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tert-Butyl Nitrite Mediated Synthesis of *N*-nitrosoamides, Carboxylic Acids, Benzocoumarins and Isocoumarins from Amides

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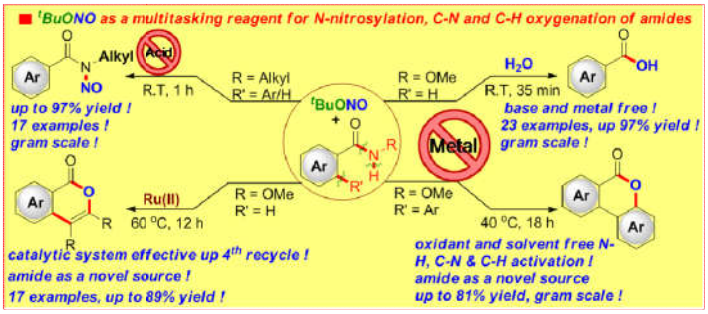
ABSTRACT: This work reports *tert*-Butyl Nitrite (TBN) as a multitask reagent for 1) the controlled synthesis of *N*-nitrosoamide from *N*-alkyl amides, 2) hydrolysis of *N*-methoxyamides to carboxylic acids, 3) metal and oxidant free benzocoumarin synthesis from *ortho*-aryl-*N*-methoxyamides *via* N-H, C-N and C-H Bond activation and 4) isocoumarin synthesis using Ru(II)/PEG as a recyclable catalytic system *via ortho* C-H activation and TBN as an oxygen source. The sequential functional group interconversion of amide to acid has also been examined using IR spectroscopic analysis. Additionally, this methodology is highly advantageous due to short reaction time, gram scale synthesis and broad substrate scope.

TOC Graphic

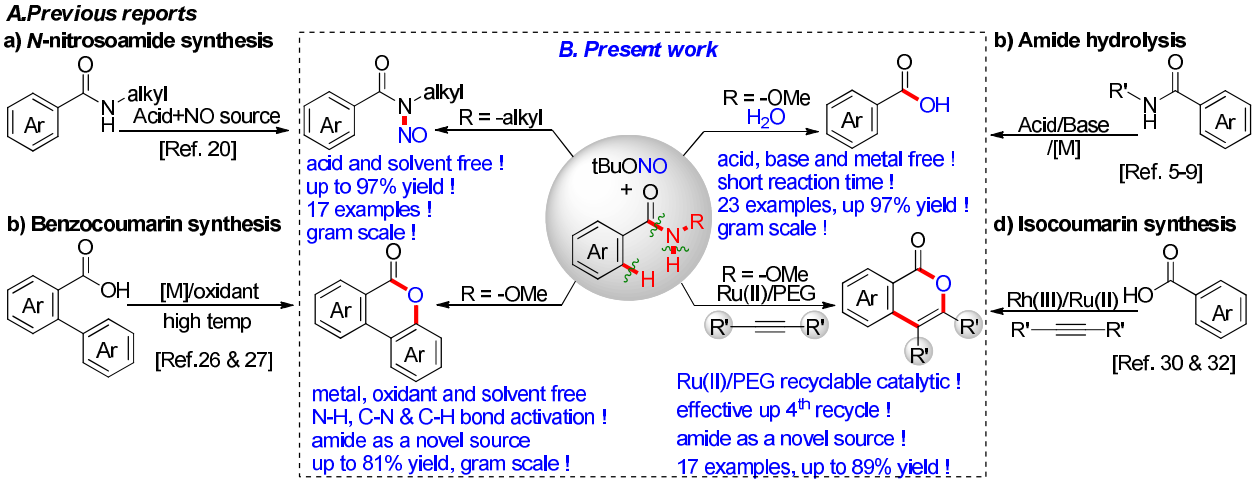


INTRODUCTION

Amide is an ubiquitous and key backbone in natural peptides and biologically active molecules.[1] Its prevalence in nature is due to its stability which in turn is due to the presence of the stable C-N bond.[2] This is attributed to the fact that, there is an overlap between the lone pair of electrons on nitrogen with the carbonyl π orbital (barrier to N-C resonance of 15–20 kcal/mol).[3] As a result, the partial double bond character $^{+}N=C-O^{-}$ arises in the amide bond due to resonance, which decreases the electrophilicity of the amide carbonyl group.[4] Classically, in acidic medium, the protonation of carbonyl amide is followed by nucleophilic addition to the carbonyl carbon thus resulting in its hydrolysis.[5] Similars equence of events take place in transamidation[6] and Friedel-Crafts acylation reaction.[7] While in basic medium or in the presence of organometallic reagents, the direct nucleophilic addition to carbonyl amide results in the synthesis of acid/ketone.[8] Moreover, enzyme/DNA catalytic system is also useful for hydrolysis of amide but requires longer reaction time.[9] To explore the chemistry of amides, contemporary research involves metal catalyzed functionalization of amide C-N bond.[10] Independently, Garg,[11] Zou,[12] Szostak,[13] and Zeng[14] have contributed in metal catalyzed cleavage of sterically hindered tertiary amide C-N bonds for various organic transformations [Scheme 1, A(a)]. However, a few reports are available on metal-catalyzed cleavage of secondary amides (transamidation)[15] due to the formation of thermodynamically stable metallacycle which makes the cleavage of C-N bond difficult [Scheme 1, A(b)].[16] Importantly, in the absence of metal catalyst, secondary amides undergo *N*-nitrosylation followed by rearrangement *via* cleavage of C-N bond.[17] The nitrosylation of secondary amides using different nitrosyl sources such as sodium or potassium nitrite in acid,[18] silver nitrate,[19] nitrosyl chloride[17] and nitrogen oxides (e.g. N_2O_3, N_2O_4, etc.)[20] have been well documented. However, difficulties in handling, the presence of acidic medium,

the formation of side products, utilization of multiple reagents and lack of step economy are some of the limitations of the protocols making use of these existing nitrosyl sources.

Scheme 1. A) Comparison of A) previous approaches with B) Present work



Recently, TBN has been used in nitrosylation of amines and urea,[21] diazotization[22] and C-nitration reactions.[23] Moreover, TBN is inexpensive and commercially available, possesses good solvent solubility and is also easy to handle. Advantageously, when used in organic reactions it provides only *t*-BuOH as the nontoxic side product.[21-23]

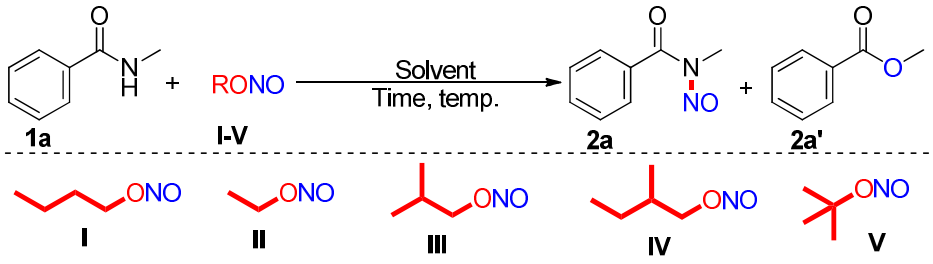
In this perspective, we herein report the first important application of TBN for the *N*-nitrosylation of *N*-alkylamides, synthesis of carboxylic acids, benzocoumarins and isocoumarins from *N*-alkoxyamides (Scheme 1B). These reactions proceed through one pot cleavage of N-H, C-N and C-H bonds of amides.

RESULTS AND DISCUSSION

a) *N*-nitrosoamide synthesis from alkyl amides

N-nitrosoamide is an important intermediate useful in various organic transformations.[24] Synthesis of *N*-nitrosoamides has been well established and requires tedious reaction processes (Scheme 1, a).[17-20] However, the transformation of this intermediate has limitations due to the use of acidic medium and the generation of hazardous side products. Notably, use of organonitrites, provide nitrosyl radical in neutral reaction conditions with only alcohol as the side product.[21-23] In view of the characteristic feature of organonitrites, we have initiated the optimization of reaction conditions for *N*-nitrosylation of *N*-methyl benzamide **1a,** using *n*-butyl nitrite **(I)** as the nitrosyl source at 60 °C for 3 h.

Table 1.Optimization of reaction conditions[a]



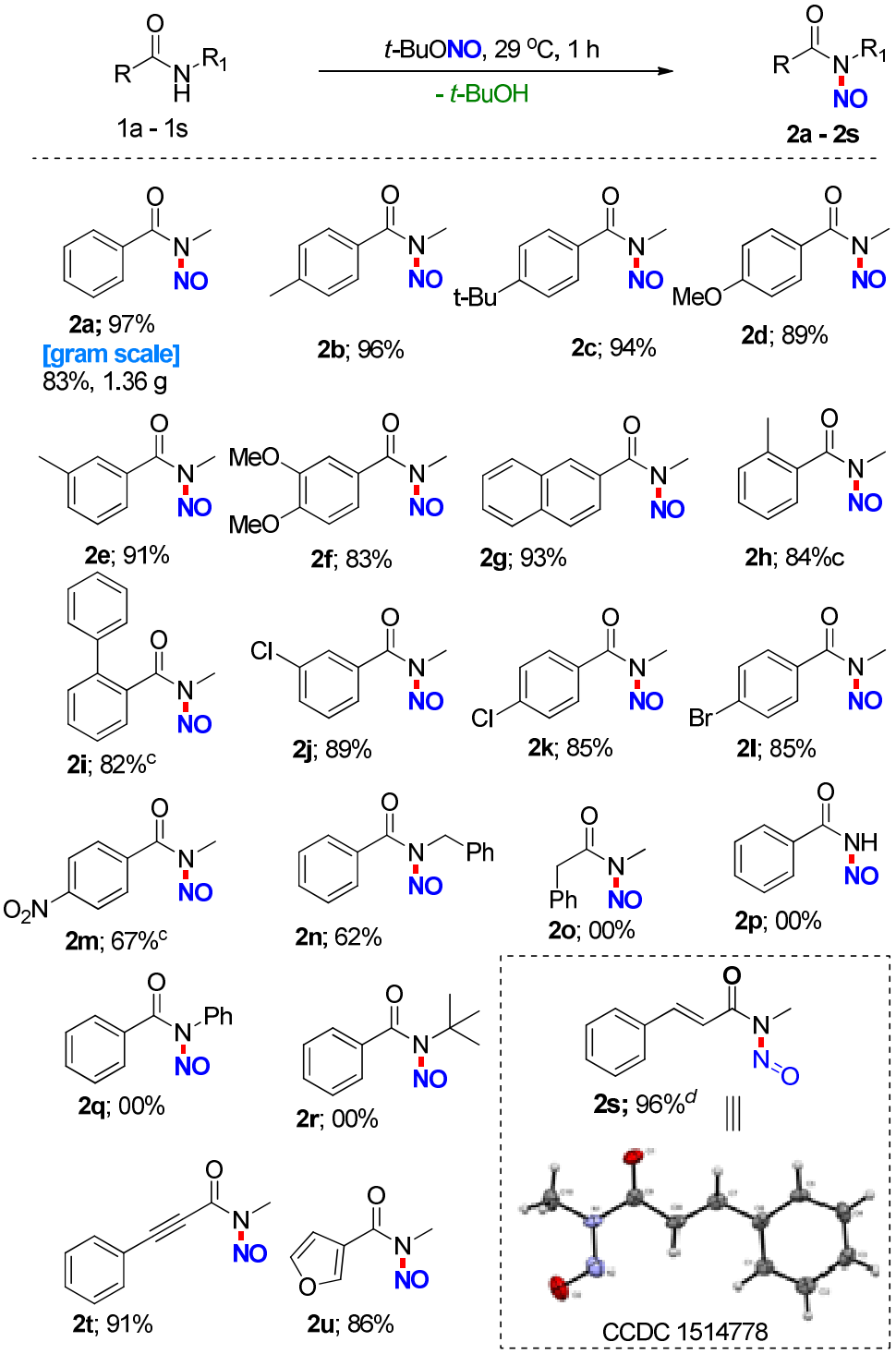
Entry	-NO reagent (equiv.)	Solvent	Time (h)	temp. (°C)	Yield (%)[b] **2a**	**2a´**
1	I	DCE	3	60	-	96
2	I	DCE	3	40	46	51
3	I	DCE	3	rt	83	Trace
4	I	DCE	1	rt	87	-
5	I	DCE	0.5	rt	63	-
6	II	DCE	1	rt	74	-
7	III	DCE	1	rt	89	-
8	IV	DCE	1	rt	89	-
9	V	DCE	1	rt	93	-
10	V	DMF	1	rt	48	-
11	V	CH_2Cl_2	1	rt	93	-
12	V	n-hexane	1	rt	93	-
13	V	-	1	rt	97	-

[a]Reaction conditions: *N*-methylbenzamide **1a** (1 mmol), alkyl nitrite **I-V** (1.5 mmol), Solvent (3 mL).

[b]Isolated yield. rt= Room temperature (29 °C).

A mixture of trace amount of *N*-nitrosoamide **2a** and 96% methylbezoate **2a´** were observed (Table 1, entry 1). On minimizing the temperature, the yield of product **2a** increases while that of **2a´** decreases (Table 1, entries 2-3). Importantly, by decreasing the reaction time, the selectively towards *N*-nitrosoamide **2a** was increased and good yield of **2a** was observed within 1 h (Table 1, entries 4-5). Moreover, the reactivity of other alkyl nitrite isomers was also checked. The yield of **2a** produced on using ethyl nitrite **(II)**, isobutyl nitrite **(III),** isopentyl nitrite **(IV)** and *t*-butyl nitrite **(V)** were 74%, 89%**,**89% and 93% respectively (Table 1, entries 6-9). From the above observations, it was found that the reactivity of nitrites towards the *N*-nitrosylation of **1a** follows the order *tert*-butyl nitrite > isopentyl nitrite = isobutyl nitrite > *n*-butyl nitrite > ethyl nitrite. Subsequently, solvent studies revealed that non-polar solvents were more effective than polar solvents (Table 1, entries 10-12). Delightfully, the reaction resulted in 97% yield of **2a** when performed under neat condition (Table 1, entry 13). Notably, under neat conditions, the solid amide converts into yellow colored liquid *N*-nitrosoamide which can be easily observed by naked eyes. With the optimized parameters in hand, we focused our attention on substrate scope for *N*-nitrosoamide synthesis (Table 2). *N*-methylamides containing electron donating groups at –*para* and –*meta* positions provided the respective *N*-nitrosoamides (**2b-2g**) in 83% to 96% yields. *Ortho* substituted amides regioselectively provided **2h** and **2i** in 84% and 82% yields after 1.25 h. Amides containing electron withdrawing groups such as –Cl and –Br at –*meta* and –*para* position afforded **2j-2l** in 85% to 89% yields. Significantly, strong electron withdrawing group like 4-nitroamide also provided a good yield of **2m** after 1.25 h. Next, *N*-benzylbenzamide provided 62% of *N*-nirosoamide product **2n**. However, aliphatic *N*-methylamide **1o**, benzamide **1p**, phenylbenzamide **1q** and *N*-*tert*-butylbenzamide **1r** were inactve for nitrosylation. Interestingly, the external double bond containing *N*-methylcinnamamide **1s**

Table 2 Substrate scope of *N*-nitrosoamide synthesis[a]



[a]Reaction conditions: amide **1a-1u** (1 mmol) and *t*-BuONO (1.5 mmol) were stirred at room temperature. [b]Isolated yields. [c]1.25 h, [d]20 min.

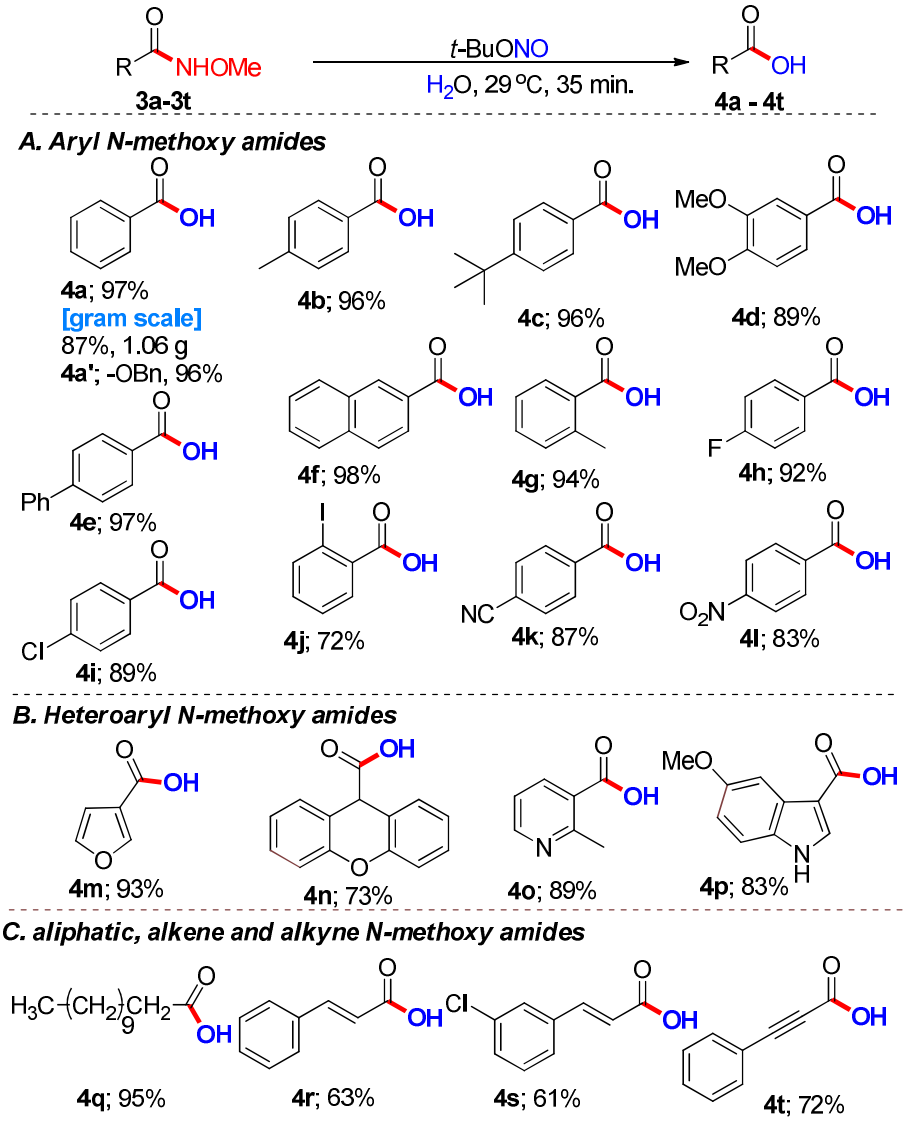
provided yellow colored crystalline *N*-methyl-*N*-nitrosocinnamamide **2s**, which was unambiguously confirmed by an X-ray crystallographic analysis (CCDC 1514778). Furthermore, the alkynyl and heteroaromatic groups containing *N*-methylamides reacted smoothly with TBN and provided 91% and 86% yield of *N*-nitrosoamides **2t** and **2u**. Additionally, the present reaction was scaled up to gram-scale yielding 83% (1.36 g) of **2a** and 89% (1.6 g) of **2s**.

b) Carboxylic acid synthesis from *N*-alkoxyamides

After the successful synthesis of *N*-nitrosoamide using organonitrite, this protocol was further extended for the synthesis of carboxylic acids by the hydrolysis of *N*-alkoxyamides. Generally, the classical hydrolysis of amides using stoichiometric amount of acid/base as well as catalytic amount of enzyme/DNA has been documented (Scheme 1, b).[5,8a-b,9] However, the aforementioned protocols require harsh reaction conditions and long reaction time which suggests the use of TBN for the reaction. To overcome this drawback and extend the scope of TBN, we selected alkoxyamide as a model substrate and water as a solvent. Interestingly, 97% yield of benzoic acid **4a** was observed within 35 min. The acid formation from amide was easily observed by the formation of a white colored solid on the surface of water with the simultaneous liberation of nitrogen. With optimal reaction conditions in hand, we explored the substrate scope for acid synthesis from respective *N*-alkoxyamides (Table 3). Various *N*-methoxyamides such as aromatic, heteroaromatic as well as aliphatic amides were well tolerated and provided the respective carboxylic acids in excellent yields. The *N*-benzyloxyamide reacted smoothly affording 96% yield of **4a´**. Notably, **3a** could be transformed into **4a** even at gram scale resulting in 87% yield of the corresponding benzoic acid. The effect of electron donating and withdrawing groups on aromatic ring was studied using *N*-methoxy aromatic amide. The amides

containing electron donating groups such as –Me, –OMe, *tert*-butyl and –Ph on phenyl ring also provided the carboxylic acids **4b-4g** in 89% to 98% yields.

Table 3. Substrate scope of carboxylic acid synthesis *via* cleavage of amide C-N bond[a]



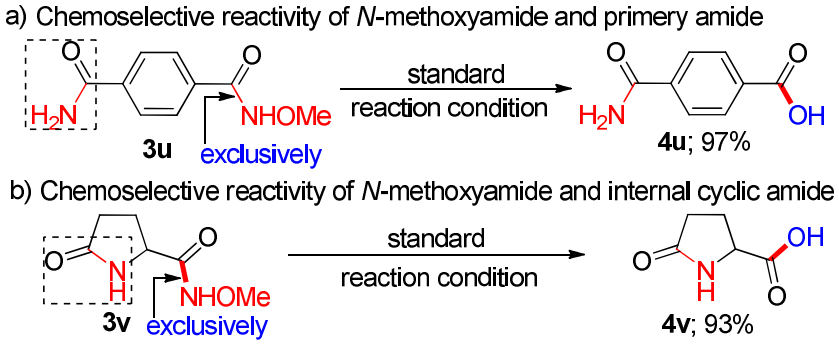
[a]Reaction conditions: amide **3a-3t** (1 mmol), *t*-BuONO (1.5 mmol), H_2O (3 mL), room temperature (29 °C), 35 min. Isolated Yield.

Significantly, the present protocol is easily tolerated with electron withdrawing substituent like –F –Cl, –I, –CN and $–NO_2$ on *N*-methoxybenzamide and the carboxylic acids **4h-4l** were obtained

in 72% to 92% yields respectively. This method is also useful for the conversion of heteroaromatic *N*-methoxyamides to the respective acids **4m-4p**. Moreover, hydrolysis of aliphatic, alkenyl and alkynyl *N*-methoxyamides, **3q-3t**, could also be satisfactorily carried out.

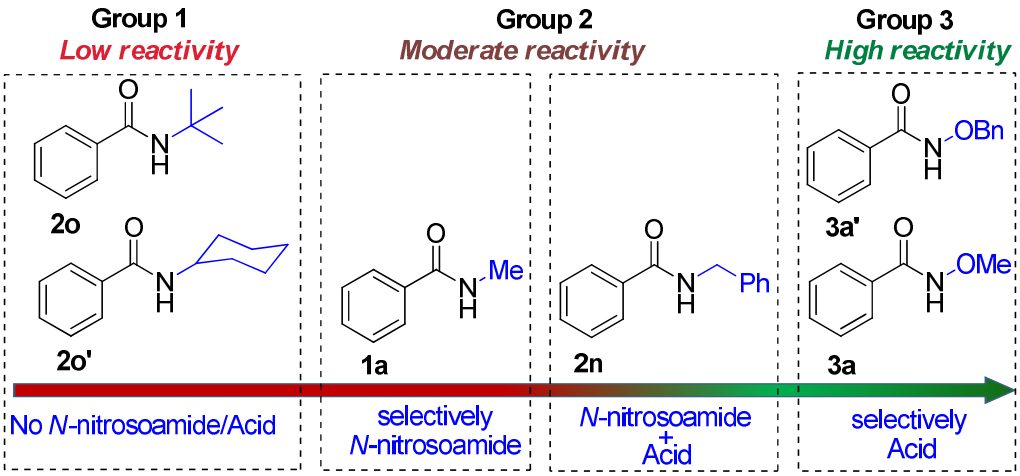
To investigate the chemoselectivity of amides with TBN, we employed the substrate **3u** containing a primary as well as *N*-methoxyamide and substrate **3v** containing both, an internal secondary amide and *N*-methoxyamide. In both the cases, the selective hydrolysis of *N*-methoxyamide was observed, while the primary and internal secondary amides were stable towards hydrolysis (Scheme 2).

Scheme 2. TBN for chemoselective hydrolysis of amides



For better understanding, the selective reactivity of amides with TBN at room temperature for the synthesis of *N*-nitrosoamide/acid has been classified into three groups (Scheme 3). The amides in **Group 1** containing electron rich *N*-substituents show low reactivity. **Group 2** contains moderately reactive amides in which *N*-methylamides exclusively undergo nitrosylation and *N*-benzylamides undergo nitrosylation and were further transformed into carboxylic acids. The amides present in **Group 3** show high reactivity towards the hydrolysis reaction as compared to other groups.

Scheme 3. Classification of amides based on reactivity with *t*-BuONO for the nitrosylation and hydrolysis reactions.



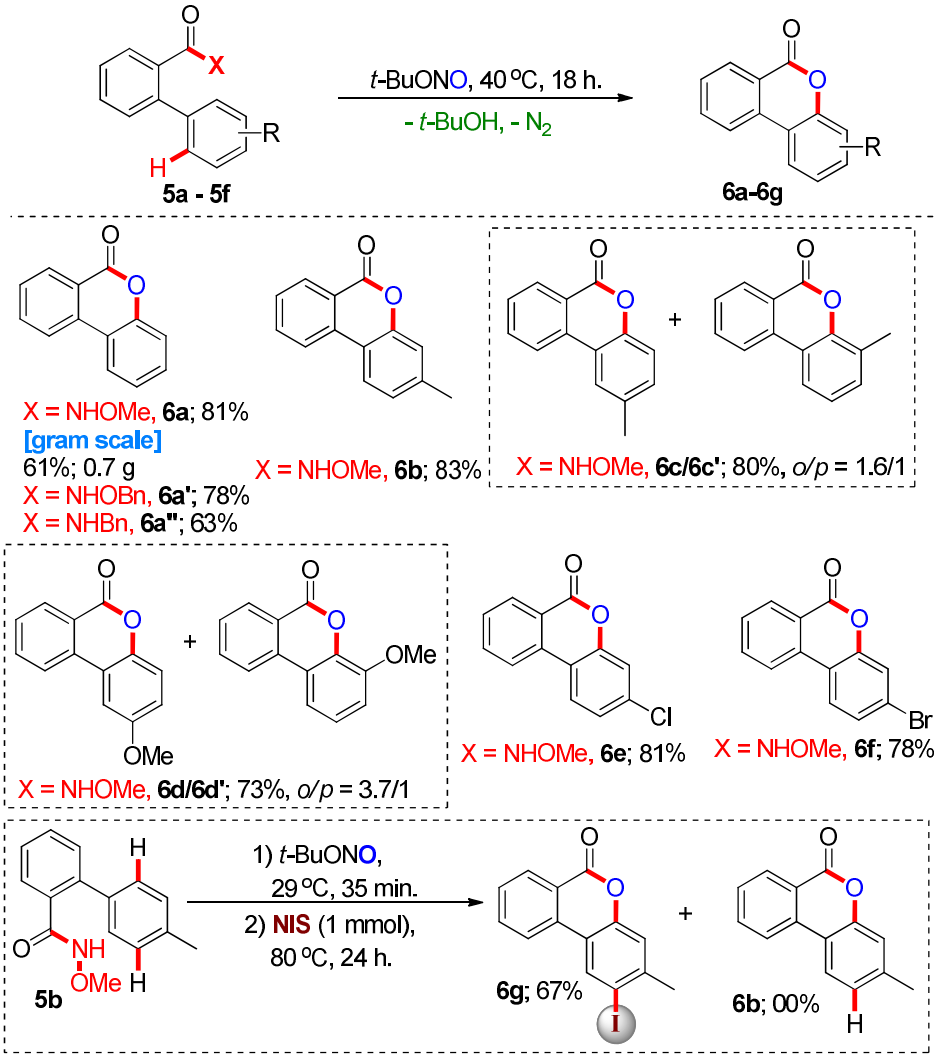
From these observations, we concluded that the TBN reactivity increases with decreasing electron deficiency on the nitrogen of the amides.

C) Benzocoumarin synthesisfrom *ortho*-aryl-*N*-methoxybenzamide

Inspired by the results obtained with TBN in the case of nitrosylation and hydrolysis of amides, we further extended this protocol for the synthesis of benzocoumarin. Benzocoumarin and their derivatives are important scaffolds found in natural products and pharmaceuticals due to their remarkable biological activity.[25] Consequently, extensive efforts have been developed for their synthesis. Benzocoumarin can be synthesized from *ortho*-aryl benzoic acid using metal catalyst[26] or under metal-free conditions[27] using a stoichiometric amount of oxidizing agents (Scheme 1, c). Based on above one-pot conversion of *N*-methoxyamide to a carboxylic acid, we tested *ortho*-aryl-*N*-methoxybenzamide **5a** as a new substrate for the benzocoumarin synthesis. Guided by prior reports,[26-27] $(NH_4)_2S_2O_8$, Ag_2O, $Cu(OAc)_2$, benzo quinone and *N*-iodosuccinimide (NIS) oxidants were screened in DCE at 60 °C for 18 h. Remarkably, even in the absence of oxidant and solvent, 76% yield of **6a** was observed. Assuming the radical reaction pathway, on

decreasing the reaction temperature, 81% (GC Yield) yield of product **6a** was observed at 40 °C. However, decreasing the reaction temperature below 40 °C and time less than 18 h, the yield of product decreased.

Table 4. Substrate scope of benzocoumarin synthesis.[a]



[a]Reaction conditions: amide (**5a-5f**, 1 mmol), *t*-BuONO (1.5 mmol), 40 °C, 18 h. Isolated Yield.

Thus, the optimized reaction conditions for benzocoumarin synthesis was **5a** (1 mmol), *t*-BuONO (1.5 mmol), at 40 °C for 18 h. The optimized reaction conditions were subsequently applied for the synthesis of a variety of benzocoumarin from 2-phenyl-*N*-methoxybenzamide

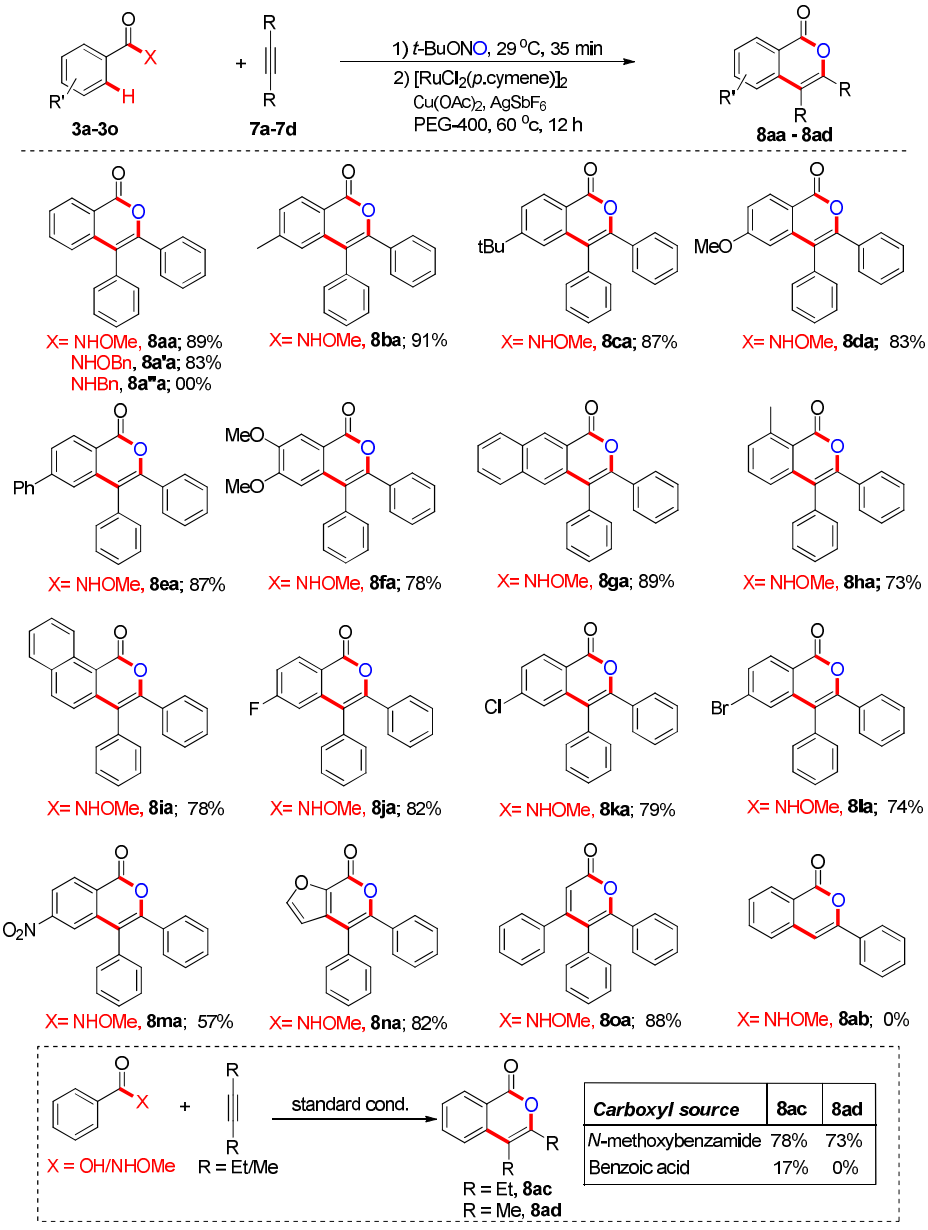
derivatives (Table 4). It was found that a variety of 2-phenyl-*N*-methoxybenzamides could be converted to the desired product in good yields. The model reaction having *N*-methoxy, *N*-benzyloxy and *N*-benzyl shows 81%, 78% and 63% isolated yield of product **6a**, **6a´** and **6a´´**, respectively. The present reaction could also tolerate electron-donating groups. *Para*-CH_3 containing amide **5b** provided the 83% yield of **6b**. However, the *meta*-substituted amides **5c** and **5d** gave a good yield with two regioisomers in ratios of **6c**/**6c´** 1.6:1 and **6d**/**6d´** 3.7:1 respectively. Furthermore, the reaction tolerates electron withdrawing groups like –Cl and –Br resulting in the synthesis of **6e** and **6f** in 81% and 78% yield respectively. To check the reactivity of amide **5b** was stirred by the addition of 1 mmol of *N*-iodosuccinimide at 80 ^{o}C for 24 h. Surprisingly, 2-iodo-3-methyl benzocoumarin **6g** was observed instead of 3-methyl benzocoumarin **6b**. Notably, **6g** is an important iodo derivative useful for coupling reactions.

d) Isocoumarin synthesis from *N*-methoxybezoamide

Isocoumarin as a structural motif has attracted attention of synthetic and medicinal chemists due to numerous biological activities.[28] Traditionally, multistep synthesis of isocoumarin has been well reported.[29] Importantly, one pot synthesis of isocoumarin has been developed using Rh(III)/Ru(II) catalytic system *via ortho* C-H activation of benzoic acid (Scheme 1, d).[30] Of late, PEG was used as a biodegradable solvent in organic transformations due to the recyclability of homogeneous transition metal catalytic system.[31] We have earlier reported the Ru(II)/PEG-400 catalytic system for isocoumarin synthesis from benzoic acid.[32] Considering the importance of isocoumarins, herein we report *N*-methoxyamide as a novel surrogate for isocoumarin synthesis using TBN as oxygen source for the rapid cleavage of the amide C-N bond and the Ru(II)/PEG catalytic system for *ortho*-C–H bond activation. The model reaction of *N*-methoxybenzamide **3a,**

TBN and diphenylacetylene **7a** was chosen for lactonization in presence of $[RuCl_2(p\text{-cymene})]_2$ (5 mol%), $Cu(OAc)_2$ (0.25 mmol), and $AgSbF_6$ (5 mol%).

Table 5. Substrate scope of the ruthenium-catalyzed isocoumarin synthesis[a]



[a]Reaction conditions: *N*-methoxybenzamide **3a-3o** (0.5 mmol), *t*-BuONO (0.75 mmol), alkyne **7a – 7d** (1 mmol), [{$RuCl_2(p$-cymene)}$_2$] (3 mol%), $Cu(OAc)_2$ (0.25 mmol), $AgSbF_6$ (5 mol%), PEG-400 (4 mL), Isolated yield.

The reaction proceeded with 89% yield of **8aa** in DCE as solvent. The catalyst loading plays a crucial role, whereby, decreasing the catalyst amount to less than 3 mol% resulted in a lower yield of **8aa**. Next, PEG-400 as a recyclable and green solvent was tested and up to 81% yield of **8aa** was observed. However, as compared to PEG-400, in the presence of PEG-600 yield of **8aa** decreases. This might be due to the low solubility of starting material in the latter. In temperature study, it was observed that by increasing or decreasing the temperature above or below 60 ^{o}C, the yield of **8aa** also decreased. Whenever, the reaction time is less than 12 h, the yield of the product decreases. Thus, the final optimized reaction conditions for isocoumarin synthesis are **3a** (0.5 mmol), diphenylacetylene **7a** (1 mmol), *t*-BuONO (0.7 mmol) [{$RuCl_2$(*p*-cymene)}$_2$] (3 mol%), $Cu(OAc)_2$ (0.25 mmol), $AgSbF_6$ (10 mol%), PEG-400 (4 mL) at 60 °C for 12 h shown the 92% (GC Yield) yield of **8aa**. With the optimal reaction conditions in hand, we further explored the detailed substrate scope for isocoumarin synthesis from *N*-methoxyaromatic amides with alkyne (Table 5). The model reaction having *N*-methoxy and *N*-benzyloxy shows 89% and 83% isolated yield of product **8aa** and **8a´a**, respectively. However, *N*-benzyl containing amide was inactive for isocoumarin synthesis. The reaction tolerates a broad range of *N*-methoxybenzamide containing various electron donating and withdrawing groups. The electron donating groups like –Me, –*tert*-butyl, –OMe and –Ph at *para* position of *N*-methoxybenzamide afforded the corresponding products, **8ba-8ea**, in 83% to 91% yields. The reaction proceeded regioselectively resulting in products **8fa-8ga** with exclusively coupling at the less hindered side. In addition, *ortho*-substituted aromatic amides such as *N*-methoxy-2-naphthamide and 2-methyl-*N*-methoxybenzamide were also tolerated and the corresponding isocoumarins **8ha** and **8ia** were observed in 73% and 78% yield respectively. Next, the halide containing amides at the *para* position also provided good yields of **8ja-8la**. Notably, the strong electron withdrawing group

like -NO_2 could be tolerated and **8ma** was obtained in 57% yield. Moreover, the reactivity study of heteroarene was carried out and *N*-methoxyfuran-2-carboxamide led to product **8na** in 82% yield. Next, the substrate containing external double bond (methoxycinnamamide) was studied and **8oa** was obtained in 88% yield. Unfortunately, terminal alkyne (phenylacetylene) was not effective for the present reaction and **8ab** was not observed. After the substrate scope of *N*-methoxybenzamides, the comparative reactivity of benzoic acid and *N*-methoxybenzamide was checked. The aliphatic internal alkynes, 3-hexyne and 2-butyne, reacted effectively in the case of *N*-methoxybenzamide and provided **8ac** and **8ad** in 78% and 73% yield respectively. However, they reacted ineffectively when benzoic acid was used as the substrate. After the successful substrate study for isocoumarin synthesis, the recyclability study of Ru(II) homogeneous catalyst was carried out. It was observed that the catalytic system was effective up to the 4^{th} recycle [92, 90, 89 and 89% (GC Yield)].

To gain insight into the reaction mechanism, we analyzed the TBN mediated functional group interconversion of amide to acid, using IR spectroscopy (Figure 1). The spectrum **(a)** and **(b)** denotes only TBN and *N*-methoxybenzamide respectively. The spectrum **(c)** is the reaction mixture after 5 min and shows the disappearance of ~3216 cm^{-1} (amide N-H) and ~1646 cm^{-1} (amide C=O) of the amide. At the same time, a new band at ~1726 $cm^{-1}$was observed which represents the formation of *N*-nitrosoamideintermediate. After 15 min., the band at ~1726 cm^{-1} disappears and a new band at ~1761 cm^{-1} was observed which represents the formation of 1-(benzoyloxy)-2-methoxydiazene intermediate (spectrum **d**). After 25 min., the band ~1761 cm^{-1} disappears with the liberation of N_2 and a new band at ~1702 cm^{-1} was observed which corresponds to C=O of benzoic acid (spectrum **e**). Finally, after 35 min, the band at ~1761 cm^{-1}

completely disappears and we observed an intense band at ~1702 cm^{-1} that confirmed the complete conversion into benzoic acid (spectrum **f**).

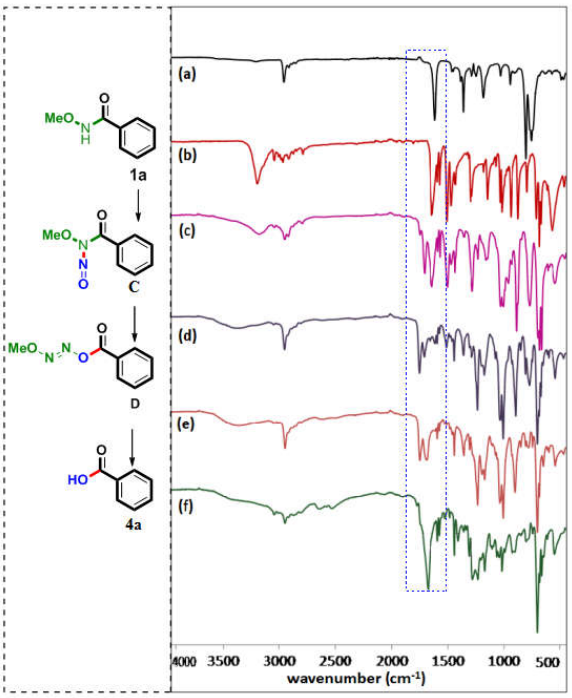
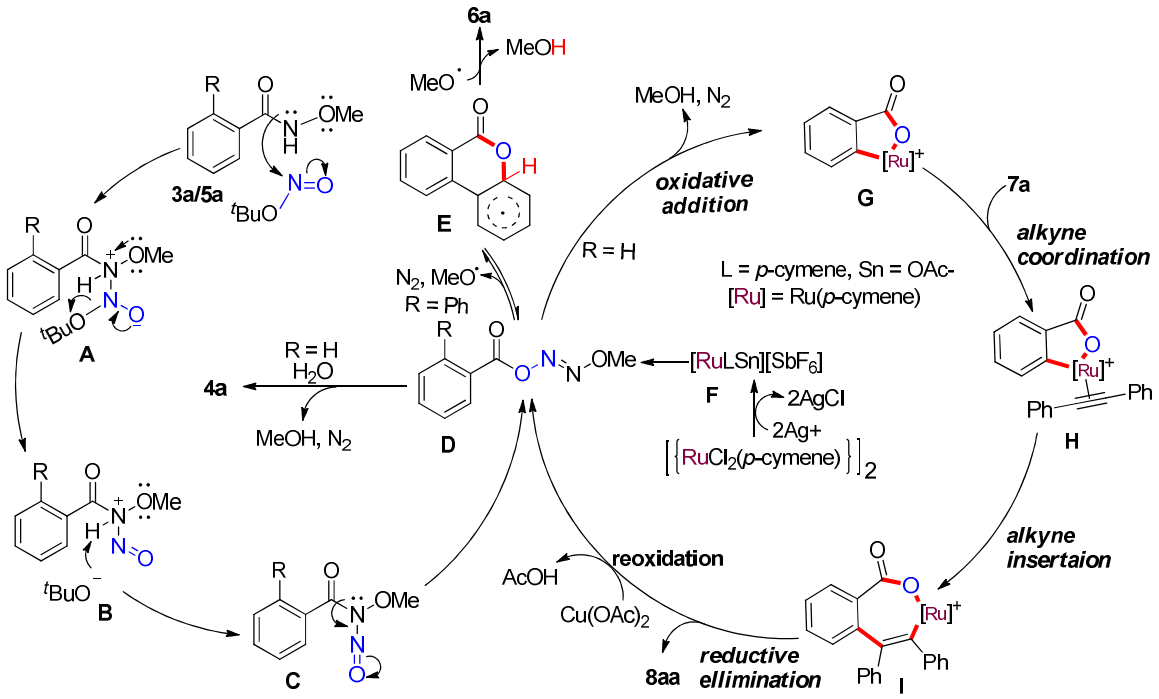


Figure 1. IR spectroscopic observations of TBN for sequential interconversions of amide to acid *via N*-nitrosoamide intermediate

A tentative reaction mechanism based on existing literature[23c] and control experiments has been proposed (Scheme 4). Initially, the nucleophilic addition of the amide N-H to electron deficient nitrogen of TBN takes place to generate intermediate **A**. From the intermediate **A**, release of the $^{t}BuO^{-}$ ion results in the formation of intermediate **B**, which absorbs the proton form intermediate **C** and undergoes rearrangement to **D**.[17] **D** is highly air and moisture sensitive and undergoes rapid hydrolysis to furnish carboxylic acid **4a**. In the case of presence of *ortho*-aryl functionality in **D,** it subsequently forms intermediate **E** through the expulsion of N_2 and OMe radical.[26a] The generated OMe radical thus abstracts H radical from intermediate **E** to affords **6a**.

Scheme 4. Plausible Reaction Mechanism



In isocoumarin synthesis, the removal of chloride ligand from $[RuCl_2(p\text{-cymene})]_2$ complex by $AgSbF_6$ salt gives active ruthenium species **F**.[32] Then Ru(II) forms a complex with hexafluoroantimonate which transforms into the five-membered ruthenacycle **G** by *ortho*-C-H bond activation of **D** with the release of MeOH and N_2 (*oxidative addition*). This is followed by co-ordination of the ruthenium with diphenylacetylene **7a** to form **H** and subsequent alkyne insertion which generates the seven-membered intermediate **I**. The reductive elimination of **I** gives the annulated product **8aa**. The Ru^0 species at the final step is oxidized by Cu(II) to regenerate the active Ru(II) species for the next catalytic cycle.[32]

In conclusion, we have applied TBN as a multitask reagent for sequential nitrosylation reactions for i) the synthesis of *N*-nitrosoamide from *N*-alkyl amide under solvent free condition at room temperature, ii) the synthesis of carboxylic acids from amides under acid/base/metal/oxidant free condition with short reaction time and water as a green solvent, iii) the synthesis of

benzocoumarin from *ortho*-aryl-*N*-methoxybenzamide under metal/oxidant/solvent free conditions and iv) one pot synthesis of isocoumarin from *N*-methoxyaromatic amide using Ru(II)/PEG-400 as a recyclable catalytic system. Significantly, the protocols described herein could tolerate a wide substrate scope and could be carried out at gram scale. Importantly, the developed protocol is environmentally benign due to the formation of *t*-BuOH, MeOH, and N_2 as non hazardous side products.

EXPERIMENTAL SECTION

All the nitrite sources, solvents, oxidants, $[RuCl_2(p\text{-cymene})]_2$, $Cu(OAc)_2$ and $AgSbF_6$ were purchased from commercial sources. All reactions were carried out in oven-dried glassware. All amide derivatives were prepared by literature procedures.[1] Analytical TLC was performed with silica gel plates (0.25 mm thickness). Column chromatography was performed with silica gel (40−200 mesh). NMR spectra were recorded with 400 MHz or 300 MHz ^{1}H NMR and 126 or 101 MHz or 76 MHz ^{13}C NMR spectrometer. The chemical shifts are reported in parts per million relative to tetramethylsilane as an internal standard and the coupling constant *J* in hertz. The reaction was monitored by GC and TLC. The products were analyzed by GC-MS and IR. HRMS was recorded on a micromass ESI TOF (time-of-flight) mass spectrometer.

Experimental procedure for *N*-nitrosoamide synthesis

In oven–dried 10 mL reaction tube equipped with magnetic stir–bar, *N*-methylbenzamide **1a** (1 mmol, 135 mg) and *tert*-butyl nitrite (1.5 mmol, 155 mg) were added by syringe. The reaction mixture was stirred at 29 °C (room temperature) for 1 h. After completion of the reaction, all volatiles were removed under vacuum. The yellow colored oil *N*-nitrosoamide product **2a** was purified by column chromatography (silica gel, 40−200 mesh) and confirmed by NMR. In gram

scale synthesis, the *N*-methylbenzamide **1a** (10 mmol, 1.35 g) and *tert*-butyl nitrite (1.5 mmol, 1.55 g) were added by syringe in oven–dried 100 mL round bottom flask. The reaction mixture was stirred at 29 °C (room temperature) for 1.25 h. After completion of the reaction, all volatiles were removed under vacuum. The 1.36 g (83%) of yellow colored oily *N*-nitrosoamide product **2a** was observed.

Experimental procedure for acid synthesis

In oven–dried 10 mL reaction tube equipped with, magnetic stir–bar, *N*-methoxybenzamide **3a** (1 mmol, 151 mg) and *tert*-btutyl nitrite (1.5 mmol, 155 mg) were added by syringe in 3 mL of water. The reaction mixture was stirred at 29 °C (room temperature) for 35 min. The colorless solid benzoic acid product **4a** was purified by column chromatography (silica gel, 40−200 mesh). In gram scale carboxylic acid synthesis, the *N*-methoxybenzamide **3a** (10 mmol, 1.35 g) and *tert*-butyl nitrite (1.5 mmol, 1.55 g) were added drop wise in 100 mL round bottom flask at the cool condition. The reaction mixture was stirred at 29 °C (room temperature) for 45 minutes. After completion of the reaction, all volatiles were removed under vacuum. The 1.06 g (87%) of benzoic acid product **4a** was observed.

Experimental procedure for benzocoumarin synthesis

In oven–dried 10 mL reaction tube equipped with, magnetic stir–bar, 2-phenyl, *N*-methoxybenzamide **5a** (1 mmol, 227 mg) and *tert*-butyl nitrite (1.5 mmol, 155 mg) was added by syringe. The reaction mixture was stirred at 40 °C for 18 h. After completion of the reaction, all the volatiles were removed under vacuum. The colorless solid benzocoumarin product **6a** was purified by column chromatography (silica gel, 40−200 mesh). In gram scale benzocoumarin synthesis, the 2-phenyl, *N*-methoxybenzamide **5a** (6 mmol, 1.36 g) and *tert*-butyl nitrite (9 mmol, 0.93 g) was added drop wise in 100 mL round bottom flask at the cool condition for 1 h.

Next, reaction was stirred to 29 °C (room temperature) for 18 h. After completion of the reaction, all the volatiles were removed under vacuum. The 0.7 g (61%) of benzocoumarin product **6a** was observed.

Experimental procedure for Ru(II)/PEG-400 catalyzed isocoumarin synthesis and catalyst recyclability

In a 15 mL Schlenk tube, *N*-methoxybenzamide **3a** (0.50 mmol, 76 mg) and *tert*-butyl nitrite (0.8 mmol, 78 mg) were added by syringe. The reaction mixture was stirred at 29 °C (room temperature) for 35 minutes, followed by added diphenylacetylene **7a** (1 mmol, 178 mg), $[RuCl_2(p\text{-cymene})]_2$ (3 mol%, 18 mg), $Cu(OAc)_2$ (0.25 mmol, 45 mg), and $AgSbF_6$ (5 mmol, 17 mg). To the same mixture 4 mL PEG-400 was added and the reaction mixture was stirred at 60 °C for 12 h. After completion of the reaction, the reaction mixture was cooled to room temperature. Next, 7-8 mL of diethyl ether was added in the same Schlenk tube and was shaken for 2-3 minutes. The upper layer containing product mixture was transferred to 150 mL round bottom flask and the process was repeated for 3-4 times. All volatiles were removed from the product mixture under vacuum. The colorless solid isocoumarin product **8aa** was purified by column chromatography (silica gel, 40−200 mesh). In the recyclability study, the lower layer of PEG-400 containing catalytic system was heated at 40-50 ^{o}C for 10 minutes to remove the miscible diethyl ether and transferred back to the Schlenk tube containing stirred mixture of *N*-methoxybenzamideand *tert*-butyl nitrite for the next cycle.

***N*-methyl-*N*-nitrosobenzamide (2a)[20a]**

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 97% (159 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.73 (d, J = 7.5

Hz, 2H), 7.53 (t, J = 7.3 Hz, 1H), 7.43 (t, J = 7.6 Hz, 2H), 3.25 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 172.8, 132.7, 132.5, 130.7, 128.1, 26.8. **IR (ATR)** ν (cm^{-1}) 1704, 1495, 1342, 961.

_N_,4-dimethyl-_N_-nitrosobenzamide (2b)[19]

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 96% (167 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (d, J = 8.0 Hz, 2H), 7.23 (d, J = 7.9 Hz, 2H), 3.24 (s, 3H), 2.38 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 172.5, 143.4, 130.9, 129.8, 128.8, 26.8, 21.5. **IR (ATR)**ν (cm^{-1}) 1698, 1497, 1339, 1160, 959.

4-(*tert*-butyl)-*N*-methyl-*N*-nitrosobenzamide (2c)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 94% (206 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.72 (d, J = 8.3 Hz, 2H), 7.47 (d, J = 8.4 Hz, 2H), 3.25 (s, 3H), 1.32 (s, 9H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 172.4, 156.2, 130.9, 129.8, 125.1, 35.0, 31.0, 26.8. **IR (ATR)**ν (cm^{-1}) 1701, 1497, 1335, 1167, 960, 804. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{12}H_{16}N_2O_2Na$ 243.1103; found 243.1104.

4-methoxy-*N*-methyl-*N*-nitrosobenzamide (2d)[19]

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 89% (172 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.74 (d, J = 8.3 Hz, 2H), 6.90 (d, J = 8.3 Hz, 2H), 3.80 (s, 3H), 3.22 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.5, 163.2, 133.4, 124.6, 113.5, 55.4, 27.0. **IR (ATR)**ν (cm^{-1}) 1688, 1497, 1255, 1159, 1020, 958.

_N_,3-dimethyl-_N_-nitrosobenzamide (2e)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 91% (161 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.56 – 7.51 (m, 2H), 7.37 – 7.30 (m, 2H), 3.26 (s, 3H), 2.38 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 173.0, 138.0, 133.3, 132.7, 131.1, 128, 127.9, 26.8, 21.2. **IR (ATR)***v* (cm^{-1}) 1700, 1503, 1342, 1163, 970, 727. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_9H_{10}N_2O_2Na$ 201.0634; found 201.0634.

3,4-dimethoxy-*N*-methyl-*N*-nitrosobenzamide (2f)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (70:30 v/v) mixture as eluent. Isolated yield: 83% (185 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.37 – 7.34 (m, 2H), 6.86 (d, J = 8.3 Hz, 1H), 3.88 (s, 3H), 3.85 (s, 3H), 3.27 – 3.15 (m, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.5, 152.9, 148.5, 125.8, 124.6, 113.5, 109.9, 55.98, 55.9, 27.1. **IR (ATR)***v* (cm^{-1}) 1695, 1597, 1493, 1341, 1243, 1132, 988, 746. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{10}H_{12}N_2O_4Na$ 247.0690; found 247.0689.

***N*-methyl-*N*-nitroso-2-naphthamide (2g)**

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 93% (199 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.31 (s, 1H), 7.85 (dt, J = 19.1, 7.6 Hz, 4H), 7.54 (dt, J = 14.8, 7.2 Hz, 2H), 3.34 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 172.8, 135.0, 132.5, 132.1, 129.9, 129.3, 128.5, 127.9, 127.7, 126.9, 126.3, 27.0. **IR (ATR)***v* (cm^{-1}) 1704, 1479, 1335, 1155, 1002, 921, 781, 754. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{12}H_{10}N_2O_2Na$ 237.0654; found 237.0634.

***N*,2-dimethyl-*N*-nitrosobenzamide (2h)**

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 84% (149 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 (d, J = 8.2 Hz, 2H), 7.29 – 7.18 (m, 2H), 3.25 (s, 3H), 2.29 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 174.5, 136.1, 133.9, 130.6, 130.6, 128.4, 125.4, 26.0, 19.7. **IR (ATR)**ν (cm^{-1}) 1707, 1502, 1340, 1167, 956, 735. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_9H_{10}N_2O_2Na$ 201.0632; found 201.0634.

_N_-methyl-_N_-nitroso-[1,1'-biphenyl]-2-carboxamide (2i)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 82% (196 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 (d, J = 7.5 Hz, 1H), 7.59 – 7.52 (m, 1H), 7.45 (dd, J = 13.1, 7.5 Hz, 2H), 7.36 – 7.20 (m, 5H), 2.91 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 175.1, 141.3, 140.1, 133.8, 131.0, 129.6, 128.7, 128.5, 128.2, 127.7, 127.3, 25.7. **IR (ATR)**ν (cm^{-1}) 1707, 1504, 1344, 1167, 962, 742. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_{14}H_{12}N_2O_2Na$ 263.0792; found 263.0791.

_N_,4-dimethyl-_N_-nitrosobenzamide (2j)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 85% (168 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.72 (s, 1H), 7.61 (d, J = 7.7 Hz, 1H), 7.51 (dd, J = 8.0, 1.0 Hz, 1H), 7.38 (t, J = 7.9 Hz, 1H), 3.26 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.6, 134.3, 134.2, 132.4, 130.5, 129.4, 128.7, 26.8. **IR (ATR)**ν (cm^{-1}) 1701, 1496, 1340, 1144, 971, 777, 734. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_8H_7ClN_2O_2Na$ 221.0091; found 221.0088.

4-chloro-_N_-methyl-_N_-nitrosobenzamide (2k)[19]

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 89% (176 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.78 – 7.57 (m, 2H), 7.54 – 7.22 (m, 2H), 3.24 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.7, 138.9, 132.2, 130.9, 128.5, 26.8. **IR (ATR)***v* (cm^{-1}) 1708, 1588, 1488, 1397, 1342, 1164, 963, 804.

4-bromo-*N*-methyl-*N*-nitrosobenzamide (2l)

Yellow solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 85% (206 mg). mp 86 – 88 ^oC. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 – 7.58 (m, 2H), 7.58 – 7.47 (m, 2H), 3.23 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.8, 132.2, 131.4, 131.1, 127.5, 26.8. **IR (ATR)***v* (cm^{-1}) 1708, 1582, 1497, 1394, 1160, 1069, 946. **HRMS** (ESI-TOF) m/z: $[M + Na]^+$ Calcd for $C_8H_7BrN_2O_2Na$ 264.9579; found 264.9583.

***N*-methyl-4-nitro-*N*-nitrosobenzamide (2m)[19]**

Yellow solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (70:30 v/v) mixture as eluent. Isolated yield: 67% (140 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.40 – 8.20 (m, 2H), 7.89 (d, J = 8.4 Hz, 2H), 3.34 – 3.25 (m, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 171.4, 149.7, 138.4, 131.4, 123.3, 26.7. **IR (ATR)***v* (cm^{-1}) 1711, 1514, 1488, 1346, 1167, 960.

***N*-benzyl-*N*-nitrosobenzamide (2n)[19]**

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 62% (148 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.82 – 7.75 (m, 2H), 7.57 (dd, J = 10.7, 4.1 Hz, 1H), 7.47 (t, J = 7.5 Hz, 2H), 7.36 – 7.24 (m, 5H), 5.13 (s, 2H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 172.9, 134.6, 132.9, 132.6, 130.7, 128.7, 128.5, 128.2, 127.9, 42.9. **IR (ATR)***v* (cm^{-1}) 1698, 1497, 1346, 1159, 951, 800.

***N*-methyl-*N*-nitrosocinnamamide (2s)**

Yellow solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 96% (182 mg). mp = 100 – 102 °C. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.97 (d, J = 15.8 Hz, 1H), 7.80 (d, J = 15.8 Hz, 1H), 7.63 – 7.55 (m, 2H), 7.38 (d, J = 4.7 Hz, 3H), 3.17 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 168.5, 147.2, 134.3, 130.9, 128.9, 128.6, 115.5, 25.8. **IR (ATR)**ν (cm^{-1}) 1695, 1624, 1475, 1206, 1023, 956. **HRMS** (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{10}H_{12}N_2O_2$ 191.0742; found 191.0813.

_N_-methyl-_N_-nitroso-3-phenylpropiolamide (2t)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 91% (171 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 7.73 – 7.67 (m, 2H), 7.42 – 7.31 (m, 3H), 3.13 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ166.0, 147.8, 136.9, 133.1, 131.1, 128.7, 127.4, 118.3, 114.5, 25.6. **IR (ATR)**ν (cm^{-1}) 1702, 1490, 1027. **HRMS** (ESI-TOF) m/z:$[M + Na]^+$ Calcd for $C_{10}H_8N_2NaO_2$211.0477; found 211.0478.

_N_-methyl-_N_-nitrosofuran-3-carboxamide (2u)

Yellow oil. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 86% (132 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.46 (t, J = 1.5 Hz, 1H), 7.02 – 6.94 (m, 1H), 3.24 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ165.38, 149.76, 143.12, 119.49, 111.70, 26.39. **IR (ATR)**ν (cm^{-1}) 1704, 1408, 1163, 956, 802. **HRMS** (ESI-TOF) m/z:$[M + H]^+$ Calcd for $C_6H_7N_2O_3$ 155.0448; found 155.0451.

Benzoic acid (4a)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 97% (118 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 13.09 (s, 1H), 8.19 (d, J = 7.7 Hz, 2H), 7.66 (t, J = 7.3 Hz, 1H), 7.52 (t, J = 7.5 Hz, 2H). **^{13}C{^{1}H}NMR**

(75 MHz, $CDCl_3$) δ 172.8, 133.9, 130.3, 129.4, 128.5. **GCMS** (EI, 70 eV) *m/z* (%) 122.00 (99.86), 105.00 (100), 77.00 (59.51), 51.00 (21.23). **IR (ATR)***v* (cm^{-1}) 1680, 1449, 1323, 1288, 704.

4-methylbenzoic acid (4b)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 96% (130 mg). **^{1}H NMR**(300 MHz, $CDCl_3$) δ 12.42 (s, 1H), 8.05 (d, J = 8.1 Hz, 2H), 7.30 (d, J = 7.9 Hz, 2H), 2.46 (s, 3H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 172.5, 144.7, 130.3, 129.2, 126.6, 21.7. **GCMS** (EI, 70 eV) *m/z* (%) 136.00 (92.22), 118.00 (100), 91.05 (69.44), 65.00 (19.18). **IR (ATR)***v* (cm^{-1})1672, 1404, 1269, 904, 733.

4-(*tert*-butyl)benzoic acid (4c)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 96% (170 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 12.27 (s, 1H), 8.10 (d, J = 8.3 Hz, 2H), 7.53 (d, J = 8.6 Hz, 2H), 1.39 (s, 9H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 172.6, 157.6, 130.2, 126.6, 125.4, 35.2, 31.1. **GCMS** (EI, 70 eV) *m/z* (%) 177.95 (20.42), 163.00 (100), 135.00 (35.34), 115.00 (5.89), 91.00 (24.55), 77.00 (7.42). **IR (ATR)***v* (cm^{-1}) 1679, 1419, 1285, 933, 706.

3,4-dimethoxybenzoic acid (4d)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (70:30 v/v) mixture as eluent. Isolated yield: 89% (161 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 11.50 (s, 1H), 7.80 (dd, J = 8.4, 2.0 Hz, 1H), 7.61 (d, J = 1.9 Hz, 1H), 6.93 (d, J = 8.5 Hz, 1H), 3.97 (d, J = 1.9 Hz, 6H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 172.1, 153.8, 148.9, 124.6, 121.7, 112.3,

110.3, 56.1, 56.0. **GCMS** (EI, 70 eV) *m/z* (%) 182.00 (100), 166.95 (35.87), 111.00 (20.02), 95.00 (16.19), 77.00 (19.14). **IR (ATR)***v* (cm^{-1}) 1669, 1586, 1420, 1234, 758.

[1,1'-biphenyl]-4-carboxylic acid (4e)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 97% (192 mg). **^{1}H NMR** (300 MHz, DMSO) δ 8.08 – 7.96 (m, 2H), 7.63 – 7.51 (m, 4H), 7.44 – 7.26 (m, 3H). **^{13}C{^{1}H}NMR**(75 MHz, DMSO) δ 168.1, 145.1, 139.9, 130.3, 129.8, 128.9, 128.1, 127.2, 126.9. **GCMS** (EI, 70 eV) *m/z* (%) 197.90 (98.48), 181.95 (43.54), 166.90 (56.18), 153.00 (46.96), 121.00 (43.57), 65.00 (100). **IR (ATR)***v* (cm^{-1})1672, 1420, 1286, 932, 746.

2-naphthoic acid (4f)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 98% (168 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 8.76 (s, 1H), 8.16 (dd, J = 8.6, 1.4 Hz, 1H), 8.02 (d, J = 7.9 Hz, 1H), 7.94 (dd, J = 8.1, 5.3 Hz, 2H), 7.63 (dt, J = 15.6, 6.8 Hz, 2H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 172.2, 135.9, 132.5, 132.2, 129.6, 128.7, 128.3, 127.8, 126.8, 126.6, 125.4. **GCMS** (EI, 70 eV) *m/z* (%) 172.00 (77.62), 155.05 (67.47), 127.05 (100), 102.05 (20.71), 63.00 (57.98). **IR (ATR)***v* (cm^{-1}) 1682, 1299, 777, 758.

2-methylbenzoic acid (4g)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 94% (127 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 8.12 (d, J = 7.6 Hz, 1H), 7.54 – 7.45 (m, 1H), 7.33 (dd, J = 10.6, 3.9 Hz, 2H), 2.71 (s, 3H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 173.6, 141.4, 133.0, 131.9, 131.6, 128.4, 125.9, 22.2. **GCMS** (EI, 70 eV) *m/z*

(%) 136.00 (89.61), 118.05 (100), 91.05 (70.42), 65.00 (19.71). **IR (ATR)***v* (cm^{-1}) 2637, 1673, 1406, 1270, 739.

4-fluorobenzoic acid (4h)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 92% (128 mg). **^{1}H NMR** (400 MHz, DMSO) δ 13.00 (s, 1H), 8.09 – 7.85 (m, 2H), 7.25 (dd, J = 12.0, 5.5 Hz, 2H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 166.8 (s), 166.6 (s), 164.1 (s), 132.5 (d, J = 9.4 Hz), 127.8 (d, J = 2.7 Hz), 116.1 (s), 115.8 (s). **GCMS** (EI, 70 eV) *m/z* (%) 140.00 (82.28), 123.00 (100), 95.00 (57.12), 63.00 (22.77). **IR (ATR)** *v* (cm^{-1}) 1676, 1602, 1293, 1156, 885, 767.

4-chlorobenzoic acid (4i)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 92% (134 mg). **^{1}H NMR** (400 MHz, DMSO) δ 13.06 (s, 1H), 7.89 (dd, J = 8.4, 3.7 Hz, 2H), 7.61 – 7.37 (m, 2H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 166.8, 138.2, 131.5, 131.5, 130.0, 129.1, 129.1. **GCMS** (EI, 70 eV) *m/z* (%) 155.95 (46.52), 138.95 (94.28), 110.95 (48.87), 63.00 (100). **IR (ATR)***v* (cm^{-1}) 1679, 1406, 1311, 1265, 904, 741.

2-iodobenzoic acid (4j)[34c]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 72% (178 mg). **^{1}H NMR** (300 MHz, DMSO) δ 8.78 (s, 1H), 7.86 (dd, J = 7.9, 1.0 Hz, 1H), 7.73 (dd, J = 7.8, 1.7 Hz, 1H), 7.30 (td, J = 7.6, 1.2 Hz, 1H), 7.03 (td, J = 7.7, 1.7 Hz, 1H). **^{13}C{^{1}H}NMR** (75 MHz, DMSO) δ 168.2, 141.0, 135.9, 132.3, 130.8, 128.2, 127.9, 93.9. **GCMS** (EI, 70 eV) *m/z* (%) 248.00 (7.51), 207.10 (7.97), 164.10

(57.83), 148.15 (100), 120.15 (31.52), 103.10 (45.23). **IR (ATR)***v* (cm^{-1}) 1672, 1581, 1265, 1014, 735.

4-cyanobenzoic acid (4k)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (70:30 v/v) mixture as eluent. Isolated yield: 87% (128 mg). **^{1}H NMR** (400 MHz, DMSO) δ 13.37 (s, 1H), 7.95 (d, J = 4.5 Hz, 2H), 7.85 (d, J = 6.3 Hz, 2H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 166.4, 135.2, 133.0, 130.3, 118.6, 115.5. **GCMS** (EI, 70 eV) *m/z* (%) 147.00 (41.03), 130.00 (100), 102.00 (52.55), 78.00 (35.53), 63.00 (54.52). **IR (ATR)***v* (cm^{-1}) 1690, 1430, 1287, 932, 768.

4-nitrobenzoic acid (4l)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (70:30 v/v) mixture as eluent. Isolated yield: 83% (138 mg). **^{1}H NMR** (300 MHz, DMSO) δ 8.23 – 8.15 (m, 2H), 8.15 – 8.06 (m, 2H). **^{13}C{^{1}H}NMR** (75 MHz, DMSO) δ 166.3, 150.2, 136.8, 130.8, 123.4. **GCMS** (EI, 70 eV) *m/z* (%) 166.90 (55.73), 138.95 (29.77), 121.00 (45.63), 95.00 (33.85), 65.00 (100). **IR (ATR)***v* (cm^{-1}) 1685, 1539, 1276, 714.

furan-3-carboxylic acid (4m)[34a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 104% (154 mg). **^{1}H NMR** (300 MHz, DMSO) δ 7.93 (dd, J = 1.4, 0.7 Hz, 1H), 7.37 (t, J = 1.7 Hz, 1H), 6.62 (dd, J = 1.9, 0.7 Hz, 1H). **^{13}C{^{1}H}NMR** (75 MHz, DMSO) δ 164.7, 147.6, 143.7, 120.0, 109.9. **GCMS** (EI, 70 eV) *m/z* (%) 112.05 (90.39), 95.05 (66.02), 78.05 (91.16), 63.00 (100). **IR (ATR)***v* (cm^{-1}) 1679, 1469, 1293, 1016, 754.

9*H*-xanthene-9-carboxylic acid (4n)[35a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 73% (164 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 7.36 – 7.27 (m, 4H), 7.17– 7.07 (m, 4H), 4.98 (s, 1H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 177.3, 151.4, 129.3, 129.1, 123.4, 117.7, 117.1, 45.0. **GCMS** (EI, 70 eV) *m/z* (%) 226.00 (0.01), 181.00 (100), 152.10 (19.77), 127.10 (2.44), 90.85 (5.09), 51.00 (2.37). **IR (ATR)***v* (cm^{-1}) 1685, 1481, 1255, 753.

2-methylnicotinic acid(4o)[35b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (60:40 v/v) mixture as eluent. Isolated yield: 89% (121 mg). **^{1}H NMR** (300 MHz, DMSO) δ 8.50 (dd, *J* = 4.8, 1.6 Hz, 1H), 8.14 (dd, *J* = 7.8, 1.6 Hz, 1H), 7.17 (dd, *J* = 7.8, 4.9 Hz, 1H), 2.74 (s, 3H). **^{13}C{^{1}H}NMR** (75 MHz, DMSO) δ 168.3, 159.5, 151.3, 138.6, 126.3, 121.0, 24.7. **GCMS** (EI, 70 eV) *m/z* (%) 137.10 (100), 119.10 (38.97), 93.10 (63.63), 63.00 (63.40). **IR (ATR)***v* (cm^{-1}) 1711, 1581, 1581, 1213, 1089, 763.

5-methoxy-1*H*-indole-3-carboxylic acid (4p)[35c]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (60:40 v/v) mixture as eluent. Isolated yield: 83% (158 mg). **^{1}H NMR** (300 MHz, DMSO) δ 10.76 (s, 1H), 7.30 (d, *J* = 8.9 Hz, 1H), 7.03 – 6.94 (m, 2H), 6.83 (dd, *J* = 8.9, 2.4 Hz, 1H), 3.75 (s, 3H). **^{13}C{^{1}H}NMR** (75 MHz, DMSO) δ 163.5, 154.2, 132.8, 128.7, 127.5, 116.1, 113.4, 107.5, 102.0, 55.6. **GCMS** (EI, 70 eV) *m/z* (%). 191.00 (3.03), 147. 00 (100), 132.10 (76.28), 104.10 (66.97), 78.05 (52.21), 63.00 (52.27). **IR (ATR)***v* (cm^{-1}) 3335, 1690, 1521, 1434, 1188, 834.

Dodecanoic acid (4q)[35d]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 95% (190 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 2.37 (t, J = 7.5 Hz, 2H), 1.72 – 1.59 (m, 2H), 1.30 (d, J = 11.9 Hz, 16H), 0.90 (t, J = 6.7 Hz, 3H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 180.3, 34.1, 31.9, 29.6, 29.4, 29.3, 29.2, 29.0, 24.7, 22.7, 14.1. **GCMS** (EI, 70 eV) *m/z* (%) 200 (4.96), 157.05 (27.94), 129.00 (44.13), 85.05 (31.63), 73.00 (100). **IR (ATR)***v* (cm^{-1}) 2914, 2848, 1697, 1302, 935.

Cinnamic acid acid (4r)[34b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 63% (93 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 7.83 (d, J = 16.0 Hz, 1H), 7.59 (dd, J = 6.7, 3.0 Hz, 2H), 7.49 – 7.40 (m, 3H), 6.49 (d, J = 16.0 Hz, 1H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 172.6, 147.1, 134.0, 130.8, 128.9, 128.4, 117.3. **GCMS** (EI, 70 eV) *m/z* (%) 148.10 (68.83), 147.10 (100), 120.10 (5.38), 103.10 (57.82), 77.05 (39.89), 51.05 (21.53). **IR (ATR)***v* (cm^{-1}) 1671, 1627, 1282, 1220, 977, 767.

3-Chlorocinnamic acid (4s)[36a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 61% (90 mg). **^{1}H NMR** (400 MHz, DMSO) δ 12.47 (s, 1H), 7.73 (d, J = 3.6 Hz, 1H), 7.60 (s, 1H), 7.53 (d, J = 16.1 Hz, 1H), 7.43 – 7.31 (m, 2H), 6.56 (dd, J = 16.0, 1.8 Hz, 1H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 167.7, 142.7, 136.9, 134.1, 130.9, 130.2, 128.2, 127.1, 121.4. **GCMS** (EI, 70 eV) *m/z* (%) 181.00 (100), 165.00 (29.87), 147.05 (68.64), 102.05 (84.33), 75.00 (53.46), 51.00 (33.98). **IR (ATR)***v* (cm^{-1}) 1672, 1634, 1321, 1299, 942.

3-phenylpropiolic acid (4t)[36b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 72% (105 mg). **^{1}H NMR** (300 MHz, $CDCl_3$) δ 7.70 – 7.59 (m, 2H), 7.56 – 7.47 (m, 1H), 7.44 – 7.39 (m, 2H). **^{13}C{^{1}H}NMR** (75 MHz, $CDCl_3$) δ 158.5, 133.3, 131.1, 128.7, 119.1, 89.1, 80.1. **GCMS** (EI, 70 eV) *m/z* (%) 147.10 (21.64), 130.10 (4.00), 78.05 (69.13), 63.00 (100). **IR (ATR)***v* (cm^{-1}) 2237, 2202, 1665, 1416, 1300, 1206, 918.

4-carbamoylbenzoic acid (4u)[37a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (50:50 v/v) mixture as eluent. Isolated yield: 97% (160 mg). **^{1}H NMR** (400 MHz, DMSO) δ 8.08 (s, 1H), 8.00 (s, 1H), 7.94 (q, J = 8.2 Hz, 4H), 7.50 (s, 1H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 167.6, 167.2, 138.5, 134.9, 133.4, 129.9, 129.6, 128.1. **GCMS** (EI, 70 eV) *m/z* (%) 165.00 (4.71), 148.05 (44.25), 103.05 (32.67), 63.00 (100). **IR (ATR)***v* (cm^{-1}) 3356, 3152, 1658, 1617, 1408, 1387.

5-oxopyrrolidine-2-carboxylic acid (4v)[37b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (60:40 v/v) mixture as eluent. Isolated yield: 93% (119 mg). **^{1}H NMR** (400 MHz, DMSO) δ 12.75 (s, 1H), 7.89 (s, 1H), 4.03 (dd, J = 8.9, 4.2 Hz, 1H), 2.28 (dd, J = 20.6, 9.1 Hz, 1H), 2.10 (dd, J = 10.6, 5.9 Hz, 2H), 1.98 – 1.87 (m, 1H). **^{13}C{^{1}H}NMR** (101 MHz, DMSO) δ 177.5, 174.9, 55.2, 29.5, 25.0. **GCMS** (EI, 70 eV) *m/z* (%) 129.15 (3.75), 127.10 (18.22), 84.05 (100), 63.00 (45.82). **IR (ATR)***v* (cm^{-1}) 3299, 1704, 1612, 1232, 696.

6*H*-benzo[c]chromen-6-one (6a)[26a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 81% (158 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.32 (d, J =

7.9 Hz, 1H), 8.02 (d, *J* = 7.9 Hz, 1H), 7.96 (d, *J* = 7.8 Hz, 1H), 7.75 (t, *J* = 7.6 Hz, 1H), 7.51 (t, *J* = 7.6 Hz, 1H), 7.41 (t, *J* = 7.6 Hz, 1H), 7.27 (t, *J* = 8.1 Hz, 2H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.1, 151.1, 134.8, 134.6, 130.4, 130.3, 128.8, 124.5, 122.7, 121.6, 121.1, 117.9, 117.6. **GCMS** (EI, 70 eV) *m/z* (%) 196.00 (100), 168.05 (58.12), 139.10 (57.06), 69.75 (7.98). **IR (ATR)***v* (cm^{-1}) 1725, 1605, 1455, 1432, 1077.

3-methyl-6*H*-benzo[c]chromen-6-one (6b)[26a]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 83% (174 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.32 (d, *J* = 7.9 Hz, 1H), 8.00 (d, *J* = 8.0 Hz, 1H), 7.85 (d, J = 7.2 Hz, 1H), 7.75 (t, *J* = 7.6 Hz, 1H), 7.49 (t, *J* = 7.6 Hz, 1H), 7.09 (s, 2H), 2.40 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.4, 151.1, 141.2, 134.9, 134.7, 130.4, 128.3, 125.6, 122.4, 121.4, 120.7, 117.8, 115.3, 21.4. **GCMS** (EI, 70 eV) *m/z* (%) 210.05 (100), 181.05 (93.64), 152.05 (78.89), 127.00 (17.83), 76.05 (64.97). **IR (ATR)***v* (cm^{-1}) 1735, 1606, 1252, 1080.

2-methyl-6*H*-benzo[c]chromen-6-one (6c) and **4-methyl-6*H*-benzo[c]chromen-6-one (6c′)**[27b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 80% (168 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.21 (d, *J* = 6.0 Hz, 1.68H), 7.86 (d, *J* = 7.5 Hz, 1.84H), 7.65 (t, *J* = 7.1 Hz, 2.30H), 7.58 (s, 1.18H), 7.42 (t, J = 7.2 Hz, 1.85H), 7.17 (d, *J* = 7.0 Hz, 0.75H), 7.11–7.03 (m, 2.74H), 2.35 (s, 1.90H), 2.32 (s, 3.03H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.1, 160.9, 149.3, 149.1, 134.8, 134.5, 133.9, 131.6, 131.1, 130.2, 130.1, 128.5, 128.4, 126.7, 123.8, 122.5, 121.7, 121.4, 121, 120.8, 120.2, 117.4, 117.3, 117.2, 21, 15.8. **GCMS** (EI, 70 eV) *m/z* (%) 210.05 (100), 181.05 (38.54), 152.10 (19.09), 76.05 (13.87). **IR (ATR)***v* (cm^{-1}) 1718, 1605, 1265, 1074.

2-methoxy-6*H*-benzo[c]chromen-6-one (6d) and **4-methoxy-6*H*-benzo[c]chromen-6-one (6d´)**[27b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 73% (164 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.29 (t, J = 10.6 Hz, 1H), 7.96 (d, J = 7.6 Hz, 1.08H), 7.75 (t, J = 7.1 Hz, 1.11H), 7.53 (d, J = 6.5 Hz, 1.12H), 7.37 (s, 0.96H), 7.19 (d, J = 8.4 Hz, 1.01H), 6.97 (d, J = 8.7 Hz, 0.85H), 3.93 (s, 0.84H), 3.86 (s, 2.94H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.2, 160.5, 156.2, 154.9, 145.4, 145.3, 134.8, 134.7, 134.5, 133.9, 130.6, 130.5, 129.2, 128.9, 128.3, 121.6, 121.4, 121.2, 121.1, 118.5, 118.4, 117.1, 106.2, 102.6, 88.2, 56.9, 55.8. **GCMS** (EI, 70 eV) *m/z* (%) 226.10 (100), 211.05 (62.60), 183.05 (39.62), 127.10 (35.34), 101.05 (9.61), 77.05 (8.77). **IR (ATR)***v* (cm^{-1}) 1709, 1497, 1271, 1208, 1034.

3-chloro-6*H*-benzo[c]chromen-6-one (6e)[26b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 81% (186 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.27 (d, J = 7.7 Hz, 1H), 7.95 (d, J = 7.9 Hz, 1H), 7.86 (d, J = 8.3 Hz, 1H), 7.75 (t, J = 7.4 Hz, 1H), 7.51 (t, J = 7.3 Hz, 1H), 7.22 (d, J = 9.7 Hz, 2H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 160.4, 151.3, 135.8, 134.9, 133.8, 130.6, 129.1, 124.9, 123.7, 121.6, 120.7, 117.8, 116.6. **GCMS** (EI, 70 eV) *m/z* (%)232.65 (60.43), 230.75 (100), 203.80 (87.36), 167.05 (77.87), 139.85 (77.77), 112.95 (57.59), 96.95 (58.65), 69.05 (93.37). **IR (ATR)***v* (cm^{-1}) 1728, 1595, 1259, 1028, 813.

3-bromo-6*H*-benzo[c]chromen-6-one (6f)[26b]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 78% (214 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.37 – 8.17

(m, 1H), 7.99 – 7.92 (m, 1H), 7.78 – 7.72 (m, 1H), 7.59 – 7.30 (m, 4H). **^{13}C{^{1}H}NMR** (126 MHz, $CDCl_3$) δ 160.5, 151.4, 135.9, 135.0, 133.9, 130.6, 129.1, 124.9, 123.7, 121.6, 120.8, 117.8, 116.6. **GCMS** (EI, 70 eV) *m/z* (%) 276.00 (97.97), 274 (100), 245.65 (27.61), 207.05 (18.94), 167.05 (41.00), 139.10 (92.75), 69.50 (39.66). **IR (ATR)***v* (cm^{-1}) 1732, 1596, 1265, 1065.

2-iodo-3-methyl-6*H*-benzo[c]chromen-6-one (6g)

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 67% (225 mg). mp = 186 – 188 ^{o}C. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.40 (s, 1H), 8.35 (d, J = 7.9 Hz, 1H), 8.00 (d, *J* = 8.0 Hz, 1H), 7.80 (t, *J* = 7.7 Hz, 1H), 7.56 (t, *J* = 7.6 Hz, 1H), 7.21 (s, 1H), 2.48 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 160.8, 151.2, 144.1, 134.9, 133.4, 132.8, 130.6, 129.0, 121.5, 120.9, 118.4, 117.7, 95.0, 28.2. **GCMS** (EI, 70 eV) *m/z* (%) 336 (100), 208.90 (36.31), 180.95 (39.37), 152.00 (71.42), 127.00 (9.59), 76.95 (12.80). **IR (ATR)***v* (cm^{-1}) 1730, 1605, 1374, 1265, 1163. **HRMS** (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{14}H_{11}IO_2$ 336.9647; found 336.9716.

3,4-diphenyl-1*H*-isochromen-1-one (8aa)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 89% (132 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.40 (d, *J* = 7.8 Hz, 1H), 7.63 (t, *J* = 7.7 Hz, 1H), 7.51 (t, *J* = 7.5 Hz, 1H), 7.40 (d, *J* = 5.4 Hz, 3H), 7.32 (d, *J* = 8.0 Hz, 2H), 7.21– 7.16 (m, 6H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.2, 150.9, 138.8, 134.6, 134.3, 132.8, 131.2, 129.5, 129.2, 129.0, 128.9, 128.0, 128.1, 127.8, 125.3, 120.4, 116.9. **GCMS** (EI, 70 eV) *m/z* (%) 298.00 (100), 269.90 (27.17), 220.90 (32.10), 164.95 (16.80), 105.00 (48.69), 77.00 (27.54). **IR (ATR)***v* (cm^{-1}) 1725, 1602, 1479, 1311, 1078, 756.

6-methyl-3,4-diphenyl-1*H*-isochromen-1-one (8ba)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 91% (141 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.29 (d, J = 7.9 Hz, 1H), 7.40 (s, 3H), 7.36 – 7.28 (m, 3H), 7.25 – 7.17 (m, 5H), 6.96 (s, 1H), 2.36 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.3, 150.9, 145.8, 142.5, 138.8, 134.4, 133.0, 131.2, 129.6, 129.5, 129.2, 129.0, 128.8, 128.0, 127.78, 125.26, 118.52, 118.01, 22.20. **GCMS** (EI, 70 eV) *m/z* (%) 311.95 (100), 283.95 (26.16), 177.90 (13.82), 105.00 (55.60), 77.00 (24.89). **IR (ATR)**ν (cm^{-1}) 1726, 1605, 1442, 1318, 1073.

6-(*tert*-butyl)-3,4-diphenyl-1*H*-isochromen-1-one (8ca)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 87% (153 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.34 (d, J = 6.7 Hz, 1H), 7.58 (d, J = 6.3 Hz, 1H), 7.41 – 7.20 (m, 11H), 1.24 (s, 9H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.3, 158.6, 150.8, 138.7, 134.4, 133.1, 131.2, 129.3, 129.2, 128.9, 128.8, 128.1, 127.8, 125.9, 121.7, 117.9, 117.2, 35.5, 30.9. **GCMS** (EI, 70 eV) *m/z* (%) 354.00 (27.33), 352.95 (100), 337.95 (40.34), 206.90 (11.73), 164.95 (8.68), 104.00 (8.72), 77.00 (10.99). **IR (ATR)**ν (cm^{-1}) 1725, 1602, 1483, 1442, 1072, 768.

6-methoxy-3,4-diphenyl-1*H*-isochromen-1-one (8da)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 83% (136 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.33 (d, J = 8.7 Hz, 1H), 7.39 (d, J = 6.0 Hz, 3H), 7.31 (d, J = 7.7 Hz, 2H), 7.28 – 7.13 (m, 6H), 7.05 (d, J = 7.4 Hz, 1H), 6.57 (s, 1H), 3.74 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 164.6, 162.0, 151.5, 141.2, 134.4, 132.9, 131.9, 131.1, 129.2, 129.0, 128.9, 128.1, 127.8, 116.7, 115.6, 113.6, 108.4,

55.5. **GCMS** (EI, 70 eV) *m/z* (%) 327.90 (100), 299.95 (25.82), 250.90 (51.56), 194.90 (14.64), 152.00 (28.40), 105.00 (87.85), 77.00 (39.71). **IR (ATR)***v* (cm^{-1}) 1728, 1609, 1483, 1294, 1076, 770.

3,4,6-triphenyl-1*H*-isochromen-1-one (8ea)

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 87% (162 mg). mp = 202 – 204 °C. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.46 (d, J = 8.2 Hz, 1H), 7.74 (d, J = 8.2 Hz, 1H), 7.49 (d, J = 7.4 Hz, 2H), 7.39 (dd, J = 9.7, 6.7 Hz, 7H), 7.34 (d, J = 7.5 Hz, 2H), 7.30 (d, J = 6.8 Hz, 2H), 7.25 – 7.18 (dd, J = 16.2, 8.4 Hz, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.2, 151.3, 147.5, 139.7, 139.3, 134.2, 132.9, 131.2, 130.2, 129.2, 129.1, 128.9, 128.9, 128.6, 128.2, 127.9, 127.4, 127.2, 123.6, 119.1, 117.0. **GCMS** (EI, 70 eV) *m/z* (%) 373.90 (92.94), 296.90 (40.09), 268.95 (21.53), 238.90 (46.36), 105.00 (100), 77.00 (41.54). **IR (ATR)***v* (cm^{-1}) 1725, 1609, 1472, 1272, 1087. **HRMS** (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{27}H_{20}O_2$ 375.1307; found 375.1376.

6,7-dimethoxy-3,4-diphenyl-1*H*-isochromen-1-one (8fa)[30g]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 78% (140 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.76 (s, 1H), 7.40 (d, J = 5.7 Hz, 3H), 7.28 (dd, J = 16.2, 7.6 Hz, 4H), 7.18 (dd, J = 14.9, 7.6 Hz, 3H), 6.55 (s, 1H), 4.00 (s, 3H), 3.72 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.1, 154.8, 150.0, 149.6, 134.6, 134.5, 133.0, 131.1, 129.1, 129.0, 128.7, 128.1, 127.8, 116.7, 113.7, 109.4, 106.1, 56.4, 55.9. **GCMS** (EI, 70 eV) *m/z* (%) 357.90 (100), 280.90 (32.77), 252.90 (30.03), 214.90 (13.77), 139.00 (16.85), 105.00 (83.02), 77.00 (27.24). **IR (ATR)***v* (cm^{-1}) 1713, 1598, 1511, 1388, 1278, 1224, 1070.

3,4-diphenyl-1*H*-benzo[g]isochromen-1-one (8ga)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 89% (155 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 9.03 (s, 1H), 8.04 (d, J = 7.9 Hz, 1H), 7.76 (d, J = 7.9 Hz, 1H), 7.55 (dd, J = 16.2, 8.3 Hz, 3H), 7.45 (d, J = 4.6 Hz, 3H), 7.34 (dd, J = 11.8, 4.9 Hz, 4H), 7.25 – 7.17 (m, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.6, 149.3, 136.3, 134.7, 133.9, 133.2, 132.1, 131.8, 131.3, 129.4, 129.2, 129.1, 128.8, 128.2, 128.1, 127.8, 126.9, 124.4, 118.8, 116.9. **GCMS** (EI, 70 eV) *m/z* (%) 347.90 (5.18), 279.00 (5.41), 214.95 (5.02), 166.90 (35.27), 148.95 (100), 113.10 (10.72), 71.05 (21.19). **IR (ATR)***v* (cm^{-1}) 1732, 1619, 1493, 1259, 1174, 1067.

8-methyl-3,4-diphenyl-1*H*-isochromen-1-one (8ha)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 73% (113 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 7.47 – 7.43 (m, 4H), 7.30 (s, 3H), 7.21 (dd, J = 21.7, 8.8 Hz, 5H), 6.99 (d, J = 8.3 Hz, 1H), 2.90 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.5, 150.6, 143.5, 140.4, 134.9, 133.7, 132.9, 131.3, 131.0, 129.1, 128.9, 128.8, 127.9, 127.8, 123.6, 118.9, 116.9, 23.6. **GCMS** (EI, 70 eV) *m/z* (%) 311.95 (100), 283.95 (28.62), 234.90 (28.33). **IR (ATR)***v* (cm^{-1}) 1723, 1605, 1472, 1440, 1272, 962, 763.

3,4-diphenyl-1*H*-benzo[h]isochromen-1-one (8ia)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 78% (135 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 9.86 (d, J = 8.7 Hz, 1H), 7.99 (d, J = 8.6 Hz, 1H), 7.87 (d, J = 8.0 Hz, 1H), 7.78 (dd, J = 8.4, 7.3 Hz, 1H), 7.63 (d, J = 7.8 Hz, 1H), 7.44 (d, J = 4.5 Hz, 3H), 7.41 – 7.35 (m, 2H), 7.30 (dd, J = 5.1, 2.1 Hz,

2H), 7.26 – 7.18 (m, 4H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ161.4, 152.5, 141.0, 139.2, 135.9, 134.8, 132.8, 132.6, 131.6, 131.5, 129.5, 129.2, 129.2, 129.1, 128.5, 128.2, 127.9, 127.0, 122.7, 117.4, 114.1, 114. **GCMS** (EI, 70 eV) *m/z* (%) 347.90 (90.51), 319.95 (20.93), 270.90 (34.99), 214.90 (72.15), 105.00 (100), 77.00 (44.38). **IR (ATR)***v* (cm^{-1}) 1735, 1623, 1493, 1262, 1172, 1065, 774.

6-fluoro-3,4-diphenyl-1*H*-isochromen-1-one (8ja)[30d]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 82% (129 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.39 (dd, J = 8.1, 6.0 Hz, 1H), 7.41 (d, J = 4.6 Hz, 3H), 7.31 (d, J = 7.4 Hz, 2H), 7.21 – 6.81 (m, 6H), 6.83 (d, J = 10.1 Hz, 1H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 168.0, 165.5, 161.3, 152.1, 141.9, 141.8, 133.7, 132.9, 132.8, 132.5, 131.0, 129.2, 129.2, 129.2, 128.4, 127.9, 116.9, 116.8, 116.4, 116.4, 116.4, 116.2, 111.4, 111.2.**GCMS** (EI, 70 eV) *m/z* (%) 316.05 (100), 288.05 (26.86), 239.00 (39.66), 105.05 (51.75), 77.00 (33.00). **IR (ATR)***v* (cm^{-1}) 1714, 1581, 1469, 1441, 1188, 1069.

6-chloro-3,4-diphenyl-*1H*-isochromen-1-one (8ka)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 79% (131 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.23 (d, J = 8.4 Hz, 1H), 7.62 (d, J = 8.4 Hz, 1H), 7.42 (d, J = 4.6 Hz, 3H), 7.31 (dd, J = 7.0, 4.8 Hz, 3H), 7.21– 7.16 (m, 5H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.6, 152.2, 140.4, 133.5, 132.5, 131.4, 131.2, 131.1, 130.5, 129.3, 129.3, 129.2, 128.4, 128.0, 127.9, 119.1, 115.9. **GCMS** (EI, 70 eV) *m/z* (%) 332.10 (100), 304.10 (23.65), 254. (39.66), 105.05 (51.75), 77.00 (35.40). **IR (ATR)***v* (cm^{-1}) 1728, 1584, 1444, 1311, 1072, 771.

6-bromo-3,4-diphenyl-*1H*-isochromen-1-one (8la)[32]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 74% (137 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.23 (d, J = 8.3 Hz, 1H), 7.62 (d, J = 8.4 Hz, 1H), 7.42 (s, 3H), 7.33 – 7.15 (m, 8H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.6, 152.2, 140.4, 133.5, 132.5, 131.4, 131.2, 131.1, 130.5, 129.3, 129.3, 129.2, 128.4, 128.01, 127.9, 119.1, 115.9. **GCMS** (EI, 70 eV) *m/z* (%) 377.75 (71.54), 375.80 (85.23), 347.80 (19.54), 298.80 (24.26), 238.90 (35.68), 162.95 (37.15), 105.00 (100), 77.00 (60.86). **IR (ATR)***v* (cm^{-1}) 1725, 1584, 1437, 1195, 107.

6-nitro-3,4-diphenyl-*1H*-isochromen-1-one (8ma)[30c]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 57% (97 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 8.56 (d, J = 8.6 Hz, 1H), 8.26 (d, J = 8.6 Hz, 1H), 8.03 (s, 1H), 7.56 – 7.41 (m, 3H), 7.38 – 7.16 (m, 7H). **^{13}C{^{1}H}NMR**(101 MHz, $CDCl_3$) δ 160.5, 153.1, 151.7, 140.3, 132.8, 132.0, 131.6, 131.5, 130.9, 129.7, 129.6, 129.2, 128.9, 128.3, 128.2, 128.0, 124.2, 123.2, 121.9, 120.5, 116.2. **GCMS** (EI, 70 eV) *m/z* (%) 342.90 (96.09), 297.90 (34.71), 239.90 (51.52), 162.95 (31.61), 105.00 (100), 77.00 (92.08). **IR (ATR)***v* (cm^{-1}) 1728, 1612, 1532, 1325, 1072.

4,5-diphenyl-7H-furo[2,3-c]pyran-7-one (8na)[30h]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (80:20 v/v) mixture as eluent. Isolated yield: 82% (118 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 7.80 (d, J = 1.9 Hz, 1H), 7.40 – 7.30 (m, 5H), 7.26 – 7.19 (m, 5H), 6.52 (d, J = 1.9 Hz, 1H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 153.5, 153.2, 150.4, 137.9, 137.4, 134.0, 132.2, 129.8, 129.4, 129.3, 129.0, 128.2, 128.0, 113.9, 108.0. **GCMS** (EI, 70 eV) *m/z* (%) 287.90 (74.62), 259.90 (17.16), 230.90

(38.18), 210.85 (44.98), 201.90 (54.14), 105.00 (85.54), 77.00 (100). **IR (ATR)***v* (cm^{-1}) 1737, 1546, 1485, 1276, 1017, 693.

4,5,6-triphenyl-2*H*-pyran-2-one (8oa)[30i]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (75:25 v/v) mixture as eluent. Isolated yield: 88% (142 mg). **^{1}H NMR**(400 MHz, $CDCl_3$) δ 7.27 – 7.07 (m, 11H), 6.99 (d, J = 8.0 Hz, 2H), 6.87 (d, J = 7.8 Hz, 2H), 6.36 (d, J = 0.9 Hz, 1H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 161.9, 159.2, 158.3, 136.9, 134.3, 132.6, 131.3, 129.5, 129.4, 128.8, 128.6, 128.3, 127.9, 127.9, 127.5, 118.5, 113.4. **GCMS** (EI, 70 eV) *m/z* (%) 323.90 (55.51), 295.95 (100), 266.95 (47.52), 188.90 (18.64), 104.95 (32.12), 77.00 (26.36). **IR (ATR)***v* (cm^{-1}) 1707, 1609, 1514, 1479, 1381, 1012, 890.

3,4-diethyl-1*H*-isochromen-1-one (8ac)[30e]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (90:10 v/v) mixture as eluent. Isolated yield: 78% (78 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.29 (d, J = 8.0 Hz, 1H), 7.71 (dd, J = 8.1, 7.3 Hz, 1H), 7.52 (d, J = 8.1 Hz, 1H), 7.43 (t, J = 7.6 Hz, 1H), 2.77 – 2.41 (m, 4H), 1.26 (td, J = 7.5, 1.1 Hz, 3H), 1.18 (td, J = 7.5, 1.0 Hz, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.9, 154.9, 137.7, 134.6, 129.9, 127.0, 122.4, 120.8, 113.0, 24.1, 19.3, 14.3, 12.6. **GCMS** (EI, 70 eV) *m/z* (%) 201.90 (100), 186.90 (94.45), 158.95 (28.71), 131.05 (100), 115.00 (43.36), 91.00 (24.55), 77.00 (13.03). **IR (ATR)***v* (cm^{-1}) 1721, 1641, 1473, 1286, 1076, 774.

3,4-dimethyl-*1H*-isochromen-1-one (8ad)[30e]

Colourless solid. Isolated through 40-200 mesh silica gel using pet ether: ethyl acetate (90:10 v/v) mixture as eluent. Isolated yield: 73% (63 mg). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.26 (d, J =

7.9 Hz, 1H), 7.75 – 7.67 (m, 1H), 7.44 (dd, J = 15.6, 7.8 Hz, 2H), 2.29 (s, 3H), 2.14 (s, 3H). **^{13}C{^{1}H}NMR** (101 MHz, $CDCl_3$) δ 162.8, 150.0, 138.6, 134.6, 129.6, 127.1, 122.4, 120.3, 107.7, 17.3, 12.1. **GCMS** (EI, 70 eV) *m/z* (%) 174.20 (100), 132.20 (68.81), 103.15 (39.31), 77.10 (20.18). **IR (ATR)***v* (cm^{-1}) 1718, 1651, 1482, 1286, 1192, 1086, 1048.

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SUPPORTING INFORMATION

The copies of ^{1}H and ^{13}C NMR spectra and Crystallographic data of compound **2s** (CIF) are available free of charge via the internet at http://pubs.acs.org

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