_2), 4.02 (1H, d, H-1′, J=11.0 Hz), 3.57 (1H, m, H-2′), 2.94 (3H, s, CH_3N), 1.92 (1H, m, HCHCH$_3$), 1.80 (1H, m, HCHCH$_3$), 1.50 (3H, s, CH_3C), 1.16 (3H, d, CH_3CH, J=6.6 Hz), 0.56 (3H, t, CH_3CH$_2$, J=7.3 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 152.9 (s, C-2), 146.7 (s, C-7a), 135.3 (s, C-3a), 127.5 (d, C-6), 121.3 (d, C-4), 118.1 (d, C-5), 104.4 (d, C-7), 93.8 (d, C-1′), 82.7 (t, CH$_2$NO$_2$), 49.4 (s, C-3), 33.8 (t, CH$_2$CH$_3$), 31.2 (d, C-2′), 28.8 (q, CH$_3$N), 27.4 (q, CH$_3$C), 20.4 (q, CH$_3$CH), 9.3 (q, CH$_3$CH$_2$). Compound **27b**: ^{1}H NMR (δ, ppm, $CDCl_3$) 6.78 (1H, t, H-5, J=7.7 Hz), 6.54 (1H, d, H-7, J=7.7 Hz), 4.03 (1H, d, H-1′, J=10.6 Hz), 1.16 (3H, d, CH_3CH, J=6.2 Hz), 0.44 (3H, t, CH_3CH_2, J=7.3 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 153.4 (s, C-2), 148.2 (s, C-7a), 121.9 (d, C-4), 118.8 (d, C-5), 105.2 (d, C-7), 94.0 (d, C-1′), 82.5 (t, CH$_2$NO$_2$), 34.0 (t, CH$_2$CH$_3$), 31.4 (d, C-2′), 20.8 (q, CH$_3$CH), 8.7 (q, CH$_3$CH$_2$).

4.5.6. (*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(3-nitro-2-phenyl)propylidene]-1*H*-indole (28a,b). The isomers **28a** and **28b** (94% yield) were obtained in 3:2 ratio and were not separable by flash chromatography. Yellow solid; mp 73–81 °C; IR (cm^{-1}, Nujol) 1650, 1605, 1550, 1495; UV (nm, CH_3OH) (log ε) 211 (4.48), 285 (4.48); UV (nm, CH_3CN) (log ε) 192 (4.96), 208 (4.60), 288 (4.50). UV (nm, cyclohexane) (log ε) 216 (4.27), 284 (4.57); EIMS (*m*/*z*) 336 ($M^{+\bullet}$, 33), 276 (45), 260 (26), 247 (31), 246 (17), 232 (13), 202 (48), 174 (100); HRMS calcd for $C_{21}H_{24}N_2O_2$ 336.1838, found 336.1833. For clarity sake the NMR values are given separately for each isomer. Compound **28a**: ^{1}H NMR (δ, ppm, $CDCl_3$) 7.33 (5H, m, Ph), 7.09 (1H, t, H-6, J=7.7 Hz), 6.98 (1H, d, H-4, J=7.0 Hz), 6.73 (1H, t, H-5, J=7.3 Hz), 6.46 (1H, d, H-7, J=8.0 Hz), 4.74–4.61 (2H, m, CHPh+$CHNO_2$), 4.54–4.46 (2H, m, $CHNO_2$+H-1′), 3.00 (3H, s, CH_3N), 1.92 (1H, m, HCHCH$_3$), 1.80 (1H, m, HCHCH$_3$), 1.58 (3H, s, CH_3C), 0.25 (3H, t, CH_3CH$_2$, J=7.3 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 153.8 (s, C-2), 146.6 (s), 141.1 (s), 135.4 (s), 128.9 (d), 127.6 (d, C-6), 127.1 (3d, Ph), 121.3 (d, C-4), 118.4 (d, C-5), 104.6 (d, C-7), 91.1 (d, C-1′), 82.3 (t, C-3′), 49.6 (s, C-3), 41.5 (d, CHPh), 33.9 (t, CH$_2$CH$_3$), 28.9 (q, CH_3N), 27.5 (q, CH$_3$C), 8.9 (q, CH$_3$CH$_2$). Compound **28b**: ^{1}H NMR (δ, ppm, $CDCl_3$) 6.78 (1H, t, H-5, J=7.3 Hz), 6.52 (1H, d, H-7, J=8.0 Hz), 3.01 (3H, s, CH_3N), 1.38 (3H, s, CH_3C), 0.55 (3H, t, CH_3CH$_2$, J=7.3 Hz). ^{13}C NMR (δ, ppm, $CDCl_3$) 153.9 (s, C-2), 141.4 (s, C-3a), 91.0 (d, C-1′), 49.6 (s, C-3), 9.3 (q, CH$_3$CH$_2$).

4.5.7. (*E*)-3-Ethyl-2,3-dihydro-1,3-dimethyl-2-[(2-nitrocyclohexyl)methylidene]-1*H*-indole (29a,b). In the crude reaction mixture the isomers *cis*-**29a** and *trans*-**29b** were detected in 3:1 ratio. After purification on flash chromatography fractions of different composition were obtained (45% yield). Yellow solid; mp 110–115 °C (for 1:9 ratio of *cis*-**29a** and *trans*-**29b**, respectively); IR (cm^{-1}, Nujol) 1658, 1606, 1550, 1496; UV (nm, CH_3OH) (log ε) 210 (4.39), 282 (4.41); UV (nm, CH_3CN) (log ε) 192 (4.82), 204 (4.55), 284 (4.48); UV (nm, cyclohexane) (log ε) 216 (4.20), 284 (4.51). EIMS (*m*/*z*) 314 ($M^{+\bullet}$, 100); HRMS calcd for $C_{19}H_{26}N_2O_2$ 314.1994, found 314.1995. For clarity sake the NMR values are given separately for each isomer. Compound **29a**: ^1H NMR (δ, ppm, $CDCl_3$) 7.07 (1H, t, H-6, J=7.7 Hz), 6.94 (1H, d, H-4, J=6.2 Hz), 6.70 (1H, t, H-5, J=7.1 Hz), 6.43 (1H, d, H-7, J=7.7 Hz), 4.62 (1H, dt, $CHNO_2$, J_1=J_2=4.3 Hz, J_3=8.8 Hz, W_H=16 Hz), 4.39 (1H, d, H-1′, J=11.0 Hz), 3.42 (1H, m, C*H*$CHNO_2$, W_H=24 Hz), 2.93 (3H, s, CH_3N), 2.23 (1H,m), 1.86 (3H, m), 1.78 (2H, m, CH_2CH_3), 1.65 (2H, m), 1.45 (2H, m), 1.40 (3H, s, CH_3C), 0.53 (3H, t, CH_3CH_2, J=7.1 Hz). ^{13}C NMR (δ, ppm, $CDCl_3$) 153.1 (s, C-2), 146.7 (s, C-7a), 135.4 (s, C-3a), 127.5 (d, C-6), 121.2 (d, C-4), 117.9 (d, C-5), 104.3 (d, C-7), 89.6 (d, C-1′), 87.6 (d, $CHNO_2$), 49.3 (s, C-3), 35.8 (d, *C*H$CHNO_2$), 34.0 (t, *C*H_2CH_3), 31.8 (t, CH_2), 28.9 (q, CH_3N), 27.8 (q, *C*H_3C), 26.0 (t, CH_2), 22.5 (t, CH_2), 21.3 (t, CH_2), 9.4 (q, *C*H_3CH_2). Compound **29b**: ^1H NMR (δ, ppm, $CDCl_3$) 7.06 (1H, t, H-6, J=7.1 Hz), 6.93 (1H, d, H-4, J=7.3 Hz), 6.68 (1H, t, H-5, J=7.3 Hz), 6.41 (1H, d, H-7, J=8.0 Hz), 4.22 (1H, m, $CHNO_2$, W_H=26 Hz), 4.09 (1H, d, H-1′, J=10.6 Hz), 3.01 (1H, dq, C*H*$CHNO_2$, J_1=J_2=J_3=10.8 Hz, J_4=3.8 Hz), 2.90 (3H, s, CH_3N), 2.23 (1H, m), 1.95 (1H, m), 1.87 (2H, m), 1.77 (2H, m, CH_2CH_3), 1.75 (1H, m), 1.42 (3H, s, CH_3C), 1.35 (2H, m), 1.22 (1H, m), 0.53 (3H, t, CH_3CH_2, J=7.3 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 152.9 (s, C-2), 146.7 (s, C-7a), 135.4 (s, C-3a), 127.4 (d, C-6), 121.2 (d, C-4), 117.9 (d, C-5), 104.3 (d, C-7), 94.3 (d, C-1′), 92.3 (d, $CHNO_2$), 49.4 (s, C-3), 40.0 (d, *C*H$CHNO_2$), 34.3 (t, *C*H_2CH_3), 34.2 (t, CH_2), 31.0 (t, CH_2), 28.8 (q, CH_3N), 27.7 (q, *C*H_3C), 24.8 (t, CH_2), 24.0 (t, CH_2), 9.4 (q, *C*H_3CH_2).

4.5.8. (*E*)-2,3-Dihydro-1,3-dimethyl-2-[(2-methyl-3-nitro)propylidene]-3-phenyl-1*H*-indole (30a,b). The isomers **30a** and **30b** (30% yield) inseparable by flash chromatography, were obtained in 3:1 ratio, respectively (determined by HRGC). Yellow oil; IR (cm^{-1}, film) 1650, 1600, 1550, 1495, 1460; UV (nm, CH_3OH) (log ε) 208 (4.24), 276 (4.17); UV (nm, CH_3CN) (log ε) 194 (4.73), 207 (4.56), 281 (4.07); UV (nm, cyclohexane) (log ε) 195 (4.62), 207 (4.52), 280 (4.18); EIMS (*m*/*z*) 322 ($M^{+\bullet}$, 12), 276 (15), 262 (37), 246 (15), 238 (52), 236 (23), 222 (100); HRMS calcd for $C_{20}H_{22}N_2O_2$ 322.1681, found 322.1680; HRGC (OV1701) t_R=39.97 min for **30a**, t_R=40.97 min for **30b** (200 °C isotherm). For clarity sake the ^1H NMR values are given separately for each isomer. Compound **30a**: ^1H NMR (δ, ppm, $CDCl_3$) 7.32–7.23 (4H, m, Ph), 7.19–7.15 (1H, m, Ph), 7.08 (1H, t, H-6, J=7.5 Hz), 6.71 (1H, d, H-4, J=7.0 Hz), 6.62 (1H, t, H-5, J=7.0 Hz), 6.55 (1H, d, H-7, J=7.3 Hz), 4.19 (2H, AB part of an ABX system, CH_2NO_2, J_{AB}=7.3 Hz), 3.99 (1H, d, H-1′, J=10.6 Hz), 3.07 (3H, s, CH_3N), 2.95 (1H, m, C*H*CH_3, J=7.0 Hz), 1.81 (3H, s, CH_3C), 0.50 (3H, d, CH_3CH, J=6.2 Hz). Compound **30b**, only some signals were identified. ^1H NMR (δ, ppm, $CDCl_3$) 3.95 (1H, d, H-1′, J=10.6 Hz), 3.64 (1H, dd, C*H*NO_2, J_1=9.1 Hz, J_2=11.3 Hz), 3.36 (1H, dd, C*H*NO_2, J_1=4.6 Hz, J_2=11.6 Hz), 3.24 (3H, s, CH_3N), 1.79 (3H, s, CH_3C), 1.04 (3H, d, CH_3CH, J=6.6 Hz); ^{13}C NMR (δ, ppm, $CDCl_3$) 156.4 (s, C-2), 145.6 (s), 145.5 (s), 138.3 (s), 134.8 (s), 128.5 (d), 128.4 (d), 128.2 (d), 128.1 (d), 127.7 (d), 127.2 (d), 126.6 (d), 126.3 (d), 122.8 (d), 122.7 (d), for **30a**: 118.6 (d, C-5), 104.9 (d, C-7), 94.0 (d, C-1′), 82.6 (t, C-3′), 51.9 (s, C-3), 31.7 (d, C-2′), 29.0 (q, CH_3N), 25.9 (q, *C*H_3C), 18.7 (q, *C*H_3CH); for **30b**: 118.7 (d, C-5), 105.0 (d, C-7), 93.5 (d, C-1′), 80.6 (t, C-3′), 52.1 (s, C-3), 30.6 (d, C-2′), 26.5 (q), 25.4 (q), 23.7 (q).

4.5.9. (*E*)-2,3-Dihydro-1,3-dimethyl-2-[(3-nitro-2-phenyl)propylidene]-3-phenyl-1*H*-indole (31a,b). The isomers **31a** and **31b** (13% yield) inseparable by flash chromatography, were obtained in 1:1 ratio. Orange oil; IR (cm^{-1}, film) 1651, 1606, 1552, 1491, 1458; UV (nm, CH_3OH) (log ε) 209 (4.50), 285 (4.15); UV (nm, CH_3CN) (log ε) 193 (4.93), 206 (4.66), 286 (4.23); UV (nm, cyclohexane) (log ε) 196 (4.69), 205 (4.63), 285 (4.32); EIMS (*m*/*z*) 384 ($M^{+\bullet}$, 31), 338 (18), 324 (91), 310 (32), 308 (19), 246 (13), 231 (22), 230 (18), 223 (100); HRMS calcd for $C_{25}H_{24}N_2O_2$ 384.1838, found 384.1838; ^1H NMR (δ, ppm, $CDCl_3$) 7.35–7.06 (10H, m, Ph), 6.70–6.40 (4H, m, Ar), 4.56 (0.5H, dd, C*H*NO_2, J_1=7.10 Hz, J_2=11.2 Hz, for **31a**), 4.48 (0.5H, m, C*H*NO_2 for **31a**), 4.40 and 4.36 (1H, d, H-1′, J=11.0 Hz), 4.14 (0.5H, dd, C*H*NO_2, J_1=8.8 Hz, J_2=11.3 Hz, for **31b**), 4.11 (1H, m, C*H*Ph, for **31a** and **31b**), 3.60 (0.5H, dd, C*H*NO_2, J_1=4.9 Hz, J_2=11.2 Hz, for **31b**), 3.10 (3H, s, CH_3N for **31a** and **31b**), 1.91 and 1.78 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 156.9 and 156.7 (s, C-2), 144.9 (2s), 141.2 (s), 139.9 (s), 138.4 (2s), 128.8 (d), 128.6 (d), 128.4 (d), 128.3 (d), 127.8 (d), 127.7 (d), 127.1 (2d), 126.7 (2d), 126.6 (2d), 126.4 (d), 122.8 (2d) (d, C-4), 119.0 and 118.9 (d, C-5), 105.1 and 105.2 (d, C-7), 91.7 and 91.3 (d, C-1′), 81.7 and 79.9 (t, C-3′), 52.2 and 52.1 (s, C-3), 42.1 and 41.0 (d, CHPh), 29.1 (2q, CH_3N for **31a** and **31b**), 26.0 and 25.4 (q, *C*H_3C).

4.5.10. 2,3-Dihydro-1,3-dimethyl-2-[(2-nitrocyclohexyl)methylidene]-3-phenyl-1*H*-indole (32a,b,c). ^1H NMR analysis of the crude reaction mixture indicated the presence of three isomers, *cis*-**32a**, *trans*-**32b** and *cis*-**32c** in 60%, 25% and 15%, respectively. After purification on flash chromatography fractions of different composition in *cis*-**32a**, *trans*-**32b** and *trans*-**32d** were isolated in only 6% yield. Oil; IR (cm^{-1}, film) 1660, 1601, 1551, 1507; UV (nm, CH_3OH) (log ε) 211 (4.34), 280 (4.09); UV (nm, CH_3CN) (log ε) 196 (4.36), 212 (4.22), 281 (4.01); UV (nm, cyclohexane) (log ε) 201 (4.27), 212 (4.32), 279 (4.08); EIMS (*m*/*z*) 362 ($M^{+\bullet}$, 28), 316 (10), 237 (15), 234 (14), 222 (100); HRMS calcd for $C_{23}H_{26}N_2O_2$ 362.1994, found 362.1990. For clarity sake the NMR values are given separately for each isomer. Compound *cis*-**32c**: ^1H NMR (δ, ppm, $CDCl_3$) 7.28–7.16 (5H, m, Ph), 7.08 (1H, t, Ar, J=7.4 Hz), 6.67–6.53 (3H, m, Ar), 4.48 (1H, dt, $CHNO_2$, J_1=J_2=4.2 Hz, J_3=8.6 Hz, W_H=18.4 Hz), 4.33 (1H, d, H-1′, J=11.2 Hz), 3.07 (3H, s, CH_3N), 2.78 (1H, m), 2.12 (1H, m), 1.9–0.5 (7H, m), 1.72 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 156.6 (s, C-2), 146.3 (s), 145.8 (s), 138.6 (s), 128.1 (d), 127.5 (d), 126.8 (d), 126.2 (d), 122.7 (d, C-4), 118.4 (d, C-5), 104.9 (d,

C-7), 89.9 (d, C-1′), 87.7 (d, $CHNO_2$), 51.8 (s, C-3), 36.3 (d, *C*HCHNO$_2$), 29.7 (t, CH_2), 29.5 (t, CH_2), 29.2 (q, CH_3N), 26.4 (t, CH_2), 26.2 (q, *C*H$_3$C), 22.4 (t, CH_2). Compound *trans*-**32b**: ^{1}H NMR (δ, ppm, $CDCl_3$) 4.10 (1H, dt, C*H*NO$_2$, J_1=J_2 11.2 Hz, J_3=3.5 Hz, W_H=30 Hz), 4.01 (1H, d, H-1′, J=10.6 Hz), 3.03 (3H, s, CH_3N), 2.49 (1H, m), 2.12 (1H, m), 1.9–0.5 (7H, m), 1.74 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 156.6 (s, C-2), 146.3 (s), 145.9 (s), 139.1 (s), 128.0 (d), 127.6 (d), 127.4 (d), 126.2 (d), 122.7 (d, C-4), 118.4 (d, C-5), 104.8 (d, C-7), 94.2 (d, C-1′), 92.0 (d, $CHNO_2$), 51.9 (s, C-3), 40.2 (d, *C*HCHNO$_2$), 32.7 (t, CH_2), 31.0 (t, CH_2), 29.1 (q, CH_3N), 25.7 (q, *C*H$_3$C), 24.6 (t, CH_2), 24.1 (t, CH_2). Compound *cis*-**32c**: ^{1}H NMR (δ, ppm, $CDCl_3$) 4.48 (1H, m, C*H*NO$_2$), 4.21 (1H, d, H-1′, J=11.0 Hz), 3.05 (3H, s, CH_3). Compound *trans*-**32d**: ^{1}H NMR (δ, ppm, $CDCl_3$) 4.24 (1H, d, H-1′, J=10.2 Hz), 3.94 (1H, dt, C*H*NO$_2$, J_1=J_2=10.0 Hz, J_3=3.5 Hz, W_H=29.0 Hz), 3.07 (3H, s, CH_3), 2.49 (1H, m), 1.9–0.8 (8H, m), 1.78 (3H, s, CH_3C); ^{13}C NMR (δ, ppm, $CDCl_3$) 155.9 (s, C-2), 145.7 (s), 145.2 (s), 138.6 (s), 128.4 (d), 127.6 (d), 126.3 (d), 126.1 (d), 122.6 (d, C-4), 118.4 (d, C-5), 104.9 (d, C-7), 95.2 (d, C-1′), 90.5 (d, $CHNO_2$), 51.7 (s, C-3), 39.3 (d, *C*HCHNO$_2$), 34.6 (t, CH_2), 29.9 (t), 29.2 (q, CH_3N), 26.3 (q, *C*H$_3$C), 24.1 (t, CH_2), 23.7 (t, CH_2).

4.6. Reactions of 2-methyleneindolines (1–3) with 1,2-diaza-1,3-butadienes (11–13)

4.6.1. General procedure. To a stirred solution of the appropriate 1,2-diaza-1,3-butadienes **11**–**13**[32] (0.85 mmol) in THF (5 ml) the substrates **1**–**3** (0.94 mmol) was added. The mixture was allowed to stand at room temperature for 2 h and then the solvent was evaporated under reduced pressure. The resulting products **33**–**40** were isolated by chromatography on silica gel column with cyclohexane–ethyl acetate (90:10 v/v) and then purified by crystallization from diethyl ether.

4.6.2. 2,2′,3,3′-Tetrahydro-1,3,3,5′-tetramethyl-4′-methoxycarbonyl-1′-ureidospiro[1*H*-indole-2,2′-pyrrole] (33). Yield 88%; pale pink solid; mp 203–206 °C; IR (cm^{-1}, Nujol) 3465, 3281, 3201, 1693, 1661, 1486, 1321, 1143, 892, 747. ^{1}H NMR (δ, ppm, $CDCl_3$) 7.09 (1H, t, J=7.6 Hz, H-6), 6.97 (1H, d, J=7.6 Hz, H-4), 6.73 (1H, t, J=7.6 Hz, H-5), 6.34 (1H, d, J=7.6 Hz, H-7), 5.24 (1H, s, NH), 4.79 (2H, br s, NH_2), 3.75 (3H, s, OCH_3), 3.03 (1H, dq, H-3′, J_1=16.5 Hz, J_2=2.2 Hz), 2.76 (1H, br d, H-3′, J=16.5 Hz), 2.68 (3H, s, NCH_3), 2.23 (3H, br s, CH_3 at C-3′), 1.40 (3H, s, CH_3 at C-3), 1.21 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, $CDCl_3$) 166.0 (s), 158.9 (s), 157.1 (s), 147.6 (s), 136.3 (s), 128.0 (d, C-6), 120.9 (d, C-4), 119.0 (d, C-5), 103.6 (d, C-7), 99.2 (s), 93.4 (s, C-2), 50.9 (q, OCH_3), 45.1 (s, C-3), 31.7 (t, CH_2), 29.7 (q, NCH_3), 28.6 (q, CH_3 at C-3), 20.2 (q, at C-3), 10.8 (q, CH_3 at C-5′); EIMS (*m*/*z*) 344 (M$^{+\bullet}$, 65), 285 (100); Anal. Calcd for $C_{18}H_{24}N_4O_3$: C, 62.77; H, 7.02; N, 16.27. Found: C, 62.54; H, 7.13; N, 16.30. The isomers **33a** and **33b** were obtained in 60:40 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Major component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 6.96 (1H, t, H-6, J=7.6 Hz), 6.94 (1H, s, NH), 6.87 (1H, d, H-4, J=7.6 Hz), 6.55 (1H, t, H-5, J=7.6 Hz), 6.34 (1H, d, H-7, J=7.6 Hz), 5.72 (2H, br s, NH_2), 3.59 (3H, s, OCH_3), 2.97 (1H, br d, H-3′, J=16.0 Hz), 2.60 (3H, s, NCH_3), 2.54 (1H, br d, H-3′, J=16.0 Hz), 2.06 (3H, br s, CH_3 at C-5′), 1.34 (3H, s, CH_3 at C-3), 1.06 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.4 (s), 160.1 (s), 156.4 (s), 148.0 (s), 136.8 (s), 126.8 (d, C-5), 120.0 (d, C-4), 117.3 (d, C-6), 103.9 (d, C-7), 97.6 (s), 89.5 (s, C-2), 50.1 (q, OCH_3), 44.9 (s, C-3), 31.4 (t, CH_2), 28.4 (q, NCH_3), 28.1 (q, CH_3 at C-3), 18.7 (q, at C-3), 10.5 (q, CH_3 at C-5′); minor component **b**: 7.22 (1H, s, NH), 6.93 (1H, d, H-4, J=7.6 Hz), 6.91 (1H, t, H-6, J=7.6 Hz), 6.52 (1H, t, H-5, J=7.6 Hz), 6.16 (1H, d, H-7, J=7.6 Hz), 5.36 (2H, br s, NH_2), 3.56 (3H, s, OCH_3), 2.94 (1H, br d, H-3′, J=16.0 Hz), 2.72 (3H, s, NCH_3), 2.70 (1H, br d, H-3′, J=16.0 Hz), 1.99 (3H, s, CH_3 at C-5′), 1.21 (3H, s, CH_3 at C-3), 1.04 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.7 (s), 159.8 (s), 157.2 (br s), 148.2 (s), 135.9 (s), 127.0 (d, C-6), 120.1 (d, C-4), 116.5 (d, C-5), 103.3 (d, C-7), 96.7 (s), 93.9 (s, C-2), 49.8 (q, OCH_3), 45.9 (s, C-3), 29.2 (t, CH_2), 28.6 (q, NCH_3), 28.0 (q, CH_3 at C-3), 19.3 (q, at C-3), 11.4 (q, CH_3 at C-5′).

4.6.3. 2,2′,3,3′-Tetrahydro-1,3,3,5′-tetramethyl-4′-methoxycarbonyl-1′ methoxycarbonylaminospiro[1*H*-indole-2,2′-pyrrole] (34). Yield 93%; pink solid; mp 182–185 °C; IR (cm^{-1}, Nujol) 3280, 1753, 1645, 1604, 1463, 1388, 1197, 1135, 999, 893, 749; EIMS (*m*/*z*) 359 (M$^{+\bullet}$, 82), 285 (100); Anal. Calcd for $C_{19}H_{25}N_3O_4$: C, 63.49; H, 7.01; N, 11.69. Found: C, 63.26; H, 7.18; N, 11.53. The isomers **34a** and **34b** were obtained in 55:45 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Major component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.24 (1H, s, NH), 6.95 (1H, t, H-6, J=7.6 Hz), 6.86 (1H, d, H-4, J=7.6 Hz), 6.54 (1H, t, H-5, J=7.6 Hz), 6.33 (1H, d, H-7, J=7.6 Hz), 3.59 (3H, s, OCH_3), 3.32 (3H, s, OCH_3), 2.98 (1H, br d, J=16.4 Hz, H-3′), 2.64 (3H, s, NCH_3), 2.59 (1H, br d, J=16.4 Hz, H-3′), 2.02 (3H, br s, CH_3 at C-5′), 1.30 (3H, s, CH_3 at C-3), 1.05 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.4 (s), 158.9 (s), 155.6 (s), 147.8 (s), 136.5 (s), 126.9 (d, C-5), 120.0 (d, C-4), 117.2 (d, C-6), 103.9 (d, C-7), 97.8 (s), 90.8 (s, C-2), 51.8 (q, OCH_3), 50.3 (q, OCH_3), 45.2 (s, C-3), 30.9 (t, CH_2), 28.1 (q, NCH_3), 28.0 (q, CH_3 at C-3), 18.2 (q, at C-3), 10.4 (q, CH_3 at C-5′); minor component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.55 (1H, s, NH), 6.91 (1H, d, H-4, J=7.6 Hz), 6.90 (1H, t, H-6, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.14 (1H, d, H-7, J=7.6 Hz), 3.57 (3H, s, OCH_3), 3.39 (3H, s, OCH_3), 2.95 (1H, br d, H-3′, J=16.4 Hz), 2.71 (3H, s, NCH_3), 2.69 (1H, br d, H-3′, J=16.4 Hz), 1.98 (3H, s, CH_3 at C-5′), 1.24 (3H, s, CH_3 at C-3), 1.03 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.6 (s), 158.6 (s), 156.0 (br s), 148.2 (s), 136.2 (s), 126.8 (d, C-6), 120.1 (d, C-4), 116.7 (d, C-5), 102.9 (d, C-7), 96.9 (s), 94.1 (s, C-2), 51.8 (q, OCH_3), 50.0 (q, OCH_3), 45.8 (s, C-3), 29.3 (t, CH_2), 28.5 (q, NCH_3), 27.9 (q, CH_3 at C-3), 18.8 (q, at C-3), 11.0 (q, CH_3 at C-5′).

4.6.4. 2,2′,3,3′-Tetrahydro-1,3,3,5′-tetramethyl-4′-methoxycarbonyl-1′-*tert*-butoxycarbonylaminospiro[2*H*-indole-2,2′-pyrrole] (35). Yield 85%; pale pink solid; mp 164–167 °C; IR (cm^{-1}, Nujol) 3253, 1744, 1643, 1605, 1453, 1377, 1133, 989, 892, 741; EIMS (*m*/*z*) 401 (M$^{+\bullet}$, 73), 301 (31), 285 (100); Anal. Calcd for $C_{22}H_{31}N_3O_4$: C, 65.81; H, 7.78; N, 10.47. Found: C, 65.97; H, 7.57; N,

10.32. The isomers **35a** and **35b** were obtained in 50:50 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 7.80 (1H, s, NH), 6.96 (1H, t, H-6, J=7.6 Hz), 6.85 (1H, d, H-4, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.34 (1H, d, H-7, J=7.6 Hz), 3.58 (3H, s, OCH_3), 2.96 (1H, br d, H-3′, J=16.4 Hz), 2.63 (3H, s, NCH_3), 2.58 (1H, br d, H-3′, J=16.4 Hz), 2.01 (3H, br s, CH_3 at C-5′), 1.32 (3H, s, CH_3 at C-3), 1.19 (9H, s, $C(CH_3)_3$), 1.04 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.4 (s), 159.1 (s), 154.4 (s), 148.2 (s), 136.5 (s), 126.8 (d, C-5), 119.8 (d, C-4), 117.2 (d, C-6), 103.9 (d, C-7), 97.9 (s), 90.5 (s, C-2), 79.1 (s, $C(CH_3)_3$), 50.1 (q, OCH_3), 45.8 (s, C-3), 30.8 (t, CH_2), 28.2 (q, NCH_3), 28.0 (q, CH_3 at C-3), 27.9 (q, $C(CH_3)_3$), 18.6 (q, at C-3), 10.5 (q, CH_3 at C-5′); component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.29 (1H, s, NH), 6.90 (1H, d, H-4, J=7.6 Hz), 6.89 (1H, t, H-6, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.13 (1H, d, H-7, J=7.6 Hz), 3.56 (3H, s, OCH_3), 2.93 (1H, br d, H-3′, J=16.4 Hz), 2.71 (3H, s, NCH_3), 2.68 (1H, br d, H-3′, J=16.4 Hz), 1.96 (3H, s, CH_3 at C-5′), 1.22 (3H, s, CH_3 at C-3), 1.19 (9H, s, $C(CH_3)_3$), 1.02 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.6 (s), 158.8 (s), 154.0 (s), 147.8 (s), 136.2 (s), 126.7 (d, C-6), 119.9 (d, C-4), 116.4 (d, C-5), 103.1 (d, C-7), 96.7 (s), 93.6 (s, C-2), 79.2 (s, $C(CH_3)_3$), 49.8 (q, OCH_3), 45.2 (s, C-3), 29.4 (t, CH_2), 28.4 (q, NCH_3), 27.9 (q, CH_3 at C-3), 27.8 (q, $C(CH_3)_3$), 18.1 (q, at C-3), 11.0 (q, CH_3 at C-5′).

4.6.5. 2,2′,3,3′-Tetrahydro-3-ethyl-1,3,5′-trimethyl-4′-methoxycarbonyl-1′-ureidospiro[2*H*-indole-2,2′-pyrrole] (36). Yield 87%; white solid; mp 171–174 °C; IR (cm^{-1}, Nujol) 3431, 3340, 3284, 1673, 1621, 1463, 1446, 1333, 1145, 887, 743; EIMS (*m*/*z*) 358 ($M^{+\bullet}$, 58), 299 (100), 262 (100); Anal. Calcd for $C_{19}H_{26}N_4O_3$: C, 63.67; H, 7.31; N, 15.63. Found: C, 63.74; H, 7.19; N, 15.79. The isomers **36a** and **36b** were obtained in 60:40 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Major component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 6.97 (1H, t, H-6, J=7.6 Hz), 6.84 (1H, s, NH), 6.80 (1H, d, H-4, J=7.6 Hz), 6.54 (1H, t, H-5, J=7.6 Hz), 6.33 (1H, d, H-7, J=7.6 Hz), 5.63 (2H, br s, NH_2), 3.59 (3H, s, OCH_3), 2.97 (1H, br d, H-3′, J=16.0 Hz), 2.59 (1H, br d, H-3′, J=16.0 Hz), 2.58 (3H, s, NCH_3), 2.05 (3H, br s, CH_3 at C-5′), 1.42 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.27 (3H, s, CH_3 at C-3), 0.59 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.4 (s), 159.9 (s), 156.4 (s), 148.6 (s), 133.6 (s), 126.9 (d, C-5), 121.5 (d, C-4), 116.7 (d, C-6), 103.7 (d, C-7), 98.3 (s), 89.4 (s, C-2), 50.1 (q, OCH_3), 48.3 (s, C-3), 31.1 (t, CH_2), 28.7 (t, CH_2), 28.4 (q, NCH_3), 16.7 (q, at C-3), 10.4 (q, CH_3 at C-5′), 8.6 (q, CH_3 at C-3); minor component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 7.19 (1H, s, NH), 6.92 (1H, t, H-6, J=7.6 Hz), 6.86 (1H, d, H-4, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.14 (1H, d, H-7, J=7.6 Hz), 5.33 (2H, br s, NH_2), 3.55 (3H, s, OCH_3), 2.93 (1H, br d, H-3′, J=16.0 Hz), 2.73 (1H, br d, H-3′, J=16.0 Hz), 2.68 (3H, s, NCH_3), 1.98 (3H, s, CH_3 at C-5′), 1.41 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.14 (3H, s, CH_3 at C-3), 0.55 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.7 (s), 159.6 (s), 157.1 (s), 148.8 (s), 132.5 (s), 127.1 (d, C-6), 121.5 (d, C-4), 115.8 (d, C-5), 102.9 (d, C-7), 97.0 (s), 93.8 (s, C-2), 49.7 (q, OCH_3), 49.2 (s, C-3), 31.1 (t, CH_2), 30.8 (t, CH_2), 27.9 (q, NCH_3), 16.3 (q, at C-3), 11.4 (q, CH_3 at C-5′), 8.6 (q, CH_3 at C-3).

4.6.6. 2,2′,3,3′-Tetrahydro-3-ethyl-1,3,5′-trimethyl-4′-methoxycarbonyl-1′-methoxycarbonylaminospiro[1*H*-indole-2,2′-pyrrole] (37). Yield 96%; pale pink solid; mp 168–171 °C; IR (cm^{-1}, Nujol) 3262, 1751, 1648, 1612, 1484, 1368, 1224, 1140, 1013, 889, 761; EIMS (*m*/*z*) 373 ($M^{+\bullet}$, 91), 358 (21), 312 (20), 299 (100); Anal. Calcd for $C_{20}H_{27}N_3O_4$: C, 64.32; H, 7.29; N, 11.25. Found: C, 64.44; H, 7.18; N, 11.19. The isomers **37a** and **37b** were obtained in 50:50 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.14 (1H, s, NH), 6.92 (1H, t, H-6, J=7.6 Hz), 6.84 (1H, d, H-4, J=7.6 Hz), 6.54 (1H, t, H-5, J=7.6 Hz), 6.32 (1H, d, H-7, J=7.6 Hz), 3.59 (3H, s, OCH_3), 3.32 (3H, s, OCH_3), 2.95 (1H, br d, H-3′, J=16.0 Hz), 2.64 (1H, br d, H-3′, J=16.0 Hz), 2.63 (3H, s, NCH_3), 1.99 (3H, br s, CH_3 at C-5′), 1.41 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.18 (3H, s, CH_3 at C-3), 0.59 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.3 (s), 158.7 (s), 155.5 (s), 148.4 (s), 133.2 (s), 126.8 (d, C-5), 121.5 (d, C-4), 116.5 (d, C-6), 103.8 (d, C-7), 98.7 (s), 90.9 (s, C-2), 51.8 (q, OCH_3), 50.2 (q, OCH_3), 48.6 (s, C-3), 30.7 (t, CH_2), 28.8 (t, CH_2), 28.0 (q, NCH_3), 15.9 (q, at C-3), 10.4 (q, CH_3 at C-5′), 8.6 (q, CH_3 at C-3); component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.51 (1H, s, NH), 6.98 (1H, t, H-6, J=7.6 Hz), 6.80 (1H, d, H-4, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.13 (1H, d, H-7, J=7.6 Hz), 3.58 (3H, s, OCH_3), 3.38 (3H, s, OCH_3), 2.95 (1H, br d, H-3′, J=16.0 Hz), 2.74 (1H, br d, H-3′, J=16.0 Hz), 2.68 (3H, s, NCH_3), 2.03 (3H, s, CH_3 at C-5′), 1.42 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.26 (3H, s, CH_3 at C-3), 0.57 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.6 (s), 158.4 (s), 155.9 (s), 148.7 (s), 132.9 (s), 127.0 (d, C-6), 121.6 (d, C-4), 116.0 (d, C-5), 102.6 (d, C-7), 97.4 (s), 94.2 (s, C-2), 51.7 (q, OCH_3), 49.9 (q, OCH_3), 49.1 (s, C-3), 30.9 (t, CH_2), 30.4 (t, CH_2), 27.9 (q, NCH_3), 15.8 (q, at C-3), 11.0 (q, CH_3 at C-5′), 8.5 (q, CH_3 at C-3).

4.6.7. 1,2′,3,3′-Tetrahydro-3-ethyl-1,3,4′-trimethyl-5′-methoxycarbonyl-1′-*tert*-butoxycarbonylaminospiro[2*H*-indole-2,2′-pyrrole] (38). Yield 85%; pink solid; mp 138–141 °C; IR (cm^{-1}, Nujol) 3248, 1738, 1650, 1602, 1458, 1367, 1271, 1135, 891, 783; EIMS (*m*/*z*) 415 ($M^{+\bullet}$, 63), 315 (31), 299 (100); Anal. Calcd for $C_{20}H_{27}N_3O_4$: C, 64.32; H, 7.29; N, 11.25. Found: C, 64.44; H, 7.18; N, 11.19. The isomers **38a** and **38b** were obtained in 50:50 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 7.67 (1H, s, NH), 6.98 (1H, t, H-6, J=7.6 Hz), 6.79 (1H, d, H-4, J=7.6 Hz), 6.55 (1H, t, H-5, J=7.6 Hz), 6.33 (1H, d, H-7, J=7.6 Hz), 3.59 (3H, s, OCH_3), 2.95 (1H, br d, H-3′, J=16.0 Hz), 2.66 (1H, br d, H-3′, J=16.0 Hz), 2.62 (3H, s, NCH_3), 2.01 (3H, br s, CH_3 at C-5′), 1.40 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.27 (3H, s, CH_3 at C-3), 1.20 (9H, s, $C(CH_3)_3$), 0.59 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.3 (s), 159.0 (s), 154.3 (s), 148.8 (s), 133.3 (s), 126.8 (d, C-5), 121.5 (d, C-4), 116.5 (d, C-6), 103.7 (d, C-7), 98.8 (s), 93.8 (s, C-2), 79.0 (s, $C(CH_3)_3$), 50.1 (q, OCH_3), 49.1 (s, C-3), 30.7 (t, CH_2), 30.2 (t, CH_2), 28.0 (q, NCH_3), 27.8 (q, $C(CH_3)_3$), 15.6 (q, at C-3), 10.4 (q, CH_3

at C-5′), 8.6 (q, CH_3 at C-3); component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.26 (1H, s, NH), 6.90 (1H, t, H-6, J=7.6 Hz), 6.84 (1H, d, H-4, J=7.6 Hz), 6.51 (1H, t, H-5, J=7.6 Hz), 6.12 (1H, d, H-7, J=7.6 Hz), 3.57 (3H, s, OCH_3), 2.94 (1H, br d, H-3′, J=16.0 Hz), 2.72 (1H, br d, H-3′, J=16.0 Hz), 2.69 (3H, s, NCH_3), 1.97 (3H, s, CH_3 at C-5′), 1.41 (2H, q, CH_2 at C-3, J=7.6 Hz), 1.20 (9H, s, $C(CH_3)_3$), 1.16 (3H, s, CH_3 at C-3), 0.56 (3H, t, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.5 (s), 158.7 (s), 154.0 (s), 148.4 (s), 132.8 (s), 126.8 (d, C-6), 121.5 (d, C-4), 115.8 (d, C-5), 102.8 (d, C-7), 97.1 (s), 90.6 (s, C-2), 79.2 (s, $C(CH_3)_3$), 49.8 (q, OCH_3), 48.6 (s, C-3), 30.8 (t, CH_2), 28.9 (t, CH_2), 28.0 (q, NCH_3), 27.9 (q, $C(CH_3)_3$), 15.9 (q, at C-3), 11.0 (q, CH_3 at C-5′), 8.5 (q, CH_3 at C-3).

4.6.8. 2,2′3,3′-Tetrahydro-1,3,5′-trimethyl-4′-methoxycarbonyl-3-phenyl-1′-ureidospiro[1*H*-indole-2,2′-pyrrole] (39). Yield 94%; white solid; mp 144–147 °C; IR (cm^{-1}, Nujol) 3428, 3285, 3173, 1666, 1606, 1493, 1440, 1363, 1319, 1200, 890, 782; EIMS (*m/z*) 406 ($M^{+\bullet}$, 74), 347 (100); Anal. Calcd for $C_{23}H_{26}N_4O_3$: C, 67.96; H, 6.45; N, 13.78. Found: C, 67.81; H, 6.50; N, 13.84. The isomers **39a** and **39b** were obtained in 65:35 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Major component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 7.25-6.73 (8H, m, Ph+NH+H-4+H-6), 6.57 (1H, t, H-5, J=7.6 Hz), 6.50 (1H, d, H-7, J=7.6 Hz), 5.92 (2H, br s, NH_2), 3.46 (3H, s, OCH_3), 2.62 (3H, s, NCH_3), 2.43 (1H, br d, H-3′, J=16.0 Hz), 2.09 (3H, br s, CH_3 at C-5′), 1.82 (1H, br d, H-3′, J=16.0 Hz), 1.75 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.2 (s), 160.1 (s), 156.6 (s), 149.3 (s), 145.2 (s), 136.3 (s), 127.8 (s), 127.7 (s), 127.2 (s), 126.2 (d, C-5), 121.8 (d, C-4), 117.7 (d, C-6), 103.6 (d, C-7), 98.0 (s), 90.0 (s, C-2), 52.7 (q, OCH_3), 50.0 (s, C-3), 33.9 (t, CH_2), 28.4 (q, NCH_3), 19.3 (q, CH_3 at C-5′), 10.6 (q, CH_3 at C-3); minor component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 7.49 (1H, s, NH), 7.25–6.73 (7H, m, Ph+H-4+H-6), 6.49 (1H, t, H-5, J=7.6 Hz), 6.34 (1H, d, H-7, J=7.6 Hz), 5.53 (2H, br s, NH_2), 3.45 (3H, s, OCH_3), 2.71 (3H, s, NCH_3), 2.36 (1H, br d, H-3′, J=16.0 Hz), 2.17 (1H, br d, H-3′, J=16.0 Hz), 2.01 (3H, s, CH_3 at C-5′), 1.65 (3H, s, CH_3 at C-3); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.5 (s), 159.5 (s), 157.6 (br s), 149.9 (s), 144.7 (s), 135.7 (s), 127.9 (s), 127.7 (s), 127.1 (s), 126.2 (d, C-6), 121.7 (d, C-4), 117.0 (d, C-5), 104.3 (d, C-7), 97.2 (s), 94.7 (s, C-2), 54.2 (q, OCH_3), 49.7 (s, C-3), 31.3 (t, CH_2), 28.2 (q, NCH_3), 18.0 (q, CH_3 at C-5′), 11.5 (q, CH_3 at C-3).

4.6.9. 2,2′3,3′-Tetrahydro-1,3,5′-trimethyl-4′-methoxycarbonyl-3-phenyl-1′-*tert*-butoxycarbonylaminospiro[1*H*-indole-2,2′-pyrrole] (40). Yield 81%; pink solid; mp 184–187 °C; IR (cm^{-1}, Nujol) 3241, 1763, 1656, 1605, 1366, 1276, 1161, 1135, 999, 752; EIMS (*m/z*) 463 ($M^{+\bullet}$, 56), 347 (62), 221 (100); Anal. Calcd for $C_{27}H_{33}N_3O_4$: C, 69.95; H, 7.18; N, 9.06. Found: C, 70.04; H, 7.01; N, 9.25. The isomers **40a** and **40b** were obtained in 55:45 ratio by using DMSO-d_6 as a solvent (determined by ^{1}H NMR). For clarity sake the NMR values are given separately for each isomer. Major component **a**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.18 (1H, s, NH), 7.23–7.00 (6H, m, Ph+H-6), 6.98 (1H, d, H-4, J=7.6 Hz), 6.58 (1H, t, H-5, J=7.6 Hz), 6.50 (1H, d, H-7, J=7.6 Hz), 3.46 (3H, s, OCH_3), 2.63 (3H, s, NCH_3), 2.46 (1H, br d, H-3′, J=16.0 Hz), 2.05 (3H, br s, CH_3 at C-5′), 1.88 (1H, br d, H-3′, J=16.0 Hz), 1.71 (3H, s, CH_3 at C-3), 1.28 (9H, s, $C(CH_3)_3$). ^{13}C NMR (δ, ppm, DMSO-d_6) 165.1 (s), 158.6 (s), 154.9 (s), 149.6 (s), 144.8 (s), 135.9 (s), 127.7 (s), 127.6 (s), 127.3 (s), 126.2 (d, C-5), 121.8 (d, C-4), 117.6 (d, C-6), 104.4 (d, C-7), 98.1 (s), 94.4 (s, C-2), 79.5 (s, $C(CH_3)_3$), 53.7 (q, OCH_3), 50.0 (s, C-3), 33.2 (t, CH_2), 28.4 (q, NCH_3), 27.9 (q, $C(CH_3)_3$), 19.0 (q, CH_3 at C-3), 10.5 (q, CH_3 at C-5′); minor component **b**: ^{1}H NMR (δ, ppm, DMSO-d_6) 8.55 (1H, s, NH), 7.23–7.00 (6H, m, Ph+H-6), 6.77 (1H, d, H-4, J=7.6 Hz), 6.53 (1H, t, H-5, J=7.6 Hz), 6.31 (1H, d, H-7, J=7.6 Hz), 3.32 (3H, s, OCH_3), 2.70 (3H, s, NCH_3), 2.43 (1H, br d, H-3′, J=16.0 Hz), 2.10 (1H, br d, H-3′, J=16.0 Hz), 1.99 (3H, s, CH_3 at C-5′), 1.67 (3H, s, CH_3 at C-3), 1.27 (9H, s, $C(CH_3)_3$); ^{13}C NMR (δ, ppm, DMSO-d_6) 165.4 (s), 159.1 (s), 154.4 (br s), 149.6 (s), 144.6 (s), 135.9 (s), 127.9 (s), 127.8 (s), 127.1 (s), 126.2 (d, C-6), 121.6 (d, C-4), 117.0 (d, C-5), 103.4 (d, C-7), 97.1 (s), 91.1 (s, C-2), 79.5 (s, $C(CH_3)_3$), 53.0 (q, OCH_3), 49.8 (s, C-3), 31.4 (t, CH_2), 28.1 (q, NCH_3), 28.0 (q, $C(CH_3)_3$), 17.3 (q, CH_3 at C-3), 11.2 (q, CH_3 at C-5′).

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