Reactivity of 3-Styrylchromones as Dienes in Diels–Alder Reactions under Microwave Irradiation: A New Synthesis of Xanthones

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Microwave irradiation under solvent-free conditions induced 3-styrylchromones to undergo Diels–Alder cycloaddition reactions with *N*-methyl- and *N*-phenylmaleimide as well as with other dienophiles. In some of these reactions the cycloadducts underwent in situ oxidation to give xanthones, whereas in other cases it was necessary to add DDQ as an oxidant. The reactions of 3-styrylchromones with *N*-methyl- and *N*-phenylmaleimide gave the cycloadducts 4-aryl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthones, which were oxidised to 4-aryl-1,3-dioxopyrrolo[3,4-*c*]xanthones with DDQ. The reactions of 3-styrylchromones with 2-(2-nitrovinyl)thiophene gave 2-aryl-3-(2-thienyl)xanthones directly through a Diels–Alder reaction followed by HNO_2 elimination and oxidation. The cycloaddition reactions of 3-styrylchromones described herein are stereoselective. The reactions of (*Z*)- and (*E*)-3-styrylchromones with *N*-methylmaleimide gave, respectively, the *endo* and *exo* cycloadducts, while reactions of (*Z*)-3-styrylchromones with the less reactive dienophile *N*-phenylmaleimide gave a mixture of compounds. This mixture contained the expected *endo* cycloadduct and another compound that was identified as the *exo* adduct of the reaction between the (*E*)-3-styrylchromone – obtained in situ from the isomerisation of its (*Z*) isomer – and *N*-phenylmaleimide. The regio- and stereoselectivity of these cycloaddition reactions have been studied by ab initio calculations and can be understood in terms of a thermodynamically controlled reaction. Theoretical calculations are in complete agreement with the experimental results.

Introduction

2-Styrylchromones are a small family of naturally occurring compounds and constitute one of the smallest groups of chromones.[1,2] Although scarce in nature, these chromones have been extensively studied as they exhibit significant biological activity. In fact, the biological activity of such compounds was reported for the first time in 1979 when Doria et al. described the significant anti-allergic activity of several 2-styrylchromones.[3] In the last decade we have explored the structure and chemistry of 2-styrylchromones, namely the development of new synthetic routes,[4] structural studies,[5] their reactivity in Diels–Alder reactions,[6] their transformation into other heterocyclic compounds[7] and, more recently, biological evaluations.[8] Recently we extended our interest to 3-styrylchromones, which have been studied less widely than their 2-isoanalogues. Reports concerning the synthesis, chemical transformations and biological evaluations of these materials are scarce.[9] We focused our attention on the development of new synthetic methods[10] as well as on the study of their reactivity. We recently reported the reactivity of these styrylchromones as dienes in Diels–Alder reactions.[11] Initial results indicated that under classical heating conditions 3-styrylchromones are reluctant to react in Diels–Alder reactions, but the use of microwave radiation proved to be a very effective alternative for introducing energy into these reactions. In order to assess the efficiency of microwave irradiation in enhancing the reactivity of 3-styrylchromones as dienes in Diels–Alder cycloaddition reactions, we compare the results obtained in the reactions carried out under solvent-free conditions with those obtained under classical heating conditions. The cycloaddition reactions of 3-styrylchromones with *N*-phenyl- and *N*-methylmaleimide are discussed in detail and this approach has led to a new method for the synthesis of novel xanthone-type compounds.

The application of microwave irradiation in organic synthesis is a very recent advance.[12] The first experiments showed that the rate of a number of organic reactions could be increased by using a microwave oven.[13] These studies

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have formed the basis of an ever-increasing range of applications of microwaves in research[12] and have shown not only that reaction times can be reduced and yields improved but also that the selectivity can be modified in relation to conventional heating.[14] The first examples of reactions performed in the absence of solvent, which was an important step in the development of green chemistry, were reported in the 1990s.[12,15]

In many cases cycloaddition reactions require the use of harsh conditions that are not compatible with sensitive reactants or products. Moreover, the applicability of Diels–Alder cycloaddition reactions is limited by the reversibility of the reaction when a long reaction time is required. All of these problems have been conveniently solved by the rapid heating produced by microwave irradiation, which cannot be achieved with classical heating methods.[16]

We decided to further explore the reactivity of 3-styrylchromones under microwave irradiation in solvent-free conditions. As a result we are able to describe the first example of a [4+2] cycloaddition reaction between 3-styrylchromones and 2-(2-nitrovinyl)thiophene − a process that constitutes a new method for the synthesis of novel xanthones.

Xanthones are an important family of polyphenolic heterocyclic compounds that occur widely in nature.[17] The great interest in these compounds is due to their abundance and also to their important biological properties and uses[18] − they have been reported to act as inhibitors of monoamineoxygenase enzymes (MAO-A and MAO-B),[17] as anti-inflammatory, anti-oxidant and anti-ulcer agents,[19] as bronchodilators in the treatment of asthma[20] and also as in vivo and in vitro anti-tumour drugs.[21]

Results and Discussion

Chemistry

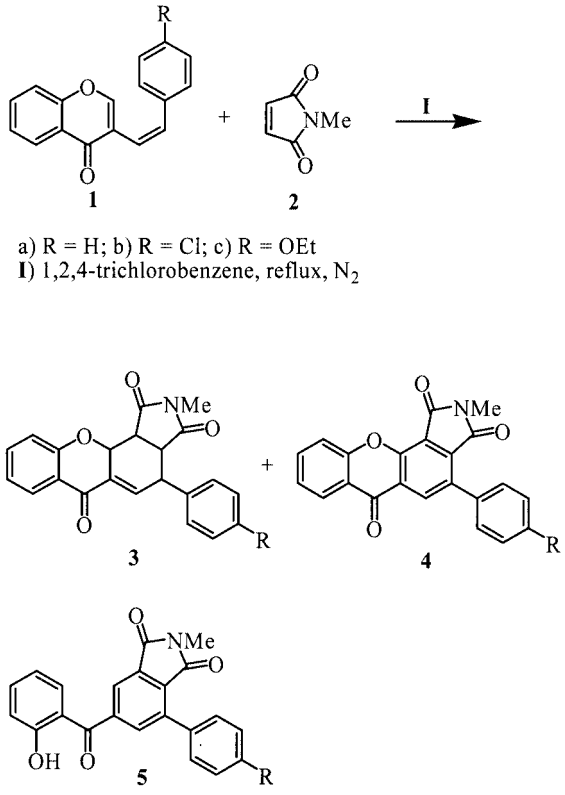
Initial experiments involved the Diels–Alder reactions of (*Z*)-3-styrylchromones **1a**–**c** with *N*-methylmaleimide (**2**), a very reactive dienophile, under classical heating conditions. The results indicate that the cycloaddition reaction only occurs at high temperatures and in an inert atmosphere (Table 1, Scheme 1). The reaction time was controlled in such a way that the cycloadducts **3a**–**c** were the major products, however, it must be stressed that these were not the only products. When the reaction time was less than 18 hours it was always possible to recover some of the reactant **1a**–**c**. The study indicates that cycloadducts **3a**–**c**, (*Z*)-3-styrylchromones **1a**–**c** and xanthones **4a**–**c** could be isolated for reaction times of between 18 and 24 hours. Total consumption of the starting materials occurred after 24 hours under reflux and the reaction produced a mixture of cycloadducts **3a**–**c** and xanthones **4a**–**c**.

Another important aspect of this reaction under classical heating conditions was that longer reaction times did not improve yields but caused degradation to give another by-product (benzophenone **5b**) (Entry 5, Table 1). It was also observed that the presence of an electron-donating substituent (OEt) in the B ring of 3-styrylchromone causes more degradation and lower product yields (Entry 6, Table 1).

Table 1. Diels–Alder reactions of (*Z*)-3-styrylchromones **1a**–**c** with *N*-methylmaleimide (**2**).

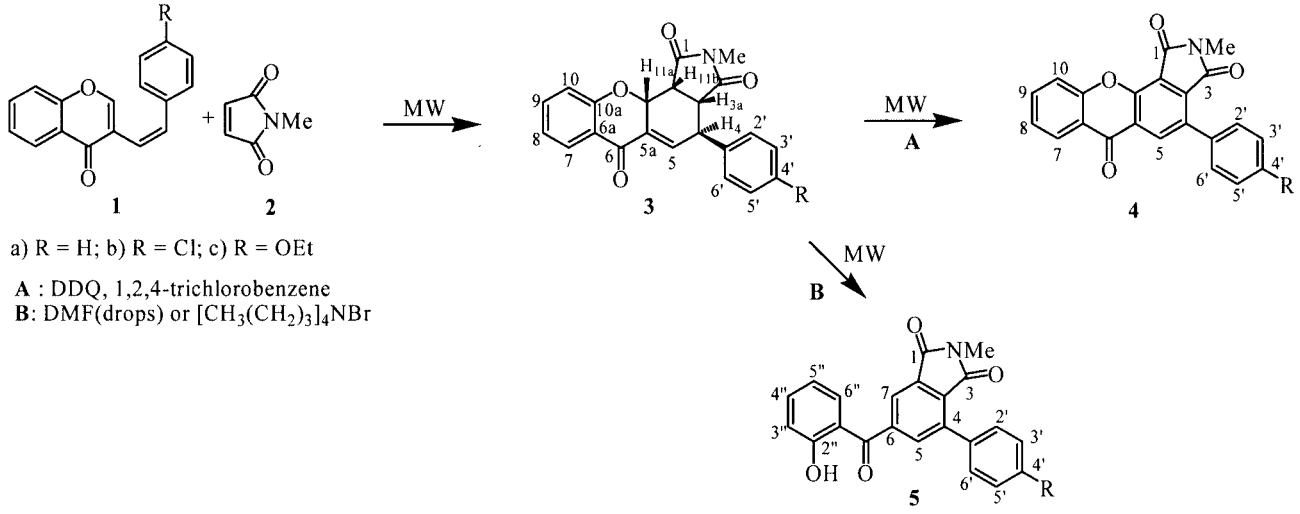
Entry	R	Reaction time [h]	Yield [%]			
			1[a]	**3**	**4**	**5**
1	H	18	25	48	–	–
2	H	24	–	40	47	–
3	Cl	18	26	51	–	–
4	Cl	24	–	40	44	–
5	Cl	48	–	10	40	23
6	OEt	18	15	41	–	–

[a] (*Z*)-3-Styrylchromone recovered.



Scheme 1.

The results obtained were not totally satisfactory and the cycloaddition reactions of (*Z*)-3-styrylchromones **1a**–**c** with the very reactive dienophile **2** only took place under extreme reaction conditions. Given that microwave radiation is an excellent alternative to conventional heating for introducing energy into reactions, we decided to perform these reactions by using microwave irradiation. These reactions were also carried out in the absence of solvent in order to take advantage of the synergy between microwave irradiation and solvent-free reactions; for example, the radiation would be directly absorbed by the reagents. By using this approach, cycloadducts **3a**–**c** were obtained as the only reaction products in good overall yields (Table 2, Scheme 2).



Scheme 2.

Table 2. Diels–Alder reactions of (*Z*)-3-styrylchromones **1a**–**c** with *N*-methylmaleimide (**2**) under microwave irradiation.

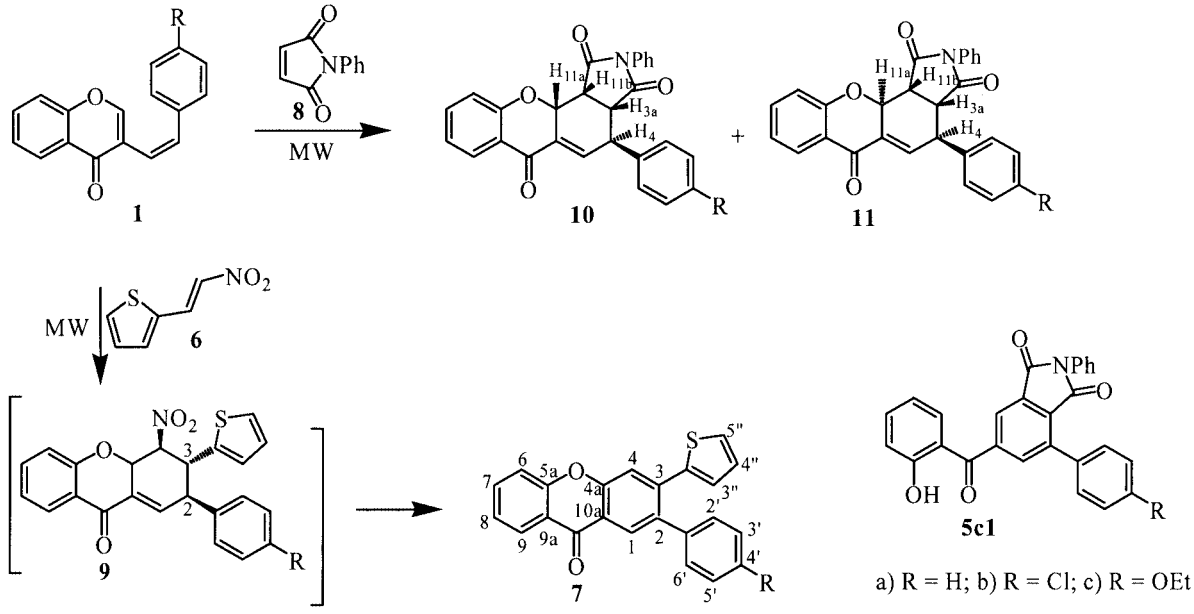
Entry	R	Reaction time [min]	Yield [%]	
			3	**4**[a]
1	H	30	76	74
2	Cl	30	75	70
3	OEt	30	77	67

[a] Calculated from the starting materials, (*Z*)-3-styrylchromones **1a**–**c**.

This new approach seems to be efficient in promoting the participation of (*Z*)-3-styrylchromones **1a**–**c** as dienes in Diels–Alder cycloaddition reactions at lower temperatures (160 °C) and shorter reaction times (30 min). The next challenge was to use this new methodology to obtain xanthones **4a**–**c**. Under classical heating conditions cycloadducts **3a**–**c** were transformed into xanthones **4a**–**c** at high temperatures without using an oxidant other than the oxygen present in the reaction medium (Scheme 1). Given this fact, it was decided to perform these reactions under microwave irradiation in the presence of an ammonium salt or three drops of DMF, which were added in order to raise the reaction temperature (Scheme 2). A considerable increase in the reaction temperature (ca. 200 °C) was observed but the resulting products were benzophenones **5a**–**c**. It seems that ring-opening of the pyran moiety in cycloadducts **3a**–**c** is more favourable than their oxidation to xanthones **4a**–**c**.

These results led us to study carefully the aforementioned oxidation reactions; attempts to oxidise cycloadducts **3a**–**c** by using a strong oxidant (DDQ) without a solvent were unproductive and the cycloadducts were destroyed. Cycloadduct oxidation was only achieved when the reactions were performed with DDQ in 1,2,4-trichlorobenzene. Finally, we focused our attention on obtaining xanthones **4** in one step. (*Z*)-3-Styrylchromones **1a**–**c** were allowed to react with *N*-methylmaleimide (**2**), but the resulting cycloadducts **3a**–**c** were not isolated; instead the solvent (1,2,4-trichlorobenzene) and oxidant (DDQ) were added and the mixtures irradiated with microwaves for 45 minutes. The desired xanthones **4a**–**c** were obtained in good overall yields (Table 2, Scheme 2).

In order to determine the scope of this reaction and its utility as a new synthetic approach to novel xanthone-type compounds, we extended our study to the cycloaddition of (*Z*)-3-styrylchromones **1a**–**c** with other dienophiles such as 2-(2-nitrovinyl)thiophene (**6**) and *N*-phenylmaleimide (**8**). It has previously been reported that the microwave-induced-Diels–Alder reactions of several dienes with 2-(2-nitrovinyl)-thiophene (**6**) as the dienophile gave reaction products with the loss of HNO_2 and/or H_2 after the cycloaddition reaction − a process that induces aromatisation of the final product.[22] Bearing this fact in mind, we expected that the reaction of this dienophile with (*Z*)-3-styrylchromones **1a**–**c** would directly give a xanthone-type compound with or without the nitro group. In the first attempt, (*Z*)-3-styrylchromone (**1a**) was allowed to react with 2-(2-nitrovinyl)-thiophene (**6**) under the reaction conditions outlined above (MW and 160 °C); the xanthone-type compound **7a** was obtained but more than 70% of the starting material [a mixture of both (*Z*)- and (*E*)-3-styrylchromones] was also recovered. The reaction conditions were then optimised and it was found that xanthones **7a**–**c** could be obtained in good yields at a higher temperature (200 °C) (Scheme 3). From these results it can be concluded that: (i) microwave irradiation can induce the isomerisation of (*Z*)-**1a**–**c** to (*E*)-3-styrylchromones **12a**–**c**; (ii) 2-(2-nitrovinyl)thiophene (**6**) is less reactive than *N*-methylmaleimide (**2**); (iii) aromatisation of the cycloadducts **9a**–**c** into the final products **7a**–**c** is favoured by the presence of two benzylic-type protons; (iv) elimination of HNO_2 is also favoured since nitroxanthones were not detected in the products of the reaction of **1a**–**c** with **6**; (v) the reaction of **1a**–**c** with **6** is regioselective as only 2-phenyl-3-(2-thienyl)xanthones **7a**–**c** were obtained. This regioselectivity can be explained by the preferential attack of the most negatively charged carbon atom C-β in (*Z*)-3-styrylchromones **1a**–**c** on the partially positively charged carbon atom C-1 of 2-(2-nitrovinyl)thiophene (**6**)



Scheme 3.

and is in complete agreement with the calculated orbital coefficients (HOMO dienophile – LUMO diene) (Figure 1).

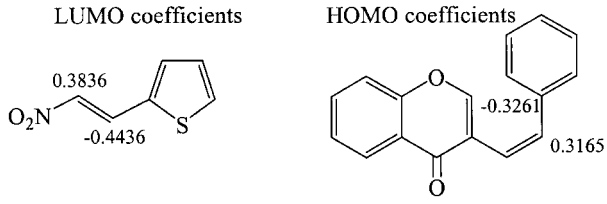


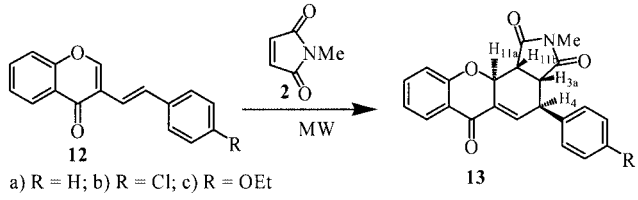
Figure 1. Calculated orbital coefficients for 2-(2-nitrovinyl)thiophene (**6**) (LUMO) and (*Z*)-3-styrylchromone (**1a**) (HOMO).

We next focused our attention on the reaction of (*Z*)-3-styrylchromones **1a**,**b** with *N*-phenylmaleimide (**8**). This dienophile is also less reactive than *N*-methylmaleimide (**2**) so we used a high temperature (200 °C) which gave a mixture of two isomeric compounds **10a**,**b** and **11a**,**b** (Scheme 3, Table 3). The reaction of 3-(4-ethoxystyryl)chromone (**1c**) under these experimental conditions gave a benzophenone-type compound **5c1**. The reaction at a lower temperature (160 °C) also gave a mixture of two isomeric compounds, **10c** and **11c** (Scheme 3, Table 3).

Table 3. Diels–Alder reactions of (*Z*)-3-styrylchromones **1a**–**c** with *N*-phenylmaleimide (**8**) under MW irradiation.

Entry	R	Temp. [°C]	Yield [%]	
			10	**11**
1	H	200	60	21
2	Cl	200	50	20
3	OEt	160	54	15

Initially we thought that these isomers were the two possible *endo* and *exo* cycloadducts. However, NMR analysis (discussed later) showed that the cycloadducts **10a**–**c** were the *endo* isomers (Scheme 3) but the other compounds were not the *exo* cycloadducts. Bearing in mind the known (*Z*)–(*E*) isomerisation induced by microwave irradiation as well as the possible *endo* and *exo* cycloadducts that can be obtained from the Diels–Alder reactions of (*E*)-3-styrylchromones **12a**–**c** with **8**, it can be seen from the NMR data that compounds **11a**–**c** were the *exo* isomers obtained from the cycloaddition reactions of **12a**–**c** with **8**. These results have prompted us to postulate that the lower reactivity of *N*-phenylmaleimide (**8**) could cause the (*Z*)-3-styrylchromones **1a**–**c** to isomerise to the (*E*) isomers **12a**–**c**,[23] which could in turn react with **8** to give the *exo* cycloadducts **11a**–**c**. This hypothesis was supported by the Diels–Alder reactions of (*E*)-3-styrylchromones **12a**–**c** and *N*-methylmaleimide (**2**) under microwave irradiation in solvent-free conditions (Scheme 4). In these cases only the *exo* cycloadducts **13a**–**c** were obtained in good yields.



Scheme 4.

NMR Spectroscopy

A detailed analysis of the aliphatic region of the ^{1}H and ^{13}C NMR spectra of cycloadducts **3a**–**c** with the aid of the

COSY and HSQC spectra revealed the presence of the newly formed cyclohexene ring [δ = 3.43–3.48 (3a-H) and 44.7–45.0 (C-3a), 3.81–3.82 (11b-H) and 43.3–43.6 (C-11b), 4.58–4.64 (4-H) and 38.5–39.2 (C-4), 5.33–5.37 (11a-H) and 70.9–71.1 (C-11a) ppm]. These data, in conjunction with the connectivities found in the HMBC spectra (4-H → C-6a, C-11b, C-3, C-2′, C-6′ and 11a-H → C-6a, C-5, C-1, Figure 2) and the presence of an *N*-methyl group (δ_H = 2.98–2.99 ppm; δ_C = 25.3 ppm), are consistent with the proposed cycloadduct structures **3a**–**c**.

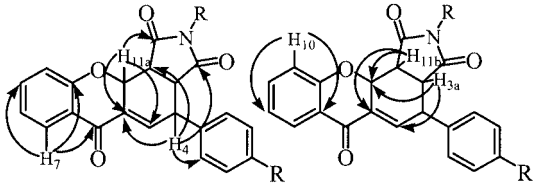


Figure 2. Important connectivities found in the HMBC spectra of the cycloadducts **3a**–**c**, **10a**–**c**, **11a**–**c** and **13a**–**c**.

Another important feature of the ^{1}H NMR spectra of cycloadducts **3a**–**c** is the resonance of the proton 5-H, which appears as a double doublet of doublets at higher frequencies than expected (δ = 7.34–7.40 ppm) as a result of the mesomeric and anisotropic deshielding effects of the carbonyl group. The coupling constant, $J_{H11a,H11b}$ = 8.5 Hz, and the signal enhancements observed in the NOE difference experiments (Figure 3) indicate that 2-methyl-1,3-dioxo-4-phenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthones **3a**–**c** are the *endo* cycloadducts. The resonances of all the other protons of these cycloadducts were determined with the aid of COSY, HSQC and HMBC spectra. The 2D spectra also allowed the unequivocal assignment of all the carbon resonances; the signals due to the quaternary carbon atoms were mainly assigned on the basis of the connectivities found in the HMBC spectra of the cycloadducts **3a**–**c** (Figure 2).

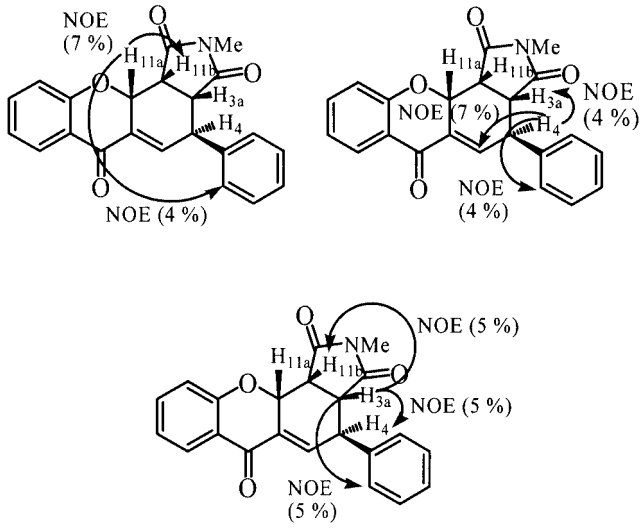


Figure 3. Main results obtained from the NOE difference spectra of the cycloadducts **3a**–**c**.

The main resonances in the ^{1}H NMR spectra of compounds **4a**–**c** are in the aromatic region. These data, together with a proton resonance at δ = 8.59–8.62 ppm (characteristic of a xanthone proton deshielded by the mesomeric and anisotropic effects of its carbonyl group), indicate that the cycloadducts **3a**–**c** had been oxidised into the corresponding 2-methyl-1,3-dioxo-4-phenylpyrrolo[3,4-*c*]-xanthones **4a**–**c**. The important features in the ^{13}C NMR spectra of these xanthones are the resonances of the carbon atoms of the pyranone ring (C-5a, C-6a, C-11a, C-10a and C-6) which appear at δ = 120.0–120.2, 121.7–121.8, 150.1–150.6, 156.0–156.1 and 175.6–175.7 ppm, respectively.

The ^{1}H NMR spectra of compounds **5a**–**c** also exhibit signals in the aromatic region and another at δ = 11.76–11.80 ppm. These data, together with a carbon resonance at δ = 199.1–199.5 ppm, indicate that the cycloadducts were oxidised with concomitant pyran ring-opening to give the 6-(2-hydroxybenzoyl)-2-methyl-4-phenylisoindole-1,3-diones **5**. The signals at δ = 11.76–11.80 ppm are due to the resonances of hydroxy protons (2′′-OH) involved in intramolecular hydrogen bonds with a carbonyl group. In the structural characterisation of these 4-phenylisoindole-1,3-diones **5** it is also important to consider the doublets at δ = 7.90–7.93 and 8.03–8.09 ppm, which correspond to the resonances of 5-H and 7-H, respectively. The unequivocal assignment of these protons was based on the connectivities found in the HMBC spectra [7-H shows connectivity with two carbonyl groups (C-1 and C-6), while 5-H only shows connectivity with one carbonyl group (C-6)]. These connectivities confirmed the presence of protonated carbon atoms and allowed the unequivocal assignment of quaternary carbon atoms (see Figure 5).

The ^{1}H and ^{13}C NMR spectra of cycloadducts **10a**–**c** are very similar to those of cycloadducts **3a**–**c**. The main differences result from the absence of the proton and carbon resonances of the *N*-methyl group and the presence of signals due to an *N*-phenyl ring. The NOESY spectra of these cycloadducts were obtained in order to confirm that the products were the *endo* adducts.

Detailed analysis of the ^{1}H, ^{13}C, and 2D HSQC and HMBC NMR spectra of cycloadducts **11a**–**c** and **13a**–**c** revealed the presence of: (i) four aliphatic protons at δ = 3.39–3.53, 3.39–3.58, 4.10–4.42 and 5.13–5.28 ppm, which correspond to the resonances of 4-H, 11b-H, 3a-H and 11a-H, respectively; (ii) one vinylic proton at δ = 5.65–5.81 ppm due to the resonance of 5-H; (iii) four aliphatic carbon atoms at δ = 39.9–40.2, 44.2–44.4, 47.8–48.0 and 72.5–73.1 ppm due to the resonances of C-3a, C-11b, C-4 and C-11a, respectively; (iv) one vinylic carbon atom at δ = 117.4–120.1 ppm corresponding to the resonance of C-5; (v) three carbonyl carbon atoms at δ = 173.2–174.4, 174.1–175.3 and 190.4–191.0 ppm due to the resonances of C-1, C-3 and C-6, respectively. These data, together with those obtained from the NOE experiments, which show a *cis* configuration for protons 11a-H and 4-H (Figure 4), and the coupling constant $J_{H11a,H11b}$ = 3.1 Hz which indicates a *trans* configuration between these two protons, are only compatible with the structure and the stereochemistry of cycloadducts

11a–**c** and **13a**–**c** as depicted in Schemes 3 and 4. The connectivities found in the HMBC spectra of cycloadducts **11a**–**c** and **13a**–**c** allowed the unequivocal assignment of the quaternary carbon resonances and confirmed the presence of protonated carbon atoms, which were assigned on the basis of the correlations found in the HSQC spectra.

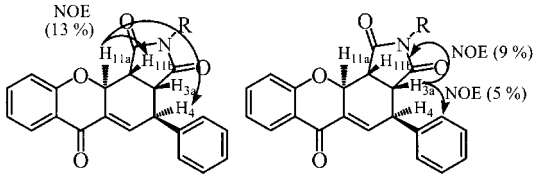


Figure 4. Main results obtained from the NOESY spectra of the cycloadducts **11a**–**c** and **13a**–**c**.

The most noteworthy characteristics of the ^{1}H and ^{13}C NMR spectra of 3-(2-thienyl)xanthones **7a**–**c** are the proton and carbon resonances of the 2-thienyl group (δ_H = 6.81–6.86, 6.92–6.96 and 7.30–7.32 ppm, δ_C = 127.2–127.4, 127.3–127.5 and 128.3–128.5 ppm, which support the proposed structure.

Other important features of the ^{1}H NMR spectra of the 3-(2-thienyl)xanthones **7a**–**c** are the resonances due to 1-H (δ = 8.27–8.30 ppm), 4-H (δ = 7.68–7.70 ppm) and 9-H (δ = 8.35–8.36 ppm) protons. Protons 1-H and 9-H are the most deshielded protons in these xanthones as a result of the mesomeric and anisotropic deshielding effects of the carbonyl group. The unequivocal assignment of these signals was based on their signal multiplicity (proton 1-H appears as a singlet and proton 9-H appears as a doublet of doublets) and on the connectivities found in the HMBC spectra. Another important aspect is the unequivocal assignment of proton 4-H (another characteristic signal which appears as a singlet) and its differentiation from proton 1-H, which was based on the frequencies of the signals and the connectivities found in the HMBC spectra of these xanthones, as shown in Figure 5.

Finally, it is important to point out the characteristic signals of the ^{13}C NMR spectra at δ = 120.5–120.6, 122.0, 155.0–155.3, 156.3 and 176.7–176.8 ppm, which correspond to the resonances of carbon atoms C-10a, C-9a, C-4a, C-5a and C-10, respectively, thus confirming the presence of the pyranone ring.

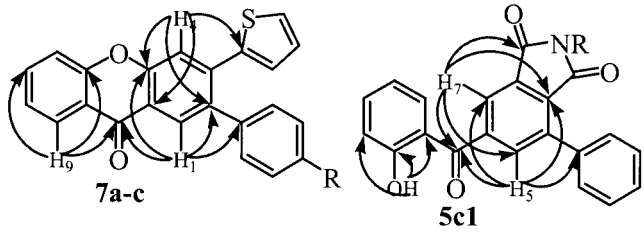


Figure 5. Important connectivities found in the HMBC spectra of the xanthones **7a**–**c** and **5c1**.

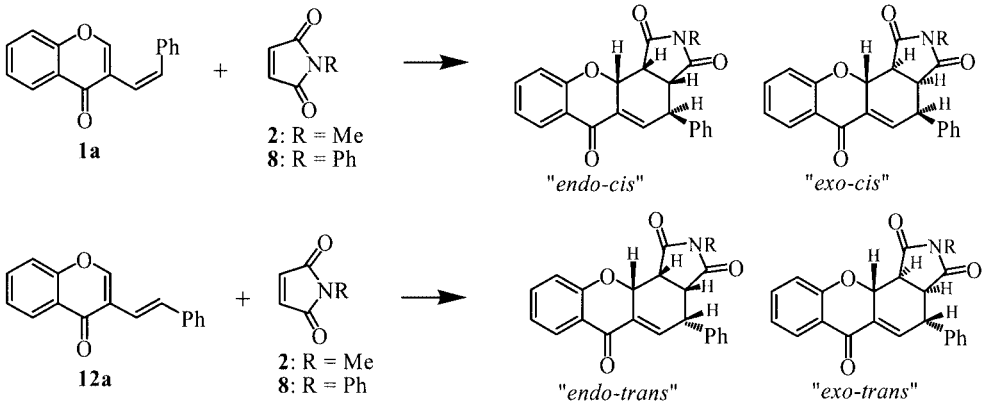
Computational Studies

In an effort to understand the stereoselectivity of the process described above, ab initio calculations on the Diels–Alder reactions were performed. 3-Styrylchromones **1a** and **12a** were selected as dienes and *N*-methyl- and *N*-phenylmaleimides (**2** and **8**) were chosen as the dienophiles (Scheme 5).

The reaction profile and all its stationary points were located using several levels of theory (HF/3-21G*, HF/6-31G* and B3LYP/6-31G*). Some of the geometrical parameters of the transition states (TSs) are given in Figures 6 and 7 and Table 4. The results indicate that *endo* TSs are more synchronous than *exo* TSs. In all cases distance **b** is longer than distance **a**, except for the *cis-endo* transition

Table 4. Bond lengths [Å] of transition structures computed at the B3LYP/6-31G*//HF 6-31G* level of theory and asynchronicity (Δd).

	d (**a**)	*d* (**b**)	Δd
TS-Me-*cis-endo*	2.206	2.165	0.041
TS-Me-*cis-exo*	2.105	2.316	0.211
TS-Me-*trans-endo*	2.147	2.187	0.040
TS-Me-*trans-exo*	2.135	2.230	0.095
TS-Ph-*cis-endo*	2.214	2.153	0.061
TS-Ph-*cis-exo*	2.105	2.311	0.206
TS-Ph-*trans-endo*	2.144	2.184	0.040
TS-Ph-*trans-exo*	2.132	2.229	0.097



Scheme 5.

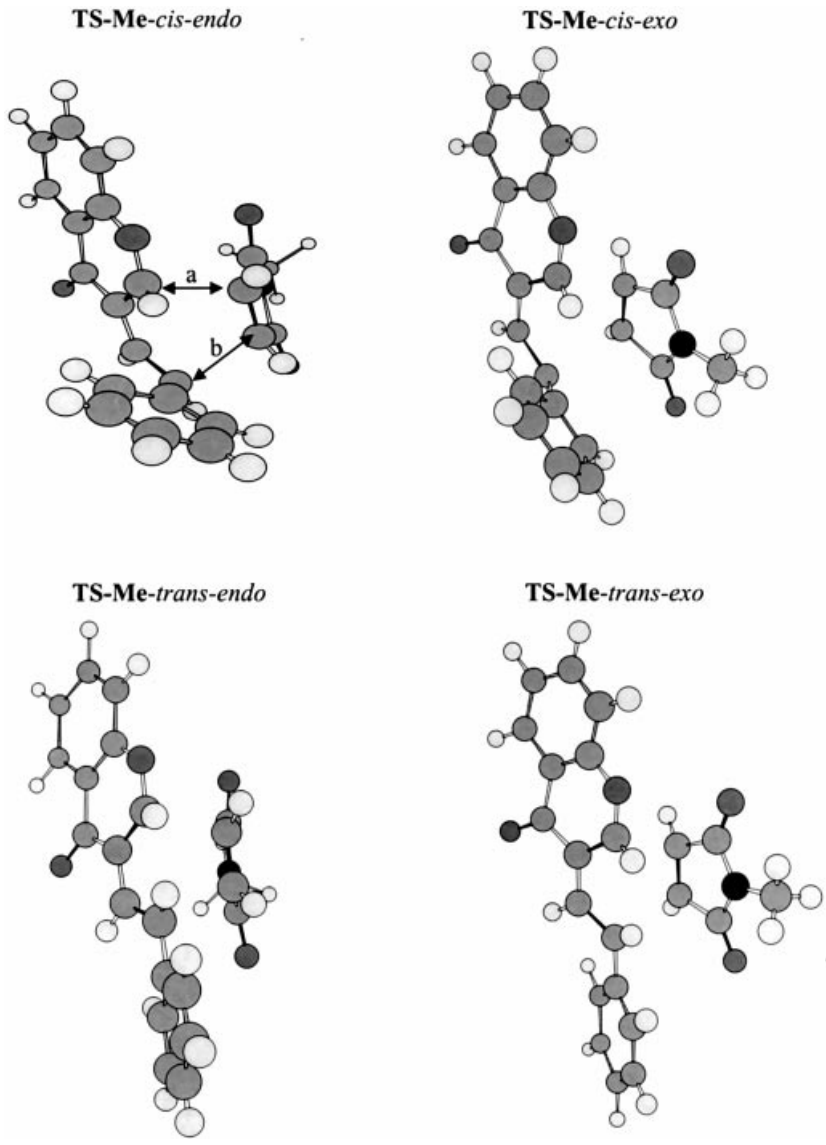


Figure 6. Transition structures found at the B3LYP/6-31G*//HF 6-31G* level of theory for the reaction of *N*-methylmaleimide (**2**) with dienes **1a** and **12a**.

states. Intrinsic reaction coordinate (IRC) calculations confirm that all TSs connected reactants with products. The corresponding energies of activation and reaction are shown in Tables 5, 6, 7 and 8.

The data in Tables 5, 6, 7 and 8 show that the *exo* cycloadducts formed from the reaction of (*E*)-3-styrylchromones with *N*-methylmaleimide (**2**) are the thermodynamically controlled products and, as a consequence, they should be the only products observed, in agreement with the experimental results. However, calculations show that the *endo* cycloadducts produced from (*Z*)-3-styrylchromones are the kinetically and thermodynamically controlled products and they should be formed exclusively, again in agreement with the experimental results, when *N*-methylmaleimide (**2**) is used as the dienophile. Similarly, the theoretical and experimental results for the reactions between (*E*)-3-styrylchromones and *N*-phenylmaleimide are in complete agreement, with *exo* adducts again being thermodynamically favoured. However, in the reaction of (*Z*)-3-styrylchromones with *N*-phenylmaleimide (**8**), cycloadducts **10a** (*endo-cis*) and **13a** (*exo-trans*) were formed. A tentative explanation for this can be found by considering the reaction conditions. Reactions with the highly reactive *N*-methylmaleimide (**2**) were performed at 160 °C while reactions with *N*-phenylmaleimide (**8**) required a temperature of 200 °C. Under the latter conditions, isomerisation of the (*Z*)-diene to the more stable (*E*)-diene could be induced by microwave irradiation. Calculations at the B3LYP/6-31G*//HF-31G* level of theory show that (*E*)-styrylchromone **12a** is 4.15 kcal mol^{-1} more stable than the (*Z*)-styrylchromone **1a**.

In conclusion, computational studies show that (*Z*)-3-styrylchromones produce *endo* cycloadducts (the kinetically and thermodynamically controlled products) while (*E*)-sty-

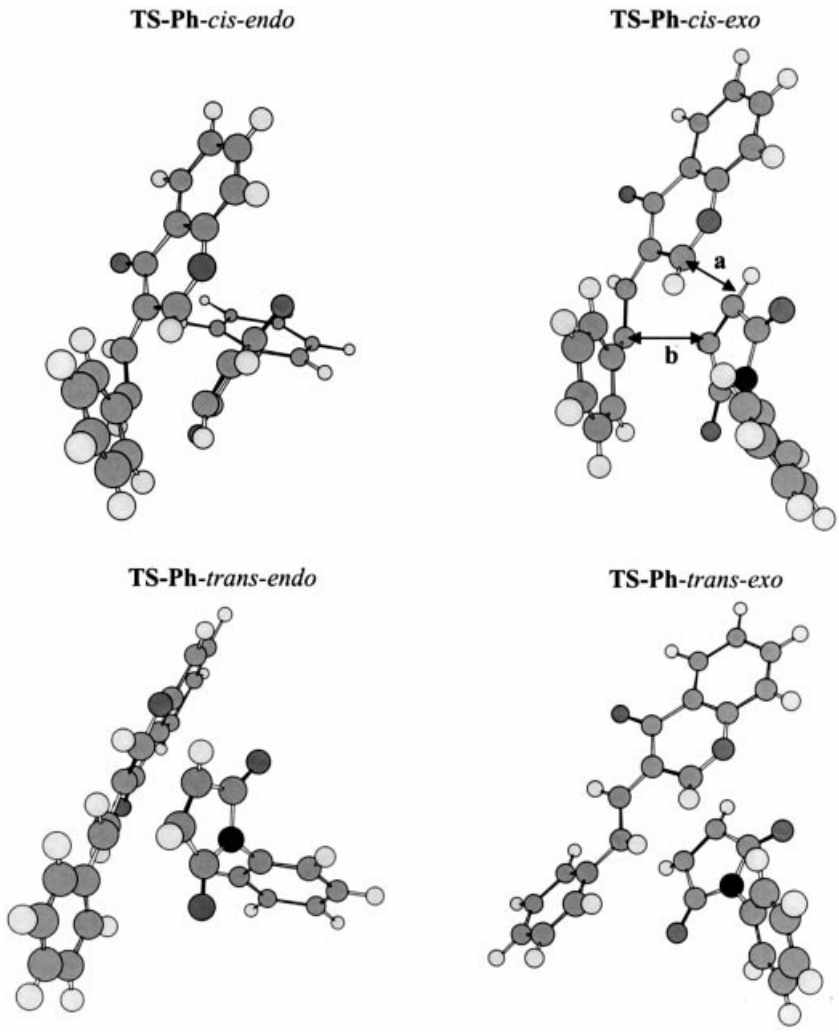
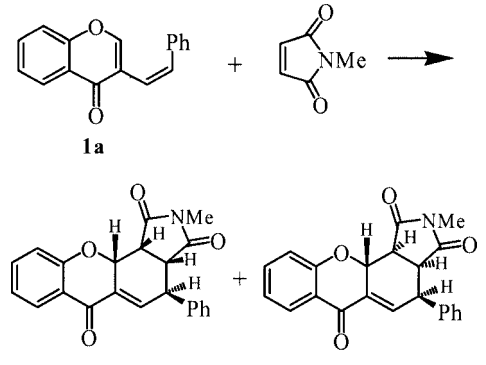


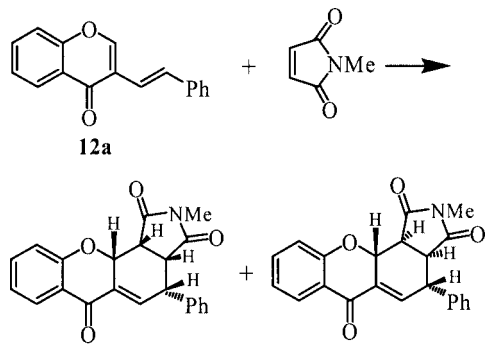
Figure 7. Transition structures found at the B3LYP/6-31G*//HF 6-31G* level of theory for the reaction of *N*-phenylmaleimide (**8**) with dienes **1a** and **12a**.

Table 5. Energies of activation (E_a, kcal mol^{-1}) and energies of reaction (ΔH, kcal mol^{-1}) for the reaction of **1a** with *N*-methylmaleimide (**2**).



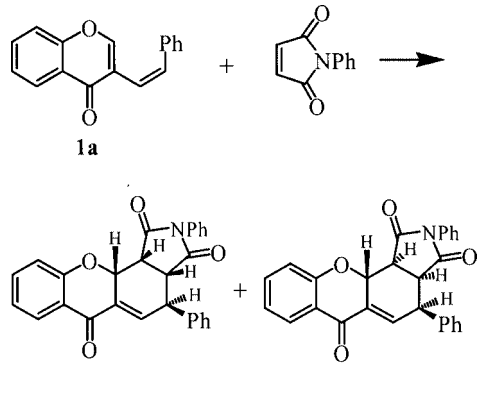
	E_a *endo*	E_a *exo*	ΔH *endo*	ΔH *exo*
HF/3-21G*	32.00	37.29	–33.14	–27.41
HF/6-31G*	46.30	50.70	–22.50	–18.60
B3LYP/631G*//HF/6-31G*	19.88	22.76	–24.68	–21.37

Table 6. Energies of activation (E_a, kcal mol^{-1}) and energies of reaction (ΔH, kcal mol^{-1}) for the reaction of **12a** with *N*-methylmaleimide (**2**).



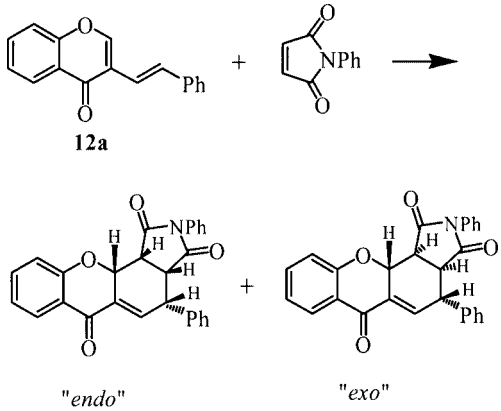
	E_a *endo*	E_a *exo*	ΔH *endo*	ΔH *exo*
HF/3-21G*	27.97	30.67	–27.28	–31.53
HF/6-31G*	42.54	44.03	–15.05	–20.92
B3LYP/631G*//HF/6-31G*	17.68	19.00	–16.80	–22.58

Table 7. Energies of activation (E_a, kcal mol^{-1}) and energies of reaction (ΔH, kcal mol^{-1}) for the reaction of **1a** with *N*-phenylmaleimides (**8**).



	E_a*endo*	E_a*exo*	ΔH *endo*	ΔH *exo*
HF/3-21G*	32.74	37.34	–32.91	–27.19
HF/6-31G*	46.39	50.81	–22.07	–18.03
B3LYP/631G*//HF/6-31G*	20.44	23.39	–23.76	–20.34

Table 8. Energies of activation (E_a, kcal mol^{-1}) and energies of reaction (ΔH, kcal mol^{-1}) for the reaction of **12a** with *N*-phenylmaleimides (**2**).



	E_a *endo*	E_a *exo*	ΔH *endo*	ΔH *exo*
HF/3-21G*	28.85	30.33	–25.91	–31.37
HF/6-31G*	42.61	44.23	–14.26	–20.31
B3LYP/631G*//HF/6-31G*	18.17	19.00	–17.56	–21.77

rylchromones produce *exo* cycloadducts (the thermodynamically controlled products). These conclusions are in complete agreement with the experimental results.

Conclusions

Diels–Alder cycloaddition reactions of 3-styrylchromones with *N*-methyl- and *N*-phenylmaleimide, as well as with other dienophiles, have been studied under classical heating conditions and under microwave irradiation. The use of microwave irradiation was found to give the corresponding cycloadducts in good yields. In some cases the resulting cycloadducts were oxidised to xanthones in situ, but in others it was necessary to add DDQ as an oxidant. These transformations have allowed novel xanthone-type compounds to be synthesised.

The cycloaddition reactions described herein were stereoselective; the (*Z*)-3-styrylchromones gave the *endo* cycloadducts while the (*E*) isomers gave the *exo* cycloadducts. These findings were supported by the experimental results and also by ab initio theoretical calculations, with the thermodynamically controlled product being formed in all cases. In the reaction of (*Z*)-3-styrylchromones with *N*-phenylmaleimide, it was found that (*Z*)–(*E*) isomerisation of the starting material was responsible for the observed result.

Experimental Section

General Remarks: Melting points were determined with a Reichert Thermovar apparatus fitted with a microscope and are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded with a Bruker Avance 300 spectrometer (at 300.13 and 75.47 MHz, respectively) in $CDCl_3$; chemical shifts (δ) are reported in ppm using TMS as an internal reference and coupling constants (*J*) are given in Hz. Percentage NOE enhancements were obtained by integrating the affected resonance relative to the irradiated resonance in the difference spectrum in each case (with an irradiation time of 2 s and a relaxation delay of 4 s). Unequivocal ^{1}H assignments were made with the aid of 2D *g*COSY and NOESY experiments (800 ms mixing time), while ^{13}C assignments were made through 2D *g*HSQC and *g*HMBC experiments (delays for one bond and long-range *J* C/H couplings were optimised for 145 and 7 Hz, respectively). Microwave irradiations were conducted in a focused microwave reactor (Prolabo MX350) with the power and temperature being measured and controlled by infrared detection. Mass spectra were obtained by using the electron impact method (EI, 70 eV) with VG Autospec Q and M spectrometers. Elemental analyses were determined on a CHNS-932 Leco apparatus. Column chromatography was carried out with silica gel, Merck type 60, 230–400 mesh. Preparative thin-layer chromatography was carried out with silica gel, Merck type 60 GF_{254}.

Computational Methods: All the computational results presented in this work were obtained with ab initio MO and DFT theories using the Gaussian 94[24] and Gaussian 98[25] programs with the standard 3-21G* and 6-31G* basis sets. Geometry optimisations of stationary points (minimum and transition structure search) were carried out at the Hartree–Fock (HF) level of theory. In larger systems electron correlation was expected to be critical in order to evaluate the reaction profile properly and, in these cases, we used density functional theory (DFT).[26] These calculations were carried out by means of the hybrid functional developed by Becke and Lee, Yang and Parr, which is customarily denoted as B3LYP.[27–29] Zero-point vibrational energies (ZPVE) were scaled by 0.89[30] when computed at the HF level. Stationary points were characterised by frequency calculations.[31] All reactants, intermediates and products have positive Hessian matrices. Transition structures (TSs) show only one negative eigenvalue in their diagonalised force constant matrices, and it was confirmed that their associated eigenvectors correspond to the motion along the reaction coordinate under consideration. Several reaction paths were checked by intrinsic reaction coordi-

nate (IRC) calculations.[32,33] All the calculations reported in this work were carried out in the gas phase.

Syntheses

3-Styrylchromones 1a–c/12a–c: Compounds **1a**–**c** and **12a**–**c** were prepared by Wittig reaction following a method reported previously.[10b]

Diels–Alder Reactions of (*Z*)-3-Styrylchromones 1a–c with *N*-Methylmaleimide (2) under Classical Heating Conditions: A mixture of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.7 mmol) and *N*-methylmaleimide (**2**) (116 mg, 1.1 mmol) in 1,2,4-trichlorobenzene (15 mL) was refluxed under nitrogen for 24 h. The reaction mixture was allowed to cool, the solvent was removed by column chromatography on silica gel using light petroleum and then the crude products were eluted with dichloromethane. The crude product in each case was purified by thin-layer chromatography on silica gel using dichloromethane as eluent. Two materials were eluted; the first consisted of tetrahydroxanthones **3a**–**c** [**3a** (76 mg, 40%), **3b** (57 mg, 40%), **3c** (52 mg, 19%)] and the second contained xanthones **4a**–**c** [**4a** (89 mg, 47%), **4b** (63 mg, 44%), **4c** (135 mg, 50%)].

When the reaction of (*Z*)-4′-chloro-2-styrylchromone (**3b**) was carried out for 48 h, three spots were obtained. The first one consisted of 4-(4-chlorophenyl)-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (**3b**) (27 mg, 10%), the second was 4-(4-chlorophenyl)-2-methyl-1,3-dioxopyrrolo[3,4-*c*]xanthone (**4b**) (108 mg, 40%) and the third 4-(4-chlorophenyl)-6-(2-hydroxybenzoyl)-2-methylisoindole-1,3-dione (**5b**) (62 mg, 23%).

2-Methyl-1,3-dioxo-4-phenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]-xanthone (3a): M.p. 159–160 °C (recrystallisation from cyclohexane/ethyl acetate). ^{1}H NMR: δ = 2.99 (s, 3 H, 2-CH_3), 3.48 (br. d, J = 8.6 Hz, 1 H, 3a-H), 3.82 (t, J = 8.6 Hz, 1 H, 11b-H), 4.64 (br. d, J = 7.0 Hz, 1 H, 4-H), 5.36 (ddd, J = 8.6, 3.0, 1.0 Hz, 1 H, 11a-H), 7.03 (dd, J = 8.2, 1.0 Hz, 1 H, 10-H), 7.06 (ddd, J = 7.7, 7.6, 1.0 Hz, 1 H, 8-H), 7.18–7.22 (m, 2 H, 2′,6′-H), 7.28–7.37 (m, 3 H, 3′,4′,5′-H), 7.40 (ddd, J = 7.0, 3.0, 0.6 Hz, 1 H, 5-H), 7.51 (ddd, J = 8.2, 7.6, 1.8 Hz, 1 H, 9-H), 7.93 (dd, J = 7.7, 1.8 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 25.3 (2-CH_3), 39.2 (C-4), 43.5 (C-11b), 44.7 (C-3a), 71.1 (C-11a), 118.2 (C-10), 120.4 (C-6a), 122.2 (C-8), 127.0 (C-2′,6′), 127.5 (C-7), 127.7 (C-4′), 129.2 (C-3′,5′), 132.8 (C-5a), 136.4 (C-9), 136.9 (C-5), 137.8 (C-1′), 160.2 (C-10a), 173.7 (C-1), 177.1 (C-3), 178.9 (C-6) ppm. MS (EI): *m*/*z* (%) = 359 (100) $[M]^{+\cdot}$, 273 (60), 268 (49), 247 (50), 215 (7), 197 (30), 183 (19), 171 (12), 152 (37), 139 (10), 128 (19), 121 (51), 115 (19), 92 (28), 77 (32), 63 (26). $C_{22}H_{17}NO_4$ (359.38): calcd. C 73.53, H 4.77, N 3.90; found C 73.66, H 4.74, N 3.56.

4-(4-Chlorophenyl)-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (3b): M.p. 112–113 °C (recrystallisation from cyclohexane/ethyl acetate). ^{1}H NMR: δ = 2.98 (s, 3 H, 2-CH_3), 3.43 (br. d, J = 8.6 Hz, 1 H, 3a-H), 3.81 (t, J = 8.6 Hz, 1 H, 11b-H), 4.60 (br. d, J = 7.0 Hz, 1 H, 4-H), 5.33 (ddd, J = 8.6, 3.0, 0.9 Hz, 1 H, 11a-H), 7.02 (dd, J = 8.0, 0.8 Hz, 1 H, 10-H), 7.06 (ddd, J = 7.9, 7.3, 0.8 Hz, 1 H, 8-H), 7.14 (d, J = 8.4 Hz, 2 H, 3′,5′-H), 7.31 (d, J = 8.4 Hz, 2 H, 2′,6′-H), 7.34 (ddd, J = 7.0, 3.0, 0.6 Hz, 1 H, 5-H), 7.51 (ddd, J = 8.0, 7.3, 1.7 Hz, 1 H, 9-H), 7.91 (dd, J = 7.9, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 25.3 (2-CH_3), 38.5 (C-4), 43.3 (C-11b), 44.7 (C-3a), 70.9 (C-11a), 118.1 (C-10), 120.3 (C-6a), 122.3 (C-8), 127.5 (C-7), 128.3 (C-2′,6′), 129.3 (C-3′,5′), 133.1 (C-5a), 133.5 (C-4′), 136.1 (C-5), 136.4 (C-1′), 136.5 (C-9), 160.1 (C-10a), 173.5 (C-1), 176.8 (C-3), 178.8 (C-6) ppm. MS (EI): *m*/*z* (%) = 393 (100) $[M]^{+\cdot}$, 307 (50), 281 (60), 268 (43), 247 (7), 215 (14), 197 (27), 188 (25), 152 (45), 136 (11), 121 (64), 92 (20), 77 (11), 63 (14). $C_{22}H_{16}NClO_4$ (393.82): calcd. C 67.10, H 4.10, N 3.56; found C 67.36, H 4.25, N 3.45.

4-(4-Ethoxyphenyl)-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (3c): M.p. 124–125 °C (recrystallisation from cyclohexane/ethyl acetate). ^{1}H NMR: δ = 1.40 (t, J = 7.0 Hz, 3 H, 4′-OCH_2CH_3), 2.99 (s, 3 H, 2-CH_3), 3.44 (br. d, J = 8.6 Hz, 1 H, 3a-H), 3.81 (t, J = 8.6 Hz, 1 H, 11b-H), 4.00 (q, J = 7.0 Hz, 2 H, 4′-OCH_2CH_3), 4.58 (br. d, J = 7.0 Hz, 1 H, 4-H), 5.37 (ddd, J = 8.6, 3.0, 1.0 Hz, 1 H, 11a-H), 6.85 (d, J = 8.6 Hz, 2 H, 3′,5′-H), 7.04 (br. d, J = 8.2 Hz, 1 H, 10-H), 7.06 (ddd, J = 7.7, 7.6, 1.1 Hz, 1 H, 8-H), 7.10 (d, J = 8.6 Hz, 2 H, 2′,6′-H), 7.38 (ddd, J = 7.0, 3.0, 0.6 Hz, 1 H, 5-H), 7.51 (ddd, J = 8.2, 7.6, 1.7 Hz, 1 H, 9-H), 7.93 (dd, J = 7.7, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 14.7 (4′-OCH_2CH_3), 25.3 (2-CH_3), 38.5 (C-4), 43.6 (C-11b), 45.0 (C-3a), 63.5 (4′-OCH_2CH_3), 71.1 (C-11a), 115.1 (C-3′,5′), 118.1 (C-10), 120.4 (C-6a), 122.2 (C-8), 127.5 (C-7), 128.0 (C-2′,6′), 129.3 (C-1′), 132.5 (C-5a), 136.4 (C-9), 137.3 (C-5), 158.3 (C-4′), 160.2 (C-10a), 173.8 (C-1), 177.1 (C-3), 178.9 (C-6) ppm. MS (EI): *m*/*z* (%) = 403 (100) $[M]^{+\cdot}$, 371 (7), 317 (17), 292 (22), 289 (20), 281 (23), 263 (21), 244 (24), 196 (25), 170 (10), 135 (15), 122 (38), 94 (12), 77 (6), 63 (7). $C_{24}H_{21}NO_5$ (403.43): calcd. C 71.45, H 5.25, N 3.47; found C 71.33, H 5.67, N 3.43.

2-Methyl-1,3-dioxo-4-phenylpyrrolo[3,4-*c*]xanthone (4a): M.p. 268–270 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.21 (s, 3 H, 2-CH_3), 7.45–7.52 (m, 4 H, 3-H, 3′,5′-H and 8-H), 7.57–7.60 (m, 2 H, 2′,6′-H), 7.73 (dd, J = 8.4, 0.8 Hz, 1 H, 10-H), 7.84 (ddd, J = 8.4, 7.0, 1.6 Hz, 1 H, 9-H), 8.36 (dd, J = 8.0, 1.6 Hz, 1 H, 7-H), 8.62 (s, 1 H, 5-H) ppm. ^{13}C NMR: δ = 24.2 (2-CH_3), 118.7 (C-10), 120.0 (C-5a), 121.7 (C-6a), 125.2 (C-8), 126.2 (C-11b), 126.9 (C-7), 128.2 (C-3′,5′), 128.9 (C-4′), 129.5 (C-2′,6′), 133.4 (C-3a), 135.0 (C-1′), 135.8 (C-5), 135.9 (C-4), 136.0 (C-9), 150.4 (C-11a), 156.0 (C-10a), 165.0 (C-1), 166.6 (C-3), 175.6 (C-6) ppm. MS (EI): *m*/*z* (%) = 355 (100) $[M]^{+\cdot}$, 356 (29), 296 (6), 283 (4), 270 (7), 213 (8), 178 (8). $C_{22}H_{13}NO_4$ (355.43): calcd. C 74.36, H 3.69, N 3.94; found C 74.65, H 3.62, N 4.19.

4-(4-Chlorophenyl)-2-methyl-1,3-dioxopyrrolo[3,4-*c*]xanthone (4b): M.p. > 300 °C (recrystallisation from ethanol). ^{1}H NMR (500.13 MHz): δ = 3.21 (s, 3 H, 2-CH_3), 7.46–7.50 (m, 1 H, 8-H), 7.47 (d, J = 8.6 Hz, 2 H, 3′,5′-H), 7.52 (d, J = 8.6 Hz, 2 H, 2′,6′-H), 7.74 (d, J = 8.1 Hz, 1 H, 10-H), 7.84 (ddd, J = 8.1, 7.8, 1.7 Hz, 1 H, 9-H), 8.36 (dd, J = 8.0, 1.7 Hz, 1 H, 7-H), 8.59 (s, 1 H, 5-H) ppm. ^{13}C NMR (125.76 MHz): δ = 24.2 (2-CH_3), 118.8 (C-10), 120.2 (C-5a), 121.8 (C-6a), 125.3 (C-8), 126.4 (C-11b), 127.0 (C-7), 128.5 (C-3′,5′), 130.9 (C-2′,6′), 133.5 (C-3a,4′), 134.6 (C-4), 135.2 (C-1′), 135.6 (C-5), 136.2 (C-9), 150.6 (C-11a), 156.0 (C-10a), 164.9 (C-1), 166.6 (C-3), 175.6 (C-6) ppm. MS (EI): *m*/*z* (%) = 389 (100) $[M]^{+\cdot}$, 388 (17), 330 (9), 304 (10), 276 (7), 213 (28), 187 (5), 137 (6), 92 (10), 77 (8). $C_{22}H_{12}NClO_4$ (389.79): calcd. C 67.79, H 3.10, N 3.59; found C 67.61, H 3.24, N 3.94.

4-(4-Ethoxyphenyl)-2-methyl-1,3-dioxopyrrolo[3,4-*c*]xanthone (4c): M.p. 279–280 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.47 (t, J = 7.0 Hz, 3 H, 4′-OCH_2CH_3), 3.21 (s, 3 H, 2-CH_3), 4.12 (q, J = 7.0 Hz, 2 H, 4′-OCH_2CH_3), 7.47 (ddd, J = 7.7, 7.6, 1.0 Hz, 1 H, 8-H), 7.01 (d, J = 8.8 Hz, 2 H, 3′,5′-H), 7.53 (d, J = 8.8 Hz, 2 H, 2′,6′-H), 7.73 (dd, J = 8.1, 1.0 Hz, 1 H, 10-H), 7.84 (ddd, J = 8.1, 7.6, 1.6 Hz, 1 H, 9-H), 8.36 (dd, J = 7.7, 1.6 Hz, 1 H, 7-H), 8.60 (s, 1 H, 5-H) ppm. ^{13}C NMR: δ = 14.9 (4′-OCH_2CH_3), 24.2 (2-CH_3), 63.5 (4′-OCH_2CH_3), 114.2 (C-3′,5′), 118.8 (C-10), 120.0 (C-5a), 121.7 (C-6a), 125.1 (C-8), 126.2 (C-11b), 126.9 (C-7), 127.1 (C-4), 130.9 (C-2′,6′), 133.1 (C-3a), 135.9 (C-1′), 135.7 (C-5), 136.0 (C-9), 150.1 (C-11a), 156.1 (C-10a), 159.6 (C-4′), 165.1 (C-1), 166.8 (C-3), 175.7 (C-6) ppm. MS (EI): *m*/*z* (%) = 399 (100) $[M]^{+\cdot}$, 371

(66), 342 (8), 312 (3), 286 (7), 257 (3), 229 (5), 200 (4), 185 (5), 92 (1), 77 (2). $C_{24}H_{17}NO_5$ (399.40): calcd. C 72.17, H 4.29, N 3.51; found C 71.83, H 4.19, N 3.50.

4-(4-Chlorophenyl)-6-(2-hydroxybenzoyl)-2-methylisoindole-1,3-dione (5b): M.p. 178–180 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.21 (s, 3 H, 2-CH_3), 6.92 (ddd, J = 8.1, 7.2, 1.0 Hz, 1 H, 5′′-H), 7.12 (dd, J = 8.5, 1.0 Hz, 1 H, 3′′-H), 7.47 (d, J = 8.6 Hz, 2 H, 3′,5′-H), 7.51–7.53 (m, 1 H, 6′′-H), 7.54 (d, J = 8.6 Hz, 2 H, 2′,6′-H), 7.58 (ddd, J = 8.5, 7.2, 1.5 Hz, 1 H, 4′′-H), 7.90 (d, J = 1.4 Hz, 1 H, 5-H), 8.09 (d, J = 1.4 Hz, 1 H, 7-H), 11.76 (s, 1 H, 2′′-OH) ppm. ^{13}C NMR: δ = 24.2 (2-CH_3), 118.4 (C-1′′), 118.9 (C-3′′), 119.3 (C-5′′), 122.3 (C-7), 128.6 (C-3′,5′), 129.6 (C-3a), 130.7 (C-2′,6′), 132.9 (C-6′′), 133.46 and 133.51 (C-1′ and C-6), 135.6 (C-4′), 136.0 (C-5), 137.4 (C-4′′), 140.0 (C-4), 143.0 (C-7a), 163.5 (C-2′′), 166.95 and 167.01 (C-1 and C-3), 199.1 (C=O) ppm. MS (EI): m/z (%) = 391 (100) $[M]^{+\cdot}$, 390 (43), 362 (7), 316 (24), 314 (60), 308 (15), 306 (42), 264 (10), 213 (7), 179 (19), 157 (16), 155 (46), 151 (13), 150 (41), 127 (9), 99 (12). EI-HRMS ($C_{22}H_{14}N^{35}ClO_4$): calcd. 391.0611, found 391.0601; ($C_{22}H_{14}N^{37}ClO_4$): calcd. 393.0582, found 393.0589.

Diels–Alder Reactions of (*Z*)-3-Styrylchromones 1a–c with *N*-Methylmaleimide (2) under Microwave Irradiation: A mixture of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.8 mmol) and *N*-methylmaleimide (**2**) (358 mg, 3.1 mmol) was irradiated at atmospheric pressure in a focused microwave reactor (270 W for 30 min; final temperature 160 °C). The crude product was purified by flash chromatography on silica gel using 3:1 or 4:1 mixtures of hexane/ethyl acetate as eluent. The resulting residue was crystallised from cyclohexane/ethyl acetate to give the expected 4-aryl-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthones **3a**–**c** [**3a** (218 mg, 76%), **3b** (236 mg, 75%), **3c** (248 mg, 77%)].

Diels–Alder Reactions of (*Z*)-3-Styrylchromones 1a–c with 2-(2-Nitrovinyl)thiophene (6) under Microwave Irradiation: Reaction of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.7 mmol) and 2-(2-nitrovinyl)thiophene (**6**) (163 mg, 1.0 mmol) using the same conditions as described, above apart from the final temperature (200 °C) for (*Z*)-3-styrylchromones **1a**,**b**, yielded 2-aryl-3-(2-thienyl)xanthones **7a**–**c** after purification by preparative thin-layer chromatography using a 3:1 mixture of hexane/dichloromethane as eluent.

2-Phenyl-3-(2-thienyl)xanthone (7a): Yield 72% (134 mg). M.p. 153–154 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 6.81 (dd, J = 3.6, 1.2 Hz, 1 H, 3′′-H), 6.92 (dd, J = 5.0, 3.6 Hz, 1 H, 4′′-H), 7.27–7.32 (m, 3 H, 2′,6′,5′′-H), 7.32–7.36 (m, 3 H, 3′,4′,5′-H), 7.40 (ddd, J = 7.4, 8.0, 0.9 Hz, 1 H, 8-H), 7.53 (br. d, J = 8.0 Hz, 1 H, 6-H), 7.70 (s, 1 H, 4-H), 7.75 (ddd, J = 8.0, 7.4, 1.8 Hz, 1 H, 7-H), 8.30 (s, 1 H, 1-H), 8.36 (dd, J = 8.0, 1.8 Hz, 1 H, 9-H) ppm. ^{13}C NMR: δ = 118.0 (C-6), 118.9 (C-4), 120.5 (C-10a), 122.0 (C-9a), 124.0 (C-8), 126.8 (C-9), 127.2 (C-5′′), 127.3 (C-4′′), 127.4 (C-4′), 128.2 (C-2′,6′), 128.4 (C-3′′), 128.7 (C-1), 129.8 (C-3′,5′), 134.9 (C-7), 136.9 (C-2), 139.9 (C-1′), 140.1 (C-3), 141.3 (C-2′′), 155.2 (C-4a), 156.3 (C-5a), 176.8 (C-10) ppm. MS (EI): m/z (%) = 354 (100) $[M]^{+\cdot}$, 353 (41), 339 (10), 321 (41), 309 (10), 292 (16), 263 (11), 234 (6), 189 (6), 177 (11), 161 (4), 121 (4), 77 (2). $C_{23}H_{14}SO_2$ (354.42): calcd. C 77.94, H 3.98; found C 77.81, H 4.16.

2-(4-Chlorophenyl)-3-(2-thienyl)xanthone (7b): Yield 68% (162 mg). M.p. 163–164 °C (recrystallisation from ethanol). ^{1}H NMR (500.13 MHz): δ = 6.82 (dd, J = 3.7, 1.1 Hz, 1 H, 3′′-H), 6.96 (dd, J = 5.2, 3.7 Hz, 1 H, 4′′-H), 7.23 (d, J = 8.4 Hz, 2 H, 2′,6′-H), 7.32 (d, J = 8.4 Hz, 2 H, 3′,5′-H), 7.33 (dd, J = 5.2, 1.1 Hz, 1 H, 5′′-H), 7.42 (ddd, J = 7.8, 7.6, 0.8 Hz, 1 H, 8-H), 7.54 (br. d, J = 8.0 Hz, 1 H, 6-H), 7.70 (s, 1 H, 4-H), 7.77 (ddd, J = 8.0, 7.6, 1.6 Hz, 1 H, 7-H), 8.27 (s, 1 H, 1-H), 8.36 (dd, J = 7.8, 1.67 Hz, 1 H, 9-H) ppm. ^{13}C NMR (125.76 MHz): δ = 118.0 (C-6), 119.2 (C-4), 120.6 (C-10a), 122.0 (C-9a), 124.2 (C-8), 126.8 (C-9), 127.4 (C-5′′), 127.5 (C-4′′), 128.5 (C-3′,5′), 128.5 (C-3′′), 128.6 (C-1), 131.1 (C-2′,6′), 133.6 (C-4′), 135.0 (C-7), 135.7 (C-2), 138.4 (C-1′), 140.0 (C-3), 140.9 (C-2′′), 155.3 (C-4a), 156.3 (C-5a), 176.7 (C-10) ppm. MS (EI): m/z (%) = 388 (100) $[M]^{+\cdot}$, 387 (14), 353 (29), 320 (14), 295 (11), 292 (10), 279 (6), 263 (8), 177 (22), 162 (8), 148 (5), 121 (7), 77 (4). $C_{23}H_{13}SClO_2$ (388.87): calcd. C 71.04, H 3.37; found C 71.13, H 3.50.

2-(4-Ethoxyphenyl)-3-(2-thienyl)xanthone (7c): Yield 75% (178 mg). M.p. 138–140 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.44 (t, J = 7.0 Hz, 3 H, 4′-OCH_2CH_3), 4.06 (q, J = 7.0 Hz, 2 H, 4′-OCH_2CH_3), 6.86 (dd, J = 3.7, 1.1 Hz, 1 H, 3′′-H), 6.86 (d, J = 8.7 Hz, 2 H, 3′,5′-H), 6.93 (dd, J = 5.1, 3.7 Hz, 1 H, 4′′-H), 7.19 (d, J = 8.7 Hz, 2 H, 2′,6′-H), 7.30 (dd, J = 5.1, 1.1 Hz, 1 H, 5′′-H), 7.39 (ddd, J = 8.0, 7.4, 1.0 Hz, 1 H, 8-H), 7.51 (br. d, J = 7.9 Hz, 1 H, 6-H), 7.68 (s, 1 H, 4-H), 7.74 (ddd, J = 7.9, 7.4, 1.7 Hz, 1 H, 7-H), 8.27 (s, 1 H, H-1), 8.35 (dd, J = 8.0, 1.7 Hz, 1 H, 9-H) ppm. ^{13}C NMR: δ = 14.8 (4′-OCH_2CH_3), 63.4 (4′-OCH_2CH_3), 114.2 (C-3′,5′), 118.0 (C-6), 118.8 (C-4), 120.5 (C-10a), 122.0 (C-9a), 124.0 (C-8), 126.8 (C-9), 127.2 (C-5′′), 127.3 (C-4′′), 128.3 (C-3′′), 128.6 (C-1), 130.9 (C-2′,6′), 132.1 (C-1′), 134.8 (C-7), 136.7 (C-2), 140.2 (C-3), 141.5 (C-2′′), 155.0 (C-4a), 156.3 (C-5a), 158.5 (C-4′), 176.8 (C-10) ppm. MS (EI): m/z (%) = 398 (100) $[M]^{+\cdot}$, 369 (23), 353 (7), 341 (11), 337 (15), 311 (10), 279 (6), 250 (5), 221 (4), 149 (4), 121 (5), 83 (5), 63 (4). $C_{25}H_{18}SO_3$ (398.48): calcd. C 75.35, H 4.55; found C 75.61, H 4.27.

Diels–Alder Reactions of (*Z*)-3-Styrylchromones 1a–c with *N*-Phenylmaleimide (8) under Microwave Irradiation: Reaction of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.8 mmol) and *N*-phenylmaleimide (**8**) (419 mg, 2.4 mmol) using the same conditions as described above, apart from the final temperature (200 °C) for (*Z*)-3-styrylchromones **1a**,**b**, yielded a mixture of compounds. The residue was purified in each case by flash chromatography using a 4:1 or 2:1 mixture of hexane/ethyl acetate to afford first the tetrahydroxanthones **10a**–**c** and then the tetrahydroxanthones **11a**–**c**.

The reaction of (*Z*)-4′-ethoxy-3-styrylchromone (**1c**) was performed using a final temperature of 160 °C since at 200 °C 4-(4-ethoxyphenyl)-6-(2-hydroxybenzoyl)-2-phenylisoindole-1,3-dione (**5c1**) was obtained.

1,3-Dioxo-2,4-diphenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (10a) and (11a): Data for **10a**: Yield 60% (202 mg). M.p. 173–174 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.61 (ddd, J = 8.5, 1.2, 0.8 Hz, 1 H, 3a-H), 3.93 (t, J = 8.5 Hz, 1 H, 11b-H), 4.73 (br. d, J = 6.7 Hz, 1 H, 4-H), 5.43 (ddd, J = 8.5, 2.5, 1.2 Hz, 1 H, 11a-H), 7.04 (dd, J = 7.8, 1.0 Hz, 1 H, 10-H), 7.10 (ddd, J = 7.7, 7.5, 1.0 Hz, 1 H, 8-H), 7.20–7.29 (m, 4 H, 2′,6′,2′′,6′′-H), 7.31–7.48 (m, 7 H, 5,3′,4′,5′,3′′,4′′,5′′-H), 7.52 (ddd, J = 7.8, 7.5, 1.8 Hz, 1 H, 9-H), 7.99 (dd, J = 7.7, 1.8 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 38.5 (C-4), 43.2 (C-11b), 45.5 (C-3a), 70.7 (C-11a), 118.2 (C-10), 121.1 (C-6a), 122.6 (C-8), 126.3 (C-2′′,6′′), 127.3 (C-2′,6′), 127.8 and/or 127.9 (C-7,4′), 128.8 (C-4′′), 129.3 (C-3′,5′), 129.4 (C-3′′,5′′), 131.7 (C-1′′), 132.7 (C-5a), 136.5 (C-9), 137.1 (C-5), 138.5 (C-1′), 160.3 (C-10a), 172.8 (C-1), 175.7 (C-3), 180.1 (C-6) ppm. MS (EI): m/z (%) = 421 (68) $[M]^{+\cdot}$, 330 (14), 301 (9), 273 (100), 247 (36), 215 (13), 197 (55), 183 (22), 171 (25), 152 (75), 139 (16), 131 (32), 121 (77), 110 (32), 103 (21), 91 (65), 77 (72), 64 (43). $C_{27}H_{19}NO_4$ (421.44): calcd. C 76.95, H 4.54, N 3.32; found C 77.06, H 4.40, N 3.30.

Data for 11a: Yield 21% (71 mg). M.p. 212–213 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.53 (dt, J = 3.1, 2.3 Hz, 1 H, 4-H), 3.58 (dd, J = 8.5, 3.1 Hz, 1 H, 11b-H), 4.42 (ddd, J = 8.5,

3.1, 2.3 Hz, 1 H, 3a-H), 5.28 (dt, *J* = 3.1, 1.3 Hz, 1 H, 11a-H), 5.81 (dt, *J* = 2.3, 1.3 Hz, 1 H, 5-H), 6.87 (dd, *J* = 8.4, 0.9 Hz, 1 H, 10-H), 7.10 (ddd, *J* = 7.7, 7.5, 0.9 Hz, 1 H, 8-H), 7.31–7.43 (m, 8 H, 2′,3′,4′,5′,6′,2′′,4′′,6′′-H), 7.47–7.54 (m, 3 H, 9,3′′,5′′-H), 7.96 (dd, *J* = 7.7, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 40.1 (C-3a), 44.3 (C-11b), 47.9 (C-4), 73.0 (C-11a), 118.1 (C-10), 119.5 (C-5), 119.9 (C-6a), 122.6 (C-8), 126.4 (C-2′,4′,6′), 127.6 (C-7), 128.4 (C-2′′,6′′), 128.3 (C-3′,5′), 128.7 (C-4′′), 129.2 (C-3′′,5′′), 131.8 (C-1′′), 135.5 (C-5a), 136.8 (C-9), 138.8 (C-1′), 159.5 (C-10a), 173.2 (C-1), 174.3 (C-3), 190.7 (C-6) ppm. MS (EI): *m*/*z* (%) = 421 (6) $[M]^{+\cdot}$, 301 (17), 273 (4), 154 (100), 120 (20), 92 (23), 77 (6), 64 (6). $C_{27}H_{19}NO_4$ (421.44): calcd. C 76.95, H 4.54, N 3.32; found C 76.94, H 4.89, N 3.25.

4-(4-Chlorophenyl)-1,3-dioxo-2-phenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (10b) and (11b): Data for **10b**: Yield 51% (185 mg). M.p. 185–186 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.54 (br. d, *J* = 8.8 Hz, 1 H, 3a-H), 3.90 (t, *J* = 8.8 Hz, 1 H, 11b-H), 4.70 (br. d, *J* = 6.5 Hz, 1 H, 4-H), 5.41 (dd, *J* = 8.8, 2.4 Hz, 1 H, 11a-H), 7.35 (d, *J* = 8.4 Hz, 2 H, 3′,5′-H), 7.05 (br. d, *J* = 8.1 Hz, 1 H, 10-H), 7.11 (dt, *J* = 7.7, 0.8 Hz, 1 H, 8-H), 7.17 (d, *J* = 8.4 Hz, 2 H, 2′,6′-H), 7.25–7.28 (m, 2 H, 2′′,6′′-H), 7.35 (dd, *J* = 6.5, 2.4 Hz, 1 H, 5-H), 7.39–7.49 (m, 3 H, 3′′,4′′,5′′-H), 7.53 (ddd, *J* = 8.1, 7.7, 1.7 Hz, 1 H, 9-H), 7.99 (dd, *J* = 7.7, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 37.9 (C-4), 43.0 (C-11b), 45.5 (C-3a), 70.5 (C-11a), 118.2 (C-10), 121.0 (C-6a), 122.7 (C-8), 126.3 (C-2′′,6′′), 128.7 (C-2′,6′), 127.9 (C-7), 133.9 (C-4′), 128.9 (C-4′′), 129.6 (C-3′,5′), 129.3 (C-3′′,5′′), 131.6 (C-1′′), 133.0 (C-5a), 136.6 (C-9), 136.3 (C-5), 134.2 (C-1′), 160.3 (C-10a), 172.5 (C-1), 175.5 (C-3), 180.0 (C-6) ppm. MS (EI): *m*/*z* (%) = 455 (50) ($[M]^{+\cdot}$, ^{35}Cl), 453 (30), 335 (20), 307 (21), 281 (12), 215 (10), 199 (11), 188 (60), 152 (32), 121 (100), 92 (26), 77 (19), 65 (21). EI-HRMS ($C_{27}H_{18}N_{14}O_4{}^{35}Cl$): calcd. 455.0924, found 455.0924; ($C_{27}H_{18}N_{14}O_4{}^{37}Cl$): calcd. 457.0895, found 457.0911.

Data for 11b: Yield 20% (72 mg). M.p. 214–216 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.52 (dt, *J* = 3.1, 2.3 Hz, 1 H, 4-H), 3.57 (dd, *J* = 8.6, 3.1 Hz, 1 H, 11b-H), 4.36 (ddd, *J* = 8.6, 3.1, 2.3 Hz, 1 H, 3a-H), 5.27 (dt, *J* = 3.1, 1.2 Hz, 1 H, 11a-H), 5.80 (dt, *J* = 2.3, 1.2 Hz, 1 H, 5-H), 6.85 (dd, *J* = 8.0, 0.9 Hz, 1 H, 10-H), 7.11 (ddd, *J* = 8.1, 7.2, 0.9 Hz, 1 H, 8-H), 7.29–7.32 (m, 4 H, 2′,3′,5′,6′-H), 7.36–7.44 (m, 3 H, 2′′,4′′,6′′-H), 7.47–7.55 (m, 3 H, 9,3′′,5′′-H), 7.96 (dd, *J* = 8.1, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 40.0 (C-3a), 44.2 (C-11b), 47.8 (C-4), 72.9 (11a), 118.1 (C-10), 120.1 (C-5), 119.8 (C-6a), 122.7 (C-8), 126.3 (C-2′′, 6′′), 127.6 (C-7), 127.7 (C-2′,6′), 128.6 (C-3′,5′), 128.8 (C-4′′), 129.2 (C-3′′,5′′), 131.6 (C-1′′), 134.2 (C-4′), 134.4 (C-5a), 136.9 (C-9), 137.2 (C-1′), 159.4 (C-10a), 173.2 (C-1), 174.1 (C-3), 190.4 (C-6) ppm. MS (EI): *m*/*z* (%) = 455 (55) ($[M]^{+\cdot}$, ^{35}Cl), 454 (36), 453 (86), 439 (46), 408 (8), 380 (7), 342 (32), 335 (49), 318 (13), 306 (26), 290 (31), 255 (9), 213 (8), 188 (83), 152 (18), 121 (100), 93 (15), 77 (24), 65 (20). $C_{27}H_{18}NClO_4$ (455.89): calcd. C 71.13, H 3.98, N 3.07; found C 71.21, H 3.95, N 3.07.

4-(4-Ethoxyphenyl)-1,3-dioxo-2-phenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (10c) and (11c): Data for **10c**: Yield 54% (200 mg). M.p. 173–175 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.41 (t, *J* = 7.0 Hz, 3 H, 4′-OCH$_2$C*H*$_3$), 3.57 (ddd, *J* = 8.5, 1.3, 0.7 Hz, 1 H, 3a-H), 3.92 (t, *J* = 8.5 Hz, 1 H, 11b-H), 4.02 (q, *J* = 7.0 Hz, 2 H, 4′-OC*H*$_2$CH$_3$), 4.66 (br. d, *J* = 6.6 Hz, 1 H, 4-H), 5.43 (ddd, *J* = 8.5, 2.5, 1.3 Hz, 1 H, 11a-H), 6.88 (d, *J* = 8.7 Hz, 2 H, 3′,5′-H), 7.05 (dd, *J* = 7.9, 0.9 Hz, 1 H, 10-H), 7.10 (ddd, *J* = 8.0, 7.3, 0.9 Hz, 1 H, 8-H), 7.12 (d, *J* = 8.7 Hz, 2 H, 2′,6′-H), 7.25–7.28 (m, 2 H, 2′′,6′′-H), 7.37–7.48 (m, 4 H, 5,3′′,4′′,5′′-H), 7.52 (ddd, *J* = 7.9, 7.3, 1.7 Hz, 1 H, 9-H), 7.99 (dd, *J* = 8.0, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 14.8 (4′-OCH$_2$*C*H$_3$), 37.8 (C-4), 43.2 (C-11b), 45.8 (C-3a), 63.6 (4′-O*C*H$_2$CH$_3$), 70.7 (C-11a), 115.3 (C-3′,5′), 118.2 (C-10), 121.1 (C-6a), 122.6 (C-8), 126.3 (C-2′′,6′′), 127.8 (C-7), 128.3 (C-2′,6′), 128.8 (C-4′′), 129.2 (C-3′′,5′′), 130.1 (C-1′), 131.7 (C-1′′), 132.3 (C-5a), 136.4 (C-9), 137.5 (C-5), 158.6 (C-4′), 160.3 (C-10a), 172.9 (C-1), 175.8 (C-3), 180.2 (C-6) ppm. MS (EI): *m*/*z* (%) = 465 (100) $[M]^{+\cdot}$, 463 (15), 345 (18), 317 (22), 291 (14), 263 (6), 196 (9), 170 (11), 159 (6), 121 (17), 92 (8), 77 (7), 65 (7). EI-HRMS ($C_{29}H_{23}N_{14}O_5$): calcd. 465.1576, found 465.1559.

Data for 11c: Yield 15% (56 mg). M.p. 214–216 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.39 (t, *J* = 7.0 Hz, 3 H, 4′-OCH$_2$C*H*$_3$), 3.51 (dt, *J* = 3.0, 2.4 Hz, 1 H, 4-H), 3.55 (dd, *J* = 8.5, 3.0 Hz, 1 H, 11b-H), 4.01 (q, *J* = 7.0 Hz, 2 H, 4′-OC*H*$_2$CH$_3$), 4.37 (ddd, *J* = 8.5, 3.0, 2.4 Hz, 1 H, 3a-H), 5.25 (dt, *J* = 3.0, 1.2 Hz, 1 H, 11a-H), 5.73 (dt, *J* = 2.4, 1.2 Hz, 1 H, 5-H), 6.84 (dd, *J* = 8.2, 1.0 Hz, 1 H, 10-H), 6.84 (d, *J* = 8.9 Hz, 2 H, 3′,5′-H), 7.09 (ddd, *J* = 7.8, 7.2, 1.0 Hz, 1 H, 8-H), 7.31 (d, *J* = 8.9 Hz, 4 H, 2′,6′-H), 7.37–7.43 (m, 3 H, 2′′,4′′,6′′-H), 7.46–7.53 (m, 3 H, 9,3′′,5′′-H), 7.95 (dd, *J* = 7.8, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 14.8 (4′-OCH$_2$*C*H$_3$), 40.1 (C-3a), 44.4 (C-11b), 47.8 (C-4), 63.4 (4′-O*C*H$_2$CH$_3$), 73.1 (11a), 114.3 (C-3′,5′), 117.6 (C-5), 118.1 (C-10), 119.8 (C-6a), 122.5 (C-8), 126.4 (C-2′′, 6′′), 127.6 (C-7), 127.5 (C-2′,6′), 128.7 (C-4′′), 129.1 (C-3′′,5′′), 131.0 (C-1′), 131.8 (C-1′′), 134.7 (C-5a), 136.7 (C-9), 159.1 (C-4′), 159.5 (C-10a), 173.3 (C-1), 174.4 (C-3), 190.8 (C-6) ppm. MS (EI): *m*/*z* (%) = 465 (69) $[M]^{+\cdot}$, 463 (39), 345 (99), 317 (6), 288 (7), 198 (69), 170 (11), 170 (100), 141 (22), 121 (40), 92 (30), 77 (12), 65 (12). EI-HRMS ($C_{29}H_{23}N_{14}O_5$): calcd. 465.1576, found 465.1572.

4-(4-Ethoxyphenyl)-6-(2-hydroxybenzoyl)-2-phenylisoindole-1,3-dione (5c1): Yield 53% (195 mg). M.p. 175–176 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.44 (t, *J* = 7.0 Hz, 3 H, 4′′-OCH$_2$C*H*$_3$), 4.09 (q, *J* = 7.0 Hz, 2 H, 4′′-OC*H*$_2$CH$_3$), 6.93 (ddd, *J* = 7.6, 7.5, 0.8 Hz, 1 H, 5′-H), 6.99 (d, *J* = 8.8 Hz, 2 H, 3′′,5′′-H), 7.12 (dd, *J* = 8.3, 0.8 Hz, 1 H, 3′-H), 7.38–7.55 (m, 7 H, 4′,6′-H and 2-C$_6$H$_5$), 7.59 (d, *J* = 8.8 Hz, 2 H, 2′′,6′′-H), 7.98 (d, *J* = 1.4 Hz, 1 H, 5-H), 8.13 (d, *J* = 1.4 Hz, 1 H, 7-H), 11.82 (s, 1 H, 2′-OH) ppm. ^{13}C NMR: δ = 14.8 (4′′-OCH$_2$*C*H$_3$), 63.4 (4′′-O*C*H$_2$CH$_3$), 114.3 (C-3′′,5′′), 118.5 (C-1′), 118.9 (C-3′), 119.3 (C-5′), 121.9 (C-7), 126.6 (C-2,6 of 2-C$_6$H$_5$), 127.0 (C-1′′), 128.3 (C-4 of 2-C$_6$H$_5$), 128.6 (C-3a), 129.1 (C-3,5 of 2-C$_6$H$_5$), 131.0 (C-2′′,6′′), 131.4 (C-1 of 2-C$_6$H$_5$), 133.0 (C-6′), 133.1 (C-6), 136.5 (C-5), 137.4 (C-4′), 141.9 (C-4), 143.2 (C-7a), 160.0 (C-4′′), 163.5 (C-2′), 166.1 and 166.4 (C-1 and C-3), 199.4 (C=O) ppm. MS (EI): *m*/*z* (%) = 463 (100) $[M]^{+\cdot}$, 434 (19), 406 (5), 390 (8), 362 (8), 342 (14), 315 (8), 288 (17), 195 (5), 167 (13), 139 (11), 121 (49), 93 (10), 77 (14), 65 (20). EI-HRMS ($C_{29}H_{21}NO_5$): calcd. 463.1420, found 463.1436.

Diels–Alder Reactions of (*E*)-3-Styrylchromones 12a–c with *N*-Methylmaleimide (2) under Microwave Irradiation: Reaction of the appropriate (*E*)-3-styrylchromone **12a**–**c** (0.3 mmol) and *N*-methylmaleimide (**2**) (113 mg, 1.0 mmol) using the same conditions described above, apart from the final temperature (180 °C), yielded 4-aryl-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]-xanthone **13a**–**c** after purification by flash chromatography using a 2:1 mixture of hexane/ethyl acetate as eluent.

2-Methyl-1,3-dioxo-4-phenyl-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]-xanthone (13a): Yield 73% (79 mg). M.p. 200–202 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.07 (s, 3 H, 2-CH$_3$), 3.43–3.46 (m, 2 H, 4,11b-H), 4.21 (dt, *J* = 8.4, 2.7 Hz, 1 H, 3a-H), 5.15 (dt, *J* = 3.1, 1.0 Hz, 1 H, 11a-H), 5.72–5.74 (m, 1 H, 5-H), 6.77 (d, *J* = 8.1 Hz, 1 H, 10-H), 7.07 (dd, *J* = 7.7, 7.5 Hz, 1 H, 8-H), 7.30–7.35 (m, 5 H, 2′,3′,4′,5′,6′-H), 7.48 (ddd, *J* = 8.1, 7.5, 1.7 Hz, 1 H, 9-H), 7.93 (dd, *J* = 7.7, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 24.7

(2-CH_3), 39.9 (C-3a), 44.2 (C-11b), 47.8 (C-4), 72.5 (C-11a), 118.2 (C-10), 119.3 (C-5), 119.7 (C-6a), 122.4 (C-8), 126.4 (C-2′,6′), 127.4 (C-7), 128.3 (C-4′), 128.4 (C-3′,5′), 135.5 (C-1′), 136.7 (C-9), 138.8 (C-5a), 159.4 (C-10a), 174.3 (C-1), 175.2 (C-3), 190.9 (C-6) ppm. MS (EI): *m*/*z* (%) = 359 (10) $[M]^{+\cdot}$, 272 (5), 255 (5), 239 (41), 170 (12), 154 (100), 121 (35), 92 (24), 77 (7), 64 (10). EI-HRMS ($C_{22}H_{17}NO_4$): calcd. 359.1158, found 359.1166.

4-(4-Chlorophenyl)-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (13b): Yield 68% (80 mg). M.p. 207–209 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.06 (s, 3 H, 2-CH_3), 3.40 (dd, *J* = 8.4, 3.1 Hz, 1 H, 11b-H), 3.43 (dd, *J* = 2.8, 2.2 Hz, 1 H, 4-H), 4.10 (dt, *J* = 8.4, 2.8 Hz, 1 H, 3a-H), 5.13 (dt, *J* = 3.1, 1.2 Hz, 1 H, 11a-H), 5.71 (dt, *J* = 2.2, 1.2 Hz, 1 H, 5-H), 6.75 (dd, *J* = 7.9, 0.9 Hz, 1 H, 10-H), 7.06 (ddd, *J* = 7.8, 7.6, 0.9 Hz, 1 H, 8-H), 7.24–7.31 (m, 4 H, 2′,3′,5′,6′-H), 7.46 (ddd, *J* = 7.9, 7.6, 1.7 Hz, 1 H, 9-H), 7.92 (dd, *J* = 7.8, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 24.7 (2-CH_3), 40.2 (C-3a), 44.3 (C-11b), 48.0 (C-4), 72.7 (C-11a), 118.2 (C-10), 120.0 (C-6a), 120.1 (C-5), 122.6 (C-8), 127.6 (C-7), 127.9 (C-2′,6′), 128.6 (C-3′,5′), 134.4 (C-5a), 134.8 (C-1′), 136.7 (C-9), 137.5 (C-4′), 159.6 (C-10a), 174.1 (C-1), 174.8 (C-3), 190.5 (C-6) ppm. MS (EI): *m*/*z* (%) = 393 (16) ($[M]^{+\cdot}$, ^{35}Cl), 391 (12), 389 (13), 306 (6), 273 (65), 188 (100), 152 (36), 121 (42), 92 (28), 77 (5), 63 (14). EI-HRMS ($C_{22}H_{16}N_{14}O_4{}^{35}Cl$): calcd. 393.0768, found 393.0761; ($C_{22}H_{16}N_{14}O_4{}^{37}Cl$): calcd. 395.0738, found 395.0739.

4-(4-Ethoxyphenyl)-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone (13c): Yield 73% (88 mg). M.p. 182–184 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.40 (t, *J* = 7.0 Hz, 3 H, 4′-OCH_2CH_3), 3.08 (s, 3 H, 2-CH_3), 3.39–3.45 (m, 2 H, 4,11b-H), 4.02 (q, *J* = 7.0 Hz, 2 H, 4′-OCH_2CH_3), 4.16 (dt, *J* = 8.4, 2.7 Hz, 1 H, 3a-H), 5.13 (dt, *J* = 3.1, 1.3 Hz, 1 H, 11a-H), 5.65 (dt, *J* = 2.2, 1.3 Hz, 1 H, 5-H), 6.76 (dd, *J* = 8.1, 0.9 Hz, 1 H, 10-H), 7.07 (ddd, *J* = 7.8, 7.5, 0.9 Hz, 1 H, 8-H), 6.85 (d, *J* = 8.8 Hz, 2 H, 3′,5′-H), 7.27 (d, *J* = 8.8 Hz, 2 H, 2′,6′-H), 7.47 (ddd, *J* = 8.1, 7.5, 1.7 Hz, 1 H, 9-H), 7.92 (dd, *J* = 7.8, 1.7 Hz, 1 H, 7-H) ppm. ^{13}C NMR: δ = 14.8 (4′-OCH_2CH_3), 24.7 (2-CH_3), 39.9 (C-3a), 44.3 (C-11b), 47.8 (C-4), 63.4 (4′-OCH_2CH_3), 72.6 (C-11a), 114.2 (C-3′,5′), 117.4 (C-5), 118.2 (C-10), 119.7 (C-6a), 122.4 (C-8), 127.4 (C-7), 127.5 (C-2′,6′), 131.0 (C-1′), 134.8 (C-5a), 136.6 (C-9), 159.0 (C-4′), 159.4 (C-10a), 174.4 (C-1), 175.3 (C-3), 191.0 (C-6) ppm. MS (EI): *m*/*z* (%) = 403 (46) $[M]^{+\cdot}$, 283 (100), 198 (34), 170 (58), 141 (15), 120 (16), 92 (21), 64 (6). EI-HRMS ($C_{24}H_{21}NO_5$): calcd. 403.1420, found 403.1419.

Oxidation of Cycloadducts 4-Aryl-2-methyl-1,3-dioxo-3a,4,11a,11b-tetrahydropyrrolo[3,4-*c*]xanthone 3a–c. Method A: A mixture of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.6 mmol) and *N*-methylmaleimide (**2**) (274 mg, 2.5 mmol) was irradiated (270 W) at atmospheric pressure in a focused microwave reactor for 30 min (final temperature 180 °C). After this period 1,2,4-trichlorobenzene (1–2 mL) and tetrabutylammonium bromide (20 mg) were added and the resulting mixture was irradiated (300 W) for 45 min (final temperature 250 °C). The crude product was purified by flash chromatography on silica gel using a 1:1 mixture of hexane/ethyl acetate as eluent to afford 6-(2-hydroxybenzoyl)-2-methyl-4-phenylisoindole-1,3-diones **5a**–**c** [**5a** (105 mg, 49%), **5b** (117 mg, 50%), **5c** (132 mg, 55%)].

Method B: A mixture of the appropriate (*Z*)-3-styrylchromone **1a**–**c** (0.6 mmol) and *N*-methylmaleimide (**2**) (274 mg, 2.5 mmol) was irradiated (270 W) at atmospheric pressure in a focused microwave reactor for 30 min (final temperature 180 °C). After this period 1,2,4-trichlorobenzene (1–2 mL) and DDQ were added and the resulting mixture was irradiated (300 W) for 45 min (final temperature 250 °C). The crude product was purified by flash chromatography on silica gel using a 1:1 mixture of hexane/ethyl acetate as eluent to afford 4-aryl-2-methyl-1,3-dioxopyrrolo[3,4-*c*]xanthones **4a**–**c** [**4a** (158 mg, 74%), **4b** (161 mg, 69%), **4c** (160 mg, 67%)].

6-(2-Hydroxybenzoyl)-2-methyl-4-phenylisoindole-1,3-dione (5a): M.p. 121–122 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 3.20 (s, 3 H, 2-CH_3), 6.92 (ddd, *J* = 8.0, 7.2, 0.9 Hz, 1 H, 5′′-H), 7.12 (dd, *J* = 8.4, 0.9 Hz, 1 H, 3′′-H), 7.47–7.61 (m, 7 H, 4′′,6′′-H, 2′,6′-H), 7.93 (d, *J* = 1.4 Hz, 1 H, 5-H), 8.09 (d, *J* = 1.4 Hz, 1 H, 7-H), 11.79 (s, 1 H, 2′′-OH) ppm. ^{13}C NMR: δ = 24.2 (2-CH_3), 118.5 (C-1′′), 118.8 (C-3′′), 119.2 (C-5′′), 122.0 (C-7), 128.3 (C-3′,5′), 129.2 (C-4′), 129.4 (C-2′,6′), 129.6 (C-3a), 133.0 (C-6′′), 133.5 (C-6), 135.1 (C-1′), 136.2 (C-5), 137.4 (C-4′′), 141.3 (C-4), 142.8 (C-7a), 163.4 (C-2′′), 167.08 and 167.11 (C-1 and C-3), 199.3 (C=O) ppm. MS (EI): *m*/*z* (%) = 357 (100) $[M]^{+\cdot}$, 356 (48), 281 (17), 280 (83), 273 (9), 272 (48), 179 (12), 152 (9), 151 (26), 150 (19), 121 (90), 93 (14), 77 (5). EI-HRMS ($C_{22}H_{15}NO_4$): calcd. 357.1001, found 357.1003.

4-(4-Ethoxyphenyl)-6-(2-hydroxybenzoyl)-2-methylisoindole-1,3-dione (5c): M.p. 145–147 °C (recrystallisation from ethanol). ^{1}H NMR: δ = 1.46 (t, *J* = 7.0 Hz, 3 H, 4′-OCH_2CH_3), 3.20 (s, 3 H, 2-CH_3), 4.11 (q, *J* = 7.0 Hz, 2 H, 4′-OCH_2CH_3), 6.92 (ddd, *J* = 8.1, 7.1, 0.9 Hz, 1 H, 5′′-H), 7.00 (d, *J* = 8.8 Hz, 2 H, 3′,5′-H), 7.12 (dd, *J* = 8.4, 0.9 Hz, 1 H, 3′′-H), 7.53–7.60 (m, 1 H, 4′′-H), 7.51–7.55 (m, 1 H, 6′′-H), 7.55 (d, *J* = 8.8 Hz, 2 H, 2′,6′-H), 7.91 (d, *J* = 1.4 Hz, 1 H, 5-H), 8.03 (d, *J* = 1.4 Hz, 1 H, 7-H), 11.80 (s, 1 H, 2′′-OH) ppm. ^{13}C NMR: δ = 14.8 (4′-OCH_2CH_3), 24.2 (2-CH_3), 63.6 (4′-OCH_2CH_3), 114.3 (C-3′,5′), 118.6 (C-1′′), 118.8 (C-3′′), 119.2 (C-5′′), 121.4 (C-7), 127.2 (C-1′), 129.2 (C-3a), 130.9 (C-2′,6′), 133.0 (C-6′′), 133.6 (C-6), 136.1 (C-5), 137.3 (C-4′′), 141.3 (C-4), 142.8 (C-7a), 160.0 (C-4′), 163.5 (C-2′′), 167.2 and 167.3 (C-1 and C-3), 199.5 (C=O) ppm. MS (EI): *m*/*z* (%) = 401 (100) $[M]^{+\cdot}$, 372 (23), 316 (7), 288 (24), 280 (26), 195 (6), 167 (12), 139 (8), 121 (58), 93 (10), 65 (15). $C_{24}H_{19}NO_5$ (401.41): calcd. C 71.81, H 4.77, N 3.49; found C 72.15, H 4.88, N 3.38.

Supporting Information: Z-Matrices and energies of the optimised stationary points located along the reaction profile using the B3LYP/6-31G*//HF/6-31G* level of theory.

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