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# Photo-dehydrogenation of 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines

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Abstract Electron-transfer-induced photo-oxidation of 4,6-diaryl-substituted 2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs) in chloroform under argon atmosphere results in the smooth formation of 4,6-diaryl-substituted 2-oxo-1,2-dihydropyrimidines. Sequentially, electron-transfer and proton removal processes in this oxidative reaction result in the occurrence of two different benzylic and allylic radical intermediates, which converted to each other via resonance. Preferably, capto-dative stabilized radical center stimulates the type of product. Based on the proposed oxidation reaction mechanism, the electron transfer from the excited THPMs to chloroform starts this oxidative reaction. The results of the computational study obtained at DFT- $B_3LYP/6-311++G^{**}$  level of theory indicate that the first electron is preferably removed from the N1 atom of the heterocyclic ring. A comparison of the sum of the Mulliken spin densities of the radical intermediates supports the argument that the more stable *capto-dative* stabilized radical is involved in the reaction.

**Keywords** Light-induced Oxidation · DFT · Captodative stabilization · Electron transfer · Substituent effect · Tetrahydropyrimidines

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#### Introduction

The nitrogen-containing heterocyclic compounds, 2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs) or dihydropyrimidinones, also known as Biginelli compounds were reported over one hundred years ago [1]. Biological and pharmacological activities of THPMs and 2-oxo-1,2-dihydropyrimidines (DHPMs) or 2-pyrimidinones (oxidized derivatives of THPMs) are known [2–7]. These activities for 5-unsubstituted THPMs known as Biginelli-like compounds and corresponding dehydro-compounds have also been observed [8, 9].

Our previous studies were concentrated on the investigation of the steric and electronic effects of the heterocyclic ring substitutions on the 4- and 5-positions of various THPMs (Scheme 1) on the rate of photochemical [10-13]and thermal [14-16] oxidation process, and voltammetric measurements [17]. The results of all these investigations elucidate the importance of the electronic effects of 4-substitution over those of 5-substitution.

On the basis of the proposed mechanism for the photooxidation of THPMs in chloroform solvent [10, 11], the excited molecule (THPMs\*) donates an electron preferably from the N<sub>1</sub>-position of the heterocyclic ring to chloroform as an electron-acceptor species (electron-transfer process = ET) under formation of the radical cation and radical anion intermediates, THPMs<sup>+</sup> and CHCl<sub>3</sub><sup>-</sup>, respectively. Elimination of HCl molecule from these species leads to the formation of trihydropyrimidyl (TrHPMs<sup>-</sup>) and dichloromethyl (CHCl<sub>2</sub>) radicals. Due to delocalization of the single electron in the trihydropyrimidyl radical intermediate (TrHPM<sup>-</sup>), this species is considered as benzylic/ allylic and allylic radicals, which is converted to each other via resonance. Further removal of the second hydrogen atom from 3-NH position of more stable benzylic/allylic



Scheme 1 Oxidation of 2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs)

radical intermediate results in the formation of 2-oxo-1,2-dihydropyrimidines (DHPM) (Scheme 2).

Considering these steric and electronic effects of the substituent on the electron-donating ability of the heterocyclic ring toward the electron-acceptor species and based on the above-mentioned mechanism, after the formation of the radical cation species (THPM<sup>++</sup>) from 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines and following deprotonation of this species, two different benzylic and also allylic radical intermediates are formed, which are converted again to each other via resonance. The second hydrogen removal is expected to occur from more stable and involved radical intermediate, which leads to the formation of the final DHPM. Possible formations of two different DHPMs, namely DHPM  $(4-Ar^1/6-Ar^2)$  and/or DHPM  $(6-Ar^1/4-Ar^2)$ , are expected in the present study depending on the preferred involvement of the benzylic/allylic radical (4) or benzylic/allylic radical (6), respectively (Scheme 3).

# **Results and discussion**

In order to elucidate the effect of the oxygen or argon atmosphere on the outcome of the photoreaction, irradiation of compound **1a** as representative carried out in airsaturated chloroform as solvent, under oxygen and argon atmosphere by bubbling oxygen or argon in the reaction vessel during the irradiation. Whereas TLC monitoring of the reaction mixture in air-saturated chloroform and



Scheme 2 Electron-transfer-induced oxidation of 2-oxo-1,2,3,4-tetrahydropyrimidines involving benzylic/allylic and allylic radical intermediates



Scheme 3 Involvement of two different benzylic/allylic radical intermediates in the oxidation of 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines



under oxygen atmosphere confirmed the formation of the oxidation product **2a** accompanied with trace amount of unidentified products, a clean reaction under formation of the sole product **2a** observed by carrying the irradiation under argon atmosphere. The results indicate also that the presence of the oxygen atmosphere accelerates the reaction. Therefore, a 0.004 M solution of each of

4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines (1a–1g) in chloroform solvent was irradiated under argon atmosphere until total disappearance of 1a–1g as monitored by TLC (Scheme 4). The results are presented in Table 1.

The results presented in Table 1 indicate that upon oxidation of **1a–1g** and removal of two hydrogens from 4-position and 1- or 3-positions of the heterocyclic ring,

Table 1 Photo-oxidation of 4,6-diaryl-2-oxo-1,2,3,4tetrahydropyrimidines (THPMs, 1a-1g) in chloroform solvent under argon atmosphere to 2-oxo-1,2-dihydropyrimidines (DHPMs)

THPM	Х	Y	DHPM	Х	Y	Time (min) <sup>a</sup>
1a	Н	Н	2a	Н	Н	86
1b	4-CH <sub>3</sub> O	Н	3b	4-CH <sub>3</sub> O	Н	40
1c	3-CH <sub>3</sub> O	Н	3c	3-CH <sub>3</sub> O	Н	50
1d	2-CH <sub>3</sub> O	Н	3d	2-CH <sub>3</sub> O	Н	55
1e	Н	4-CH <sub>3</sub> O	3b <sup>b</sup>	4-CH <sub>3</sub> O	Н	45
1f	Н	3-CH <sub>3</sub> O	3c <sup>c</sup>	3-CH <sub>3</sub> O	Н	60
1g	Н	2-CH <sub>3</sub> O	3d <sup>d</sup>	2-CH <sub>3</sub> O	Н	50

<sup>a</sup> The times are given after total disappearance of **1a–1g** (100% conversion according to TLC observation) <sup>b-d</sup> These products are also obtained by the photo-oxidation of **1e-1g**, respectively

dihydropyrimidin-2-one products are formed. Whereas the irradiation of 1a results in the formation of the photoproduct 2a, the same as 3a, irradiation of 1b-1g causes the formation of 3b-3d. UV, IR, <sup>1</sup>H NMR and <sup>13</sup>C NMR spectroscopic data gave useful information about the structural assignment of the photoproducts, especially the similarity of the photoproduct 3b obtained by irradiation of either 1b or 1e, and 3c from 1c or 1f and finally 3d from 1d or 1g. Some of these spectra are presented here, and the remaining spectra are provided in the supporting materials.

The maximum absorption in the UV spectra of 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines appears in the lower wavelengths in comparison with those of the oxidation products. Formation of the semi-aromatic heterocyclic ring containing the amino-conjugated dienone system leads to an extended conjugation toward 2-CO group. Consequently, a decrease in the  $\pi$  and  $\pi^*$  levels and bathochromic shifts accompanied with the hyperchromic effect in the UV spectra are observed. These phenomena are presented in Fig. 1, as representative by comparison of the UV spectra of 1a and corresponding photoproduct 2a.

The effective extended conjugation in the heterocyclic ring is not only supported by these UV absorptions, but also by calculation of the dipole moment ( $\mu$ ) of **1a–1g** and the oxidation products based on the DFT calculation given in Table 2. These data support the argument that due to the formation of the semi-aromatic heterocyclic ring, the electron delocalization of the N<sub>1</sub> lone pair toward the 2-CO group is increased; therefore, the enhancement of the dipolar nature of the heterocyclic ring and an increase in the value of the dipole moment are expected.

The interesting results of the present study, as already mentioned, are obtaining the same products **3b-3d** by irradiation of either 1b or 1e, either 1c or 1f, and either 1d or 1g, respectively. The difference between the starting materials is the location of the methoxy-substituted phenyl ring either on the 4- or 6-positions of the heterocyclic ring. Due to the mentioned difference in absorption, the UV spectra of **1b** and **1e** containing the 4-methoxyphenyl group on the 4- and 6-positions of the heterocyclic ring, respectively, are given as representative in Fig. 2 (left), which indicates clearly different UV absorptions of 1b and 1e. In contrast to these observations, the UV spectra of the corresponding photoproducts illustrated in Fig. 2 (right) are very similar and indicates the formation of the similar product upon oxidation of different starting materials. The remaining UV spectra are presented as supporting materials.



Fig. 1 UV spectra of compound 1a and corresponding oxidation product 2a

**Table 2** Dipole moment  $(\mu)$ of compounds 1a-1g and the oxidation compounds 2a, 3b-3d calculated by B3LYP/6-31++G (d,p) method

Comp.	1a	1b	1c	1d	1e	1f	1g
$\mu$ (Debye)	4.22	4.30	3.63	4.14	5.68	5.10	4.33
Comp.	2a	3b	3c	3d	3e = 3b	3f = 3c	3g = 3d
$\mu$ (Debye)	7.28	7.81	6.11	7.97	7.81	6.10	7.95



Fig. 2 UV spectra of compound 1b and 1e (*left*), and corresponding oxidation products 3b and 3e = 3b (*right*)

The most useful information for the characterization of the photoproducts obtained by comparison of the <sup>1</sup>H NMR spectra of **1a–1g** and their photoproducts **2a** and **3b–3d** is described below:

- In <sup>1</sup>H NMR spectra of **1a–1g**, characteristic absorption of 5-CH, 3-NH and 1-NH protons appeared around 5.1, 7.2 and 8.5 ppm, respectively. Upon photo-oxidation, the loss of two hydrogen atoms, namely one hydrogen atom from the 4-position of the heterocyclic ring and another hydrogen atom either from 1-NH or 3-NH positions, is observed.
- Owing to the formation of the semi-aromatic heterocyclic ring in the photoproducts **2a** and **3b–3d**, the shift of the absorption of remaining NH proton to lower field (higher frequency) is observed, which is attributed to the delocalization of the nitrogen lone pair toward the extended azadiene system.
- Anisotropic effect of the semi-aromatic ring on the 5-CH proton causes the shift of its absorption to the aromatic region around 7.5 ppm.
- The hydrogen atoms of the methyl moiety of the methoxy group in all photoproducts are shifted toward the lower field. This is due to the formation of the aminoconjugated dienone system and possible conjugation of the oxygen lone pairs toward the aromatic ring.
- The formation of 3b-3d upon photo-oxidation of either 1b or 1e, either 1c or 1f and 1d or 1g was confirmed by obtaining the same <sup>1</sup>H NMR spectra of each pair of photoproducts. These spectra are illustrated in Fig. 3 for 3b obtained upon photo-oxidation of either 1b or 1e.

Comparison of the infrared spectra of **1a–1g** and the photoproducts indicates a decrease in the NH peak intensity and the shift of the 2-CO stretching to lower frequency.

Comparison of the <sup>13</sup>C NMR spectra showed an increase in peaks in the aromatic region and the lack of  $C_4$  peak in region for the aliphatic carbons. All these spectroscopic data support the results of photo-oxidation of THPMs considered in the present study.

## **Mechanistic studies**

In order to elucidate the electronic effect of  $C_4$ - and  $C_6$ -aryl substitutions on the irradiation time especially for a very closed reaction time in the present study, the reactions of **1b** and **1e** containing the *para*-methoxyphenyl substituent on the 4- and 6-positions of the heterocyclic ring, respectively, were followed by UV spectroscopy. The UV reaction spectra are presented in Fig. 4, and the corresponding slope of the extinction *versus* time (ET diagram)<sup>1</sup> at 370 nm shows that the compound **1b** has comparatively greater rate constant of  $5.7 \times 10^{-2}$  mol L<sup>-1</sup> s<sup>-1</sup> than **1e** with the rate constant of  $5.3 \times 10^{-2}$  mol L<sup>-1</sup> s<sup>-1</sup>. These data support the observed shorter irradiation time of 40 min for total disappearance of **1b** compared to 45 min for compound **1e**.

The results given in Table 1 indicate that the presence of the methoxyphenyl substituent on the 4- or 6-position of the heterocyclic ring facilitates the photo-oxidation process compared to that of the parent molecule **1a**. The electronic effect of the methoxy-substituted phenyl ring on the shortening of the reaction time can be explained by considering the reaction mechanism presented in Scheme 3. According to the proposed mechanism, UV irradiation of the THPM molecule leads to the promotion of the molecule to the excited state (THPM\*). The electron-transfer process (ET) from the excited molecule as an electron-donating species in the next step to chloroform molecule as an electronacceptor species causes the formation of tetrahydropyrimidine radical cation (THPM<sup>+</sup>) and chloroform radical

<sup>&</sup>lt;sup>1</sup> The absolute term "extinction" is a German word and has now been replaced with "absorbance," but the phrase "Extinction time" is still using.



Fig. 3 Comparison of the <sup>1</sup>H NMR of compounds 1b, 1e, 3b and 3e=3b



Fig. 4 Reaction spectra of photochemical oxidation of 1b (*left*) and 1e (*middle*) in chloroform solvent and the corresponding extinction time (ET) diagrams at 370 nm (time interval 8 min)

anion (CHCl<sub>3</sub><sup>-</sup>) intermediates, respectively. In the next step, elimination of HCl molecule from both these intermediates (C<sub>4</sub>–H removal accompanied with Cl<sup>-</sup>) produces trihydropyrimidyl (TrHPM<sup>-</sup>) and dichloromethyl (CHCl<sub>2</sub>) radical intermediates. Finally, hydrogen removal from the N<sub>1</sub>- or N<sub>3</sub>-positions of TrHPM<sup>-</sup> intermediate and formation of CH<sub>2</sub>Cl<sub>2</sub> can possibly form the photoproduct DHPM (4-Ar<sup>1</sup>/6-Ar<sup>2</sup>) and/or (6-Ar<sup>1</sup>/4-Ar<sup>2</sup>).

The methoxy group on each position of  $C_4$ -aryl ring acts as a  $\sigma$ -donor or  $\sigma$ -acceptor substituent due to the attachment of the methoxy-substituted aryl ring with the sp<sup>3</sup> hybridized  $C_4$ -atom of the heterocyclic ring, whereas this group behaves as a  $\pi$ -donor or  $\pi$ -acceptor due to the attachment of the methoxy-substituted aryl ring with the sp<sup>2</sup> hybridized  $C_6$ -atom of the heterocyclic ring. Coplanar orientation of the methoxy group on the *para- and ortho*-positions with the aryl ring results in the delocalization of its oxygen lone pair toward the C-aryl ring (C<sub>8</sub>) attached to the C<sub>4</sub>-atom of the heterocyclic ring (Scheme 5), acting the aryl ring as a  $\sigma$ -donor substituent. Consequently, an increase in the electron density of the heterocyclic ring via  $\sigma$ -bond is expected, which facilitates the electron removal from the N<sub>1</sub>-atom compared to that of compound **1a** containing the normal phenyl ring on the 4-position.

The methoxy group in **1e–1g** has different electrondonor and electron-acceptor properties depending on its location on the *ortho-* or *para-* and *meta-*positions, respectively. These properties completely depend on the orientation of  $C_6$ -aryl ring toward the  $C_6=C_5$  double bond of the heterocyclic ring. DFT calculations of **1e–1g** show that due



Scheme 6 Participation of the oxygen lone pair in the  $CH_3O$  group in 1e as representative via resonance (route 1) or inductive way (route 2) to increase the electron density of the heterocyclic ring and showing the *ortho*-repulsion

to the observed *ortho*-repulsion, this co-planarity is not possible; therefore, an effective  $\pi$ -delocalization toward the heterocyclic ring is not expected (Scheme 6, route 1), and the aryl group can act only as a  $\sigma$ -donor (Scheme 6, route 2).

In order to elucidate the steric and electronic effects of the methoxy group on the electron-donor ability of the aryl ring toward the heterocyclic ring, cyclic voltammetric measurements were carried out. The results presented in Table 3 indicate that the substituted methoxyphenyl group on both  $C_4$ - and  $C_6$ -positions causes a decrease in the oxidation peak potential compared to that of the parent compound **1a**. These results are in agreement with the proposed electron-transfer-induced photo-oxidation and the reduced irradiation time given in Table 2 compared to that of **1a**. The results of the CV measurements of 5-carboethoxy THPMs (Scheme 1,  $R=OC_2H_5$ ) having the same aryl group on the 4-position as in the present study are compared with the CV data reported in the present work. These data clearly indicate that by failure of 5-substitution in THPMs, namely the electron-withdrawing carboethoxy group and having only the hydrogen atom on this position, the oxidation peak potential is lowered compared to those of 5-substituted THPMs [17]. On the other hand, a comparison of the irradiation times of 5-substituted THPMs [10, 11] with the results presented in this work elucidates the facile electron transfer of the excited molecule (THPMs\*) toward the electron-acceptor species chloroform in the absence of 5-substitution and drastic decreasing of the irradiation times.

Table 3 Comparison of the oxidation peak potential (Ep) versus ferrocene redox potential (0.583 V), obtained from cyclic voltammograms in acetonitrile for THPMs (**1a–1g**) and 5-carboethoxy-substituted THPMs (E)

	5-Unsubstituted	THPMS	5-Carboetnoxy THPMs					
	4-Position	6-Position	Ep	4-Position	6-Position	Ep		
1a	C <sub>6</sub> H <sub>5</sub>	C <sub>6</sub> H <sub>5</sub>	1.274	C <sub>6</sub> H <sub>5</sub>	CH <sub>3</sub>	1.513		
1b	$4-CH_3OC_6H_4$	C <sub>6</sub> H <sub>5</sub>	1.154	$4-CH_3OC_6H_4$	CH <sub>3</sub>	1.464		
1c	3-CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>	$_{3}OC_{6}H_{4}$ $C_{6}H_{5}$		3-CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>	CH <sub>3</sub>	1.472		
1d	2-CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>	C <sub>6</sub> H <sub>5</sub>	1.248	$2-CH_3OC_6H_4$	CH <sub>3</sub>	1.365		
1e	$C_6H_5$	$4-CH_3OC_6H_4$	1.165					
1f	$C_6H_5$	$3-CH_3OC_6H_4$	1.245					
1g	C <sub>6</sub> H <sub>5</sub>	2-CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>	1.181					
Comp.	N <sub>I</sub>	C <sub>2</sub>	N <sub>3</sub>	$C_4$	C <sub>5</sub>	C <sub>6</sub>		
1a	-0.670	0.819	-0.680	-0.081	-0.279	0.166		
1a <sup>.+</sup>	-0.568	0.810	-0.672	-0.116	-0.057	0.259		
1a <sup>-</sup>	-0.639	0.822	-0.639	0.172	-0.286	0.166		
1b	-0.669	0.819	-0.685	-0.080	-0.280	0.167		
1b <sup>.+</sup>	-0.594	0.892	-0.666	-0.103	-0.132	0.253		
1b <sup>-</sup>	-0.643	0.834	-0.634	0.180	-0.297	0.162		
1c	-0.670	0.817	-0.679	-0.082	-0.276	0.164		
1c <sup>.+</sup>	-0.592	0.810	-0.665	-0.106	-0.123	0.268		
1c <sup>-</sup>	-0.639	0.882	0.643	0.166	-0.284	0.165		
1d	-0.670	0.820	-0.677	-0.093	-0.289	0.171		
1d <sup>.+</sup>	-0.550	0.811	-0.647	-0.134	-0.049	0.225		
1d <sup>-</sup>	-0.641	0.822	-0.638	0.166	-0.208	0.165		
1e	-0.670	0.818	-0.678	-0.082	-0.287	0.170		
1e <sup>.+</sup>	-0.599	0.813	-0.661	-0.115	-0.070	0.245		
1e <sup>-</sup>	-0.644	0.837	-0.642	0.161	-0.290	0.170		
1f	-0.668	0.820	-0.685	-0.081	-0.281	0.169		
1f+	-0.557	0.810	-0.655	-0.120	-0.043	0.256		
1f	-0.640	0.822	-0.640	0.166	-0.286	0.165		
1g	-0.664	0.820	-0.683	-0.082	-0.286	0.175		
1g <sup>.+</sup>	-0.562	0.825	-0.658	-0.118	-0.056	0.254		
1g <sup>-</sup>	-0.638	0.821	-0.640	0.165	-0.289	0.165		

# Table 4NBO spin densitieson the THPMs, radical cation(THPM') and radical (TrHPM')

# **Computational studies**

The interesting results of the present study are that the same photo-oxidation products is obtained from two different dispositional substitution in THPMs, namely the photo-oxidation of **1b** or **1e**, **1c** or **1f** and **1d** or **1g** produce the same photoproducts **3b–3d**, respectively. In order to elucidate this observation, especially to support the proposed electron-transfer process in the photo-oxidation reaction, computational studies were performed using Gaussian 98 program package [18]. Density functional theory (DFT) at the B3LYP/6-31++G (d,p) level has been used to study structural, electronic and bonding characteristics of THPMs, THPMs<sup>++</sup>, TrHPMs<sup>-</sup> intermediates and the corresponding oxidation products (DHPMs) considered in the

present study. In addition, natural bond orbital (NBO) analysis should explain the active position of the heterocyclic ring in donation of the electron to chloroform.

Since the oxidation does not occur in the absence of UV exposure, the electron transfer from excited molecule THPM\* to chloroform leads to the formation of THPM<sup>++</sup> and CHCl<sub>3</sub><sup>--</sup> intermediates, respectively. A comparison of the natural bond orbital (NBO) results of THPM compounds and corresponding THPM<sup>++</sup> intermediates presented in Table 4 indicates that the first electron removal is occurred preferably from the N<sub>1</sub>-atom. This is explained due to effective stabilization of the single electron on the N<sub>1</sub>-atom of THPM(N<sub>1</sub>)<sup>++</sup> intermediate in conjugation with the C<sub>6</sub>=C<sub>5</sub> double bond (Scheme 7). Therefore, the back electron-transfer process (BET) is more possible in



Scheme 7 Possible delocalization of the single electron in the N1 and N3 radical cation intermediates

THPM( $N_3$ )<sup>++</sup> intermediate due to failure of such effective electron delocalization (Scheme 8).

Illustration of the reaction mechanism in Scheme 8 indicates that the elimination of the first proton from each of THPM $(N_1)^{++}$  and THPM $(N_3)^{++}$  intermediates results in the formation of TrHPM<sup>-</sup> intermediate. Due to delocalization of the single electron in this intermediate, the involvement of two different benzylic/allylic 4 and benzylic/allylic 6 is expected. The experimental results of the present study revealed that upon irradiation of either 1b or 1e, either 1c or 1f, and either 1d or 1g, the same products 3b, 3c or 3d are obtained; therefore, the resultant radicals are responsible to generating of the same photoproducts. Electronic properties of the substituted aryl ring can affect the stability of these radicals during the oxidation reaction. The electron-releasing and electron-accepting properties of the aryl and phenyl rings can change the HOMO and LUMO levels on the olefinic C=C double bond, such that electronreleasing groups increase and electron-accepting groups decrease these levels of electronic energies, respectively. Frontier Molecular Orbital (FMO) theory described this effect [19]. According to this theory, the stability of the radical species is strongly relay on the nature of substituents in the  $\alpha$ -position. The interaction of the radical center with the alkyl substituent (via hyper-conjugation), the attached  $\pi$ -system (via resonance) or the lone pair of the neighboring heteroatom results in the stabilization of the single electron. These interactions are classified into three major groups: Electron-withdrawing, electron donating or combination of both of them [20]. One-Electron Molecular Orbital (OEMO) theory can explain how these interactions affect the stability of the single-electron radicals. Based on the *capto-dative* concept [21], simultaneous interaction of the radical centers with the electron-donor and electron-acceptor substitutions increases the stabilization energy compared to the sum of their donor- or acceptor-substituted radicals.

Compounds 1b-1d have two aryl ring  $(Ar^1 = 4,3,2-(methoxy)-C_6H_4 \text{ and } Ar^2 = Ph)$  on the 4- and 6-positions of the heterocyclic ring, respectively. When the radical species is formed, this radical is benzylic/allylic 4 (Scheme 8). This radical can become benzylic/allylic 6 by electron delocalization. If this radical existence is on the 4-position, the radical center can interact with the N<sub>3</sub> lone pair as a donor species, the methoxy-substituted aryl ring again as a donor species and the  $\pi$  or  $\pi^*$  orbitals of the attached C=C double bond. Therefore, an effective captodative stabilization for this radical center is not expected. In contrast to this situation, when this radical is located on the 6-position, capto-dative effect is expected due to the



Scheme 8 Involvement of two different benzylic/allylic radical intermediates in the oxidative process

simultaneous interaction of the radical center with the N<sub>1</sub> lone pair and electron-withdrawing C<sub>6</sub> phenyl ring. As a result, the radical on the 6-position is more stable than on the 4-position; therefore, the formation of the 4-ph/6-Ar<sup>1</sup> product, namely **3b–3d** is expected. In the cases of **1e–1g** compounds having the phenyl and the aryl rings (Ar<sup>1</sup> = Ph and Ar<sup>2</sup> = 4,3,2-(methoxy)-C<sub>6</sub>H<sub>4</sub>) on the 4- and 6-positions of the heterocyclic ring, respectively, the firstly formed radical is benzylic/allylic 4. The radical center on this position now assigned as a *capto-dative* stabilized radical and gained more stability due to the simultaneous interaction with the N<sub>3</sub> lone pair as an electron donor and the phenyl group as an electron acceptor group, which leads again to the formation of the 4-ph/6-Ar<sup>1</sup> product (**3b–3d**).

To support the above-mentioned arguments, the benzylic radical centers on the C4- and C6-positions assigned as part A and B, respectively. The sum of the Mulliken atomic spin densities of the radicals 1a', 1b' and 1e' obtained from DFT study is given in Table 5. The radical 1a either on the C<sub>4</sub>-position (part A) or C<sub>6</sub>-position (part B) of the heterocyclic ring has similar benzylic character due to the attachment of the radical center with the phenyl ring on both positions. Therefore, the sum of the Mulliken atomic spin densities for both parts is 0.7607. In radical 1b, the C<sub>4</sub>-radical center (part A) is attached to the electron-donating *p*-methoxyphenyl group, whereas the C<sub>6</sub>-radical center (part B) is attached to the electron-withdrawing phenyl ring. The phenyl ring as a part of a capto-dative radical stabilizes the radical center effectively; therefore, the sum of the Mulliken spin densities for part B (0.8073) is greater than for part A (0.7080). The reverse results are obtained for the radical 1e, in which the parts A and B contain the phenyl and *p*-methoxyphenyl substitutions, respectively; therefore, the sum of the Mulliken spin densities for part A (0.7879) is greater than that for part B (0.6969).

 Table 5
 Sum of the Mulliken spin densities in 1a<sup>+</sup>, 1b<sup>+</sup> and 1e<sup>+</sup> radical intermediates in A and B parts



**Table 6** Bond lengths (Å) and dihedral angles (°) of 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs), trihydropyrimidyl radical (TrHPM<sup>-</sup>) obtained by using the B3LYP/6-31++G (d,p) calculations

Comp.	N <sub>1</sub> -C <sub>2</sub>	C <sub>2</sub> -N <sub>3</sub>	N <sub>3</sub> -C <sub>4</sub>	C <sub>4</sub> –C <sub>5</sub>	C <sub>5</sub> -C <sub>6</sub>	N <sub>1</sub> -C <sub>6</sub>	C <sub>2</sub> -O <sub>7</sub>	C <sub>4</sub> –C <sub>8</sub>	C <sub>6</sub> -C <sub>14</sub>	β1	β <sub>2</sub>	γ <sub>1</sub>	γ <sub>2</sub>
1a	1.3889	1.3680	1.4680	1.5093	1.3462	1.4026	1.2290	1.5312	1.4837	-52.1	71.2	-37.5	140.2
1a <sup>.+</sup>	1.4347	1.3573	1.4567	1.4885	1.4051	1.3517	1.2127	1.5428	1.4599	-43.2	79.3	-27.4	149.8
1a <sup>-</sup>	1.3823	1.3823	1.4051	1.3932	1.3932	1.4051	1.2248	1.4574	1.4574	21.2	157.4	-21.1	157.4
1b	1.3876	1.3714	1.4726	1.5125	1.3469	1.4017	1.2289	1.5246	1.4835	-54.35	67.5	37.7	-140.8
1b <sup>.+</sup>	1.4235	1.3612	1.4551	1.4924	1.3932	1.3616	1.2152	1.5362	1.4668	-37.7	82.9	27.1	-152.9
1b <sup>.</sup>	1.3813	1.3831	1.4064	1.3908	1.3964	1.4073	1.2254	1.4574	1.4544	-21.3	155.7	18.9	-158.0
1c	1.3878	1.3685	1.4687	1.5094	1.3461	1.4024	1.2295	1.5327	1.4835	-51.3	72.4	-37.5	140.5
1c <sup>.+</sup>	1.4221	1.3631	1.4537	1.4988	1.3910	1.3629	1.2155	1.5434	1.4640	-15.3	105.1	-29.9	147.2
1c <sup>-</sup>	1.3816	1.3827	1.4054	1.3923	1.3937	1.4058	1.2252	1.4582	1.4569	-22.8	155.4	-20.7	157.8
1d	1.3952	1.3656	1.4737	1.5049	1.3469	1.4029	1.2291	1.5357	1.4839	68.5	-167.3	38.1	-139.8
1d <sup>.+</sup>	1.4403	1.3519	1.4641	1.4782	1.4062	1.3484	1.2127	1.5299	1.4626	74.9	-156.4	27.6	-150.6
1d <sup>-</sup>	1.3856	1.3770	1.4042	1.3975	1.3911	1.4042	1.2264	1.4614	1.4580	23.5	-159.3	21.4	-156.6
1e	1.3874	1.3693	1.4698	1.5090	1.3467	1.4026	1.2294	1.5322	1.4814	-56.4	67.4	-37.8	140.5
1e <sup>.+</sup>	1.4260	1.3588	1.4586	1.4912	1.4012	1.3607	1.2149	1.5401	1.4493	-47.6	73.2	-22.1	155.0
1e <sup>-</sup>	1.3828	1.3813	1.4069	1.3964	1.3901	1.4059	1.2253	1.4545	1.4585	-19.7	158.7	-23.5	155.2
1f	1.3867	1.3716	1.4711	1.5115	1.3464	1.4012	1.2288	1.5273	1.4842	-53.9	67.9	38.6	-139.7
1f <sup>+</sup>	1.4359	1.3556	1.4593	1.4869	1.4068	1.3494	1.2128	1.5401	1.4616	-50.6	73.2	27.1	-151.8
1f	1.3822	1.3828	1.4060	1.3941	1.3923	1.4054	1.2250	1.4567	1.4587	-20.2	156.8	21.6	-155.3
1 g	1.3896	1.3703	1.4685	1.5116	1.3476	1.4037	1.2295	1.5266	1.4867	-54.0	67.6	44.6	-138.4
1g <sup>.+</sup>	1.4287	1.3560	1.4564	1.4888	1.4113	1.3522	1.2149	1.5408	1.4604	-49.2	74.6	-10.9	167.6
1g <sup>-</sup>	1.3769	1.3843	1.4029	1.3900	1.3999	1.4039	1.2266	1.4589	1.4602	-21.7	155.5	19.8	-161.4

 $\beta_1 = N_3 - C_4 - C_8 - C_9 \text{ dihedral angle; } \\ \beta_2 = C_4 - C_5 - C_8 - C_9 \text{ dihedral angle; } \\ \gamma_1 = N_1 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} \text{ dihedral angle; } \\ \gamma_1 = C_5 - C_6 - C_{14} - C_{15} + C_{15}$ 

The results of the DFT study from the optimized structures for the selected bond lengths and inner-ring and interring dihedral angles are extracted and listed in Table 6. Comparison of the bond lengths of each compound and its corresponding radical cation intermediate indicates that the first electron removal occurred from the N<sub>1</sub>-atom, which displays on the drastic shortening of the N<sub>1</sub>-C<sub>6</sub> bond length, while comparison of the bond lengths of each compound and its corresponding radical intermediate indicates that the effective benzylic stabilization by the phenyl ring is characterized by comparatively shorter C<sub>4</sub>-C<sub>phenyl</sub> or C<sub>6</sub>-C<sub>phenyl</sub> bond lengths with the C<sub>6</sub>-C<sub>arvl</sub> or C<sub>4</sub>-C<sub>arvl</sub> bond lengths.

#### Conclusion

In summary, this present work describes electron-transfer-induced photo-oxidation of various 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs) to 4,6-diaryl-2-oxo-3,4-dihydropyrimidines in chloroform solvent under argon atmosphere. The results indicate that the *captodative* stabilized radical intermediate between two possibly formed double benzylic/allylic radical centers controlled the type of formed product. The data of the DFT computational studies concerning the bond lengths to the radical centers and Mulliken population analysis support the results of the experimental work.

### **Experimental**

5-Unsubstituted 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs) considered in the present work were synthesized by the reported procedure [22]. All irradiations were performed using a 400 W high-pressure Hgvapor lamp from NARVA. The cyclic voltammetry (CV) measurements were performed using SAMA 500 Potentio/Galvanostat. All electrochemical experiments were carried out in a conventional three-electrode system at room temperature. A silver electrode, a large area Pt plate (99.99%) and a glass carbon electrode (GCE) were used as reference, counter and working electrodes, respectively.

# General procedure for Photo-oxidation of 4,6-diaryl-2-oxo-1,2,3,4-tetrahydropyrimidines (THPMs)

A solution of 5-unsubstituted 4,6-diaryl-2-oxo-1,2,3,4tetrahydropyrimidines (0.04 mmol) in 10 ml of distilled chloroform (c = 4 mM) was irradiated under bubbling of argon gas with a 400-W high-pressure mercury lamp in a Pyrex tube at ambient temperature. The progress of the reaction was monitored by TLC until total disappearance of starting material. After completion of reaction, the solvent was evaporated to obtain the pure product. The physical and spectroscopic data of the product are already reported [23].

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