JOC The Journal of Organic Chemistry

Article

pubs.acs.org/joc

Steric-Hindrance-Induced Regio- and Chemoselective Oxidation of Aromatic Amines

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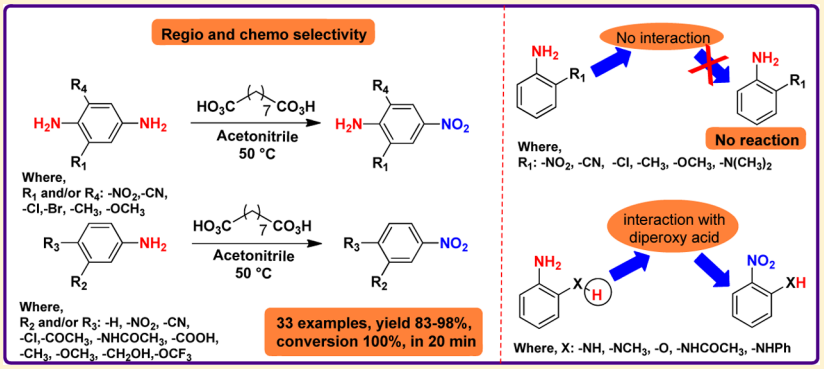
Supporting Information



ABSTRACT: Unusual regio- and chemoselective oxidation of aromatic amines hindered with ortho substituents (except -NH_2, -$NHCH_3$, and -OH) to the corresponding nitro compounds is described by use of nonanebis(peroxoic acid). The mechanistic investigation for selective oxidation of amines ortho-substituted with -NH_2 or -OH showed the involvement of H-bonding between the ortho hydrogen of the adjacent -XH group (where X = NH, NR, or O) and an oxygen atom from the diperoxy acid. Various mono- and diamines are oxidized into corresponding mononitro derivatives in high yield and purity without employing any protection strategies. The protocol was also found to successful on the gram scale.

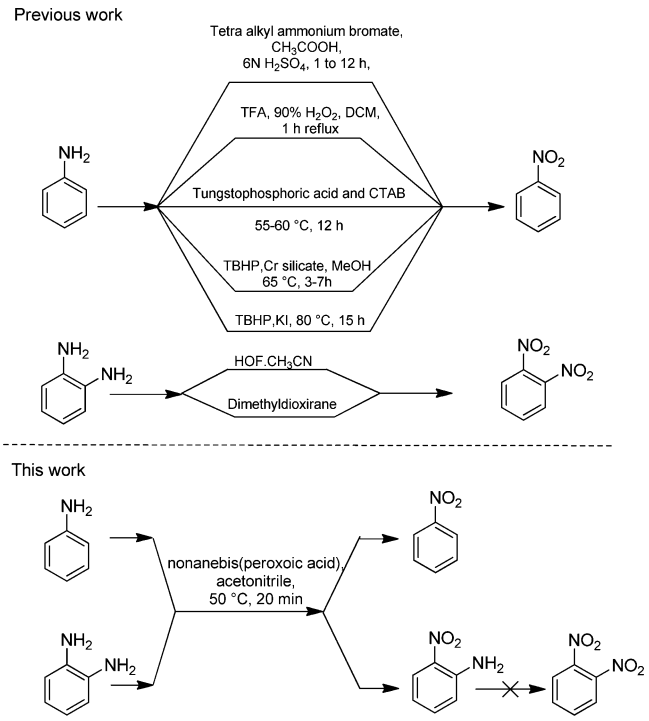
INTRODUCTION

The oxidation of amines into nitro compounds is considered one of the indispensable transformations in organic synthesis, as it is a direct route for the synthesis of nitro compounds. Aromatic nitro compounds are well-established industrially, as these compounds work as a backbone to many commercially important chemicals such as dyes,[1,2] polymers,[3,4] perfumes,[5,6] pharmaceuticals,[7] pesticides,[8,9] and extensively in explosives.[8,10] They serves as important reagents for the synthesis of complex target molecules. Numerous oxidation strategies have been employed for this purpose[11] using various oxidants (Scheme 1) such as HOF−CH_3CN,[12−14] dimethyldioxirane,[15−17] peracetic acid,[18] peroxytrifluoroacetic acid,[19] *m*-chloroperoxybenzoic acid (*m*-CPBA),[20] oxone,[21] sodium perborate with tungstophosphoric acid and cetyltrimethylammonium bromide (CTAB),[22] sodium perborate with acetic acid,[23] tetraalkylammonium bromate,[24] combination of *tert*-butyl hydroperoxide (TBHP) with various catalysts such as KI,[25] chromium silicate,[26] zirconium[27] and Fe(III) and Mn(III) tetraarylporphyrins,[28] superoxide and H_2O_2 mixture,[29] and titanium superoxide.[30] The major shortcoming in most of these oxidation protocols was uncontrolled oxidation resulting in formation of multiple products such as nitroso, azo, azoxybenzene, hydroxylamine, and oxime derivatives, which in turn lack selectivity.[11] Furthermore, some of those systems suffer various disadvantages. Hazardous halogenated solvents such as chloroform, dichloromethane, and dichloroethane were most preferred to carry out this oxidation. Peracids such as peracetic acid and peroxytrifluoroacetic acid are difficult to handle in anhydrous condition. Peroxytrifluoroacetic acid itself attacks the benzene ring to give phenol-containing complex mixtures.[19] This reagent was also found to be ineffective to oxidize *p*-methoxyaniline to *p*-methoxynitrobenzene, whereas oxidation with *m*-CPBA in 1,2-dichloroethane occurred in 10 h under reflux conditions.[20] The most-studied oxidant, HOF−CH_3CN, required hazardous fluorine gas for the preparation; also, this reagent is quite unstable and needs to be prepared in situ.[11] Oxidizing systems such as KI−TBHP or sodium perborate−tungstophosphoric acid with CTAB follow some principles of green chemistry, but reaction requires longer times (12−15 h) for completion with moderate to good yields. The heterogeneous catalytic system reported by Sudalai and co-workers[30] was found to be most effective for selective oxidation of amine to nitro and it also gives good yields in a shorter period with recycling of the catalyst. It is noticeable that, in all above-mentioned reports, attempts were made to give selective nitro as a product, but none of the chemical methods successfully gave chemo- or regioselective oxidation. For instance, the oxidation of *o*-diamine results in formation of dinitro

Received: March 14, 2015
Published: July 25, 2015

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883

Scheme 1. Oxidation Strategies Reported Previously and in This Work



compounds (Scheme 1), and if a mononitro derivative is desired, then one needs to protect one of the amines to avoid dinitro product formation.[13] On the other hand, enzymes served as a better option to achieve chemo- and regioselectivity for this transformation.[31−33] Hertweck and co-workers[31] have reported the chemo- and regioselective oxidation of various *p*-aminobenzoic acid derivatives by use of *p*-aminobenzoate N-oxygenase (AurF) enzyme from *Streptomyces thioluteus*. Interaction between positively charged protein residues and the anionic part of the acid is responsible for the higher selectivity of this protocol. Owing to this acid-selective interaction, the protocol was relevant only to amines with an anionic acid part at the para position. Thus, the need to develop a chemical method that will overcome all above shortcomings as well as provide a certain sort of selectivity drives our attention toward this transformation. In our previous work, we have demonstrated that the long-chain diperoxy acid nonanebis(peroxoic acid) can overcome various shortcomings[34] of conventional peracids and can be a good alternative for them.[35] It is easy to prepare and handle, non-shock-sensitive in nature, and stable at room temperature.[35,36]

As part of our research to explore the applicability of diperoxy acids in organic synthesis, we decided to investigate the above oxidation reaction in this peroxy acid. During this attempt, we found that this diperoxy acid was not only capable of oxidizing amino to nitro in a shorter period and under mild conditions but also showed one unusual selectivity trend that was not yet reported in the literature for any chemical oxidation method of this kind. The steric hindrance of ortho substituents and the interaction between diperoxy acids and the hydrogen atom present on a heteroatom (X = N/O) ortho to the amine play a vital role to induce an interesting selectivity, which to the best our knowledge is not yet explored in organic synthesis. This trend was also found in the other diperoxy acids we investigated here. It is noticeable that the protocol we report here is found to be effective to synthesize commercially important molecules such as dichloran, which is widely used as a fungicide,[37] from 2,6-dichlorobenzene-1,4-diamine. Molecules such as 2-amino-3-bromo-5-nitrobenzonitrile[38,39] and 2-methyl-4-nitroaniline,[40] which are used as intermediates to synthesize azo dyes for nonlinear optics (NLO) and for dyeing polymers, were also prepared by the present approach. 2-Methoxy-4-nitroaniline, which is widely used for textile dying, in the printing industry, and as an intermediate for the synthesis of azo dyes for tattoo inks, emulsion paints, and toy enamels, was also synthesized under the present protocol.

Thus, here we report, a metal-catalyst-free, mild, and efficient approach for regio- and chemoselective oxidation of aromatic amine to nitro using nonanebis(peroxoic acid) as a oxidant. This work highlights the important properties of these diperoxy acids, which have remained unnoticed since their discovery.

RESULTS AND DISCUSSION

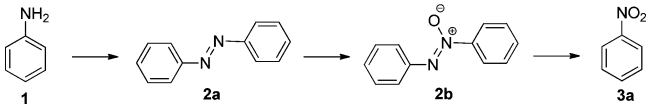
Reaction conditions were optimized by taking aniline **1a** (1 equiv) as a key substrate and nonanebis(peroxoic acid) as an oxidant at 50 °C (Table 1). The oxidant equivalent study illustrated that formation of nitro product proceeds through azobenzene **2a** and azoxybenzene **2b** as intermediate products (Table 1, entries 1−3), and 3 equiv of oxidant was required for the formation of nitro product **3a** (Table 1, entry 4). The influence of solvents for conversion studies revealed acetonitrile to be the most appropriate solvent, as 100% conversion into nitrobenzene was achieved within 20 min (Table 1, entry 4). On the contrary, when hexane was used as solvent, selectiveformation of azoxybenzene **2b** was observed (Table 1, entry 5). The other solvents gave mixtures of azoxybenzene and nitrobenzene (Table 1, entries 6−13). It was also observed that the rate of formation of nitro product increased as temperature increased from 20 to 50 °C (Table 1, entries 13−15). Further rise in the temperature has not shown any influence on time or yield (Table 1, entry 16).

We also examined the feasibility of other common peroxides under the present conditions (Table 1, entries 17−24). It was observed that, except for *m*-CPBA (Table 1, entry 19), no other oxidants show formation of nitrobenzene under optimized conditions. In the cases of 50% H_2O_2, 70% TBHP, and potassium peroxydisulfate, only starting aniline was observed by thin-layer chromatography (TLC) even after the reaction was held for 2 h at 50 °C (Table 1, entries 17, 18, and 22). With sodium perborate, trace nitrobenzene formation was observed under optimized conditions (Table 1, entry 20). The reaction with performic acid gives 6% N-formylated product, 9% **2a**, and 85% **2b** (Table 1, entry 23). Similarly, in the case of peracetic acid, 10% N-acylated product was formed with 90% **2b** (Table 1, entry 24). In both peracids, formation of **3a** was not observed.

Encouraged by these promising results, we applied the optimized reaction conditions to examine the substrate scope. The oxidation of various aniline derivatives under optimized reaction conditions gives corresponding nitro products in 20 min (Table 2). It was found that aniline derivatives with meta and/or para substituents such as -Cl, -NO_2, -OCH_3, -CH_3, -COOH, -OH, -$NHCOCH_3$, -CN, -OCF_3, and −$COCH_3$ were oxidized smoothly into corresponding nitro derivatives in 20 min (Table 2, entries **3b**−**3r**). However ortho-substituted derivatives of aniline such as 2-chloroaniline, 2-nitroaniline, 2-anisidine, 2-toluidine, and 2-aminobenzonitrile failed to undergo oxidation under existing conditions, even after exceeding

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883

Table 1. Optimization of Reaction Conditions[a]



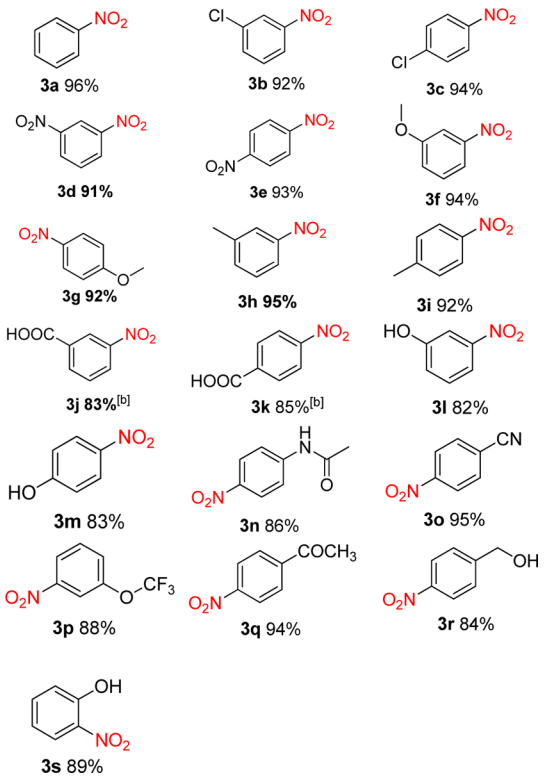
			% conversion[b]		
entry	solvent	oxidant equiv	2a	2b	3a
1	acetonitrile	1	41	59	
2	acetonitrile	2	4	55	41
3	acetonitrile	2.5		39	61
4	acetonitrile	3			100
5	hexane	3		100	
6	toluene	3		71	29
7	chloroform	3		56	42
8	dichloromethane	3		41	59
9	ethyl acetate	3		35	65
10	dimethylformamide	3		62	38
11	ethanol	3		72	28
12	water	3		75	25
13[c]	acetonitrile	3		51	49
14[d]	acetonitrile	3		20	80
15[e]	acetonitrile	3		8	92
16[f]	acetonitrile	3			100
Comparison with Other Oxidants					
entry	oxidant	oxidant equiv	3a % conversion[b]		
17[g]	50% H_2O_2	6	NR		
18[g]	70% TBHP	6	NR		
19[h]	*m*-CPBA	6	30		
20[g]	sodium perborate	6	trace		
21[h]	oxone	6	trace		
22[g]	potassium peroxydisulfate	6	NR		
23	performic acid	6			
24	peracetic acid	6			

[a]Reaction conditions: **1a** (1.07 mmol), oxidant nonanebis(peroxoic acid), solvent 5 mL. All reactions were performed for 20 min at 50 °C unless otherwise indicated. [b]Conversion determined by GC. NR, no reaction. [c]Reaction kept for 24 h at 20 °C. [d]Reaction kept for 24 h at 30 °C. [e]Reaction kept for 1 h at 40 °C. [f]Reaction kept for 20 min at 60 °C. [g]Reaction maintanined for 2h at 50 °C. [h]Reaction maintanined for 30 min at 50 °C.

reaction conditions for 2 h at 50 °C. In the case of aminophenols, no quinone formation was observed and only nitro derivative was formed (Table 2, entries **3l**, **3m**, and **3s**). The protocol was also found to be compatible with various functional groups such as -COOH, -$NHCOCH_3$, -CN, -OCF_3, -$COCH_3$, and -CH_2OH (Table 1, entries **3j**, **3k**, and **3n**−**3r**). For substrates that contain oxidizable groups such as -CN, -$COCH_3$, and -CH_2OH, no oxidation products of respective functional groups such as N-oxide, ester, and aldehyde or acid were detected (Table 1, entries **3o**, **3q**, and **3r**). The protocol was found to be unsuccessful when we tried competitive reaction in the presence of styrene; it was found that styrene undergoes oxidation along with aniline under the present conditions to give a mixture of oxidation products of both substrates. Similarly, the protocol failed with substrates containing aldehyde, as reaction gives multiple products.

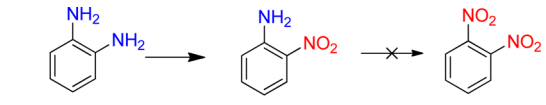
To our surprise, oxidation of benzene-1,2-diamine under the present conditions selectively gave 2-nitroaniline as a product (Scheme 2). Addition of extra oxidant (3 equiv) failed to show formation of 1,2-dinitrobenzene.

Table 2. Regio- and Chemoselective Oxidation of Various Aromatic Monoamines[a]



[a]Reaction conditions: amine (1 equiv), nonanebis(peroxoic acid) (3 equiv), acetonitrile 5 mL. All reactions were performed for 20 min. Yields given are isolated yields. [b]The reaction mass was quenched by 0.1 M sodium thiosulfate solution, extracted with ethyl acetate, and purified by column chromatography with hexane/ethyl acetate as an eluting system.

Scheme 2. Selective Oxidation of Benzene-1,2-diamine into 2-Nitroaniline

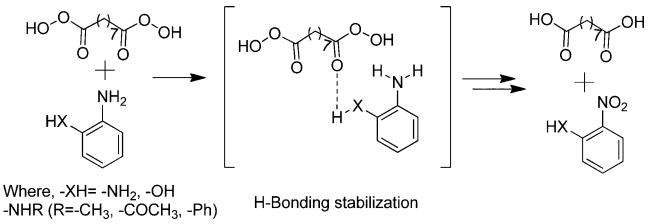


This result was further confirmed from the reaction of 2-nitroaniline, which does not undergo oxidation under the present conditions. From this, it was confirmed that once one of the *o*-NH_2 groups of benzene-1,2-diamine is oxidized, it prevents further oxidation of an amino group at the ortho position. Again, we also understood that amines bearing hydrogen on a heteroatom at the ortho position are only oxidized to the corresponding nitro derivative. To check feasibility, we carried out reactions with 2-aminophenol and 2-aminothiophenol. It was found that the reaction with 2-aminophenol gave 2-nitrophenol as a product (Table 2, entry **3s**). But in the case of 2-aminothiophenol the protocol was found to be unsuccessful, as the reaction yields a mixture of oxidation products of both sulfur and amine instead of 2-nitrothiophenol. From the above fallouts, it was clear that only those ortho-substituted amines that possess hydrogen on a heteroatom are oxidized to corresponding nitro derivatives. We believe that the reason for this selectivity could be the hydrogen

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883

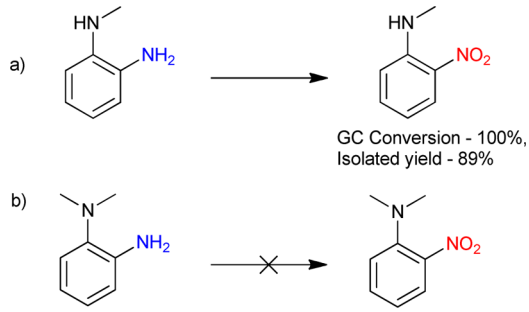
bonding between hydrogen on the ortho-XH group with oxygen of the peracid, which in turn facilitates the oxidation reaction (Scheme 3).

Scheme 3. Hydrogen Bonding between Hydrogen Atom on *o*-XH Substituent (NH_2/$NHCH_3$/OH) with Carbonyl Oxygen of Diperoxy Acid



To validate this assumption, we carried out reaction on N^1-methylbenzene-1,2-diamine and N^1,N^1-dimethylbenzene-1,2-diamine (Scheme 4a,b). Gas chromatography (GC) analysis

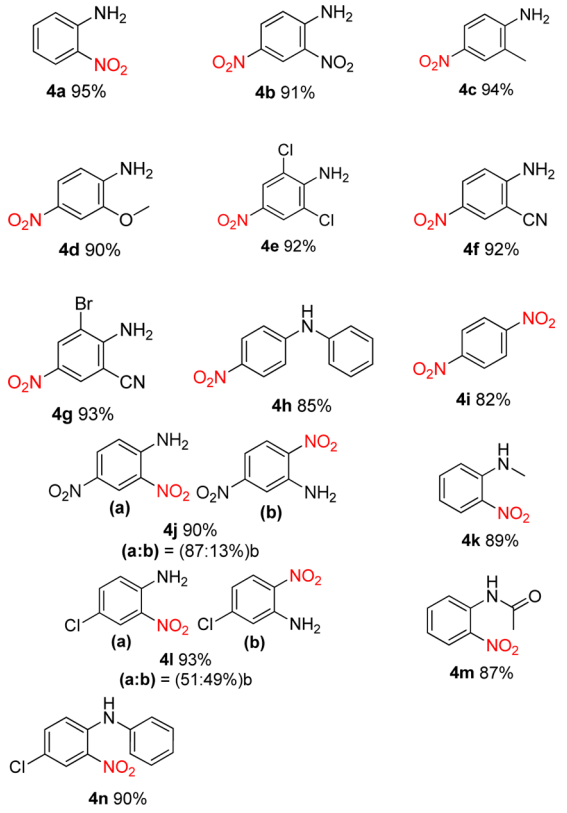
Scheme 4. Influence of Hydrogen Atom of *o*-NH_2 Group on Oxidation of *o*-Diamine



shows that the former amine derivative is oxidized to *N*-methyl-2-nitroaniline, whereas latter persisted as it is. This assumption was further confirmed from the reaction of 2-aminophenol and 2-methoxyaniline, as the former was oxidized to 2-nitrophenol whereas 2-methoxyaniline failed to undergo any oxidation reaction under the present conditions. Further validation of this assumption was done by carrying out reactions with *N*-(2-aminophenyl)acetamide and 4-chloro-N^1-phenylbenzene-1,2-diamine to give **4m** (87%) and **4n** (90%), respectively, in 20 min (Table 3, entries **4m** and **4n**).

This confirmed the significant importance of hydrogen atom present on a heteroatom at the ortho position in the selective oxidation of diamine and aminophenol. In order to study chemoselectivity further, we carried out oxidation of various diamines in which one of the amino groups was ortho-substituted with groups other than -NH_2 and -OH (Table 3). The results obtained shows that amines with ortho substituents (other than -NH_2 and -OH) remained unaffected under the present reaction conditions, while amines without any ortho substituents or ortho-substituted with -NH_2 or -OH undergo oxidation into the corresponding nitro group (Table 3, entries **4a**–**4i**). A further advantage of this protocol was the easy synthesis of the important fungicide dichloran. Oxidation of 2,6-dichloro-*p*-phenylenediamine gives 92% yield of dichloran in 20 min (Table 3, entry **4e**). The reaction of benzene-1,4-diamine with 6 equiv of peroxy acid gave 1,4-dinitrobenzene (Table 3, entry **4i**), but in the case of benzene-1,3-diamine, a polar spot was observed on TLC instead of 1,3-dinitrobenzene.

Table 3. Selective Oxidation of Various Aromatic Diamines[a]



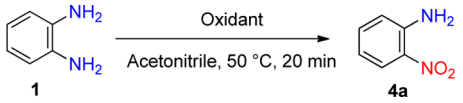
[a]Reaction conditions: **1** (1 equiv), nonanebis(peroxoic acid) (3 equiv), acetonitrile 5 mL. All reactions were kept for 20 min. Yields given are isolated yields. [b]Conversion was determined by GC analysis and products were confirmed by GC-MS analysis.

It was noticeable that substrates like 4-nitrobenzene-1,2-diamine, with a strongly electron-withdrawing -NO_2 group at the para position, showed a pronounced effect on oxidation of *p*-NH_2 group, as 2,4-dinitroaniline (**4j-a**) was formed as a major product over 2,5-dinitroaniline (**4j-b**) (Table 3, entry **4j**). In the case of substrates like 4-chlorobenzene-1,2-diamine, with a less electron-withdrawing -Cl group, both products were obtained in almost equal amounts (Table 3, entry **4l**). The oxidation of substrates bearing acyl and aryl groups on benzene-1,2-diamine further confirmed the role of hydrogen on a neighboring heteroatom in the oxidation of *o*-amine to nitro (Table 3, entries **4m** and **4n**). Both substrates were smoothly oxidized to corresponding nitro derivatives in 20 min to give 87% and 90% yields, respectively.

Furthermore, when we examined conventionally used oxidizing agents for selectivity (Table 4, entries 1–6), it was observed that, except for *m*-CPBA, none of the oxidants showed formation of *o*-nitroaniline. In case of *m*-CPBA, only 28% **4a** formation was observed (Table 4, entry 6). In order to check this selectivity trend in other diperoxy acids, we carried out reaction of benzene-1,2-diamine with hexanebis(peroxoic acid) and dodecanebis(peroxoic acid) (with 6 and 12 carbon atoms, respectively), which also give 100% conversion to 2-nitroaniline with 90% and 92% isolated yields, respectively (Table 4, entries 7 and 8). Reaction of other diperoxy acids with substrates such as *o*-nitroaniline and *o*-toluidine also failed to show any oxidation of amino group under identical conditions. This confirms the regio- and chemoselective nature of diperoxy acids for oxidation of aromatic amines. The reaction

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876–7883

Table 4. Selective Oxidation of Benzene-1,2-diamine by Use of Conventional Oxidants and Other Diperoxy Acids[a]



1 4a

entry	oxidant	4a conversion[b](%)
1	50% H_2O_2	
2	70% TBHP	
3	oxone	
4	sodium perborate	
5	potassium peroxydisulfate	
6	*m*-CPBA	28
7	hexanebis(peroxoic acid)	100
8	dodecanebis(peroxoic acid)	100
9[c]	performic acid	
10[d]	peracetic acid	100 (58)[e]

[a]Reaction conditions: **1** (1 equiv), oxidant (6 equiv for entries 1−6 or 3 equiv for entries 7 and 8), acetonitrile 5 mL, time 2 h (entries 1−6) or 20 min (for entries 7 and 8). [b]Conversion was determined by GC. [c]Reactions were carried out with 6, 12, and 24 equiv of peracid. [d]With 24 equiv of peracetic acid. [e]Isolated yield.

of benzene-1,2-diamine **1** with aliphatic monoperoxy acids such as performic acid does not show formation of **4a**, though we increased the peracid equivalents from 6 to 24 (Table 4, entry 9). In the case of peracetic acid, **4a** formation was not observed when 6 equiv of peracetic acid was used. As we increased equivalents of peracetic acid from 6 to 24, formation of **4a** was observed. The moderate yield of **4a** is due to formation of a blackish insoluble solid along with the desired product, which was not detected on GC-MS (Table 4, entry 10).

The present approach was also examined on a gram scale. We carried out oxidation of aniline and benzene-1,2-diamine for a 5 g scale-up of each. The reaction yielded 97% nitrobenzene and 95% 2-nitroaniline in 20 min, respectively. Thus, it was also confirmed that the protocol can be successfully used on a gram scale.

CONCLUSIONS

We have developed a simple, efficient, and transition-metal-free protocol for oxidation of aromatic amine to nitro groups. The reaction selectively yields desired nitro products in a shorter period, with high yield and purity irrespective of the substituents present on the ring. The most exciting feature of the present approach is meta- and para-selective oxidation of amine, whereas anilines ortho-substituted with groups other than -NH_2, -$NHCH_3$, and -OH remained unaffected. Such ortho-substituent-hindered selectivity plays a vital role for the selective oxidation of diamine into its mononitro derivative, in which amines with ortho substituents remained unaffected. The protocol shows unexceptional selectivity for oxidation of benzene-1,2-diamine to 2-nitroaniline without further oxidizing it to the 1,3-dinitro compound. Oxidation of amines by peroxy acids is well reported, but such regio- and chemoselectivity was not yet reported in any of these peroxy acids. We have also shown that the protocol was successful on a gram scale.

EXPERIMENTAL SECTION

All products were confirmed by melting point and ^{1}H NMR and mass spectrometry. All melting points are uncorrected and are presented in degrees Celsius. The ^{1}H NMR spectroscopic data were recorded on 400 and 500 MHz instruments in $CDCl_3$ and deuterated dimethyl sulfoxide (DMSO-d_6) as solvent, and chemical shifts are expressed in δ, parts per million (ppm), with tetramethylsilane (TMS) as an internal standard. GC analysis was carried out on a TR-1 column, 30m × 0.25 mm i.d. × 0.25 μm film, flame ionization detector (FID) and sample size 0.1 μL. Nitrogen was used as the carrier gas at a flow rate of 2 mL/min, 80−250 °C at 10 °C/min. Gas chromatography/mass spectrometry (GC-MS) was performed on a Rtx-17 column, 30 m, 25 mm i.d., film thickness 0.25 μm, column flow 2 mL/min, 80−250 °C at 10 °C/min.

General Procedure for Synthesis of Nonanebis(peroxoic acid). Nonanebis(peroxoic acid) was synthesized per the procedure given in the literature[35,36] on a 10 g scale.

General Procedure for Oxidation of Aromatic Amines by Use of Nonanebis(peroxoic acid). In a 50 mL round-bottom flask, 0.1 g of amine was stirred in 5 mL of acetonitrile for 5 min. To this was added nonanebis(peroxoic acid) (3 equiv) over 10 min with constant stirring. The reaction mass was heated to 50 °C for 20 min. The reaction mass was quenched by saturated sodium thiosulfate solution (2 mL) and extracted in ethyl acetate (3 × 10 mL). The organic layer was treated with saturated sodium bicarbonate solution until the acid was neutralized and then with water, and the solution was dried over anhydrous Na_2SO_4. The crude product was obtained after evaporation of the solvent under vacuum, which was further purified by column chromatography on silica gel with hexane/ethyl acetate as the eluent.

Procedure for Scale-up Reaction. In a 500 mL round-bottom flask equipped with a mercury sealed stirrer, 5 g of amine (aniline or benzene-1,2-diamine) was taken up in 250 mL of acetonitrile. The reaction mass was stirred for 5 min at room temperature. To this reaction mass was added 6 equiv of nonanebis(peroxoic acid) (71 g for aniline and 61 g for benzene-1,2-diamine) carefully and slowly over 45−50 min at room temperature. The reaction mass was maintained at 50 °C for 20 min, and then the reaction mass was quenched by 50 mL of saturated sodium thiosulfate and extracted in ethyl acetate (3 × 20 mL). The organic layer was further treated with saturated sodium bicarbonate solution until it was free from acids and then further with water. It was then dried over anhydrous Na_2SO_4. The solvent was evaporated under vacuum to give 97% nitrobenzene or 95% 2-nitroaniline.

Spectral Data. *Nitrobenzene (**3a**).*[20] Yellow oil; yield 0.127 g, 96%; purity 99.4% (GC); bp 208−210 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 7.54−7.58 (m, 2H), 7.69−7.72 (m, 1H), 8.23−8.25 (m, J = 8.5, 1 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 123 (52.8) $[M]^+$, 93 (10.8), 77 (100).

*3-Chloronitrobenzene (**3b**).*[20] Light yellow solid; yield 0.114 g, 92%; purity 99.1% (GC); mp 46−47 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 7.50−7.53 (t, J = 8, 8.5 Hz, 1H), 7.68−7.70 (q, J = 7.5, 1 Hz, 1H), 8.13−8.15 (q, J = 7, 1.5 Hz, 1H), 8.23−8.24 (t, J = 2 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 157 (87.6) $[M]^+$, 159 (28), 127 (41.6), 129 (13.6), 113 (31), 111 (98.4), 101 (11.2), 99 (33.6), 75 (100).

*4-Chloronitrobenzene (**3c**).*[20] Light yellow solid; yield 0.117 g, 94%; mp 82−83 °C; purity 99.0% (GC); ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 7.52−7.53 (q, J = 2, 7 Hz, 2H), 8.18−8.20 (q, J = 2.5, 6.5 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 157 $[M]^+$, 127, 11, 75 (100).

*1,3-Dinitrobenzene (**3d**).*[41] Yellow solid; yield 0.111 g, 91%; mp 89−90 °C; purity 98.6% (GC); ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 7.81−7.84 (t, J = 8, 8 Hz, 1H), 8.58−8.60 (q, J = 8, 2 Hz, 2H), 9.08−9.09 (t, J = 8, 2 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 168 (94.4) $[M]^+$, 122 (36.4), 92 (44.0), 76 (80), 75 (78.8), 74 (22.8).

*1,4-Dinitrobenzene (**3e**).*[20] Yellow solid; yield 0.112 g, 92%; mp 165−166 °C; purity 98.9% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.43 (s, 4H); GC-MS (EI, 70 eV) m/z (%) = 168 (60) $[M]^+$, 122 (20), 90 (19), 76 (46), 30 (100).

*1-Methoxy-3-nitrobenzene (**3f**).*[42] Yellow solid, yield 0.116 g, 93%; purity 99.2% (GC); ^{1}H NMR ($CDCl_3$, 300 MHz) δ = 3.90 (s, 3H), 7.17−7.20 (d, J = 8.3 Hz, 1H), 7.38−743 (t, J = 8.1 Hz, 1H), 7.70 (s, 1H), 7.79−7.82 (d, J = 7.4 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 153 (100) $[M]^+$, 107 (53), 92 (74), 77 (92).

*1-Methoxy-4-nitrobenzene (**3g**).*[20] White solid; yield 0.118 g, 95%; mp 51−52 °C; purity 98.8% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ

DOI: 10.1021/acs.joc.5b00582
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3.89 (s, 3H), 6.96−6.92 (m, 2H), 8.19−8.15 (m, 2H); GC-MS (EI, 70 eV) m/z (%) = 153 (100) $[M]^+$, 123 (47), 107 (12), 92 (56), 77 (56).

3-Nitrotoluene (**3h**).[43,44] Light yellow liquid; yield 0.119 g, 95%; bp 230−232 °C; purity 99.5% (GC); ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 2.47 (s, 3H), 7.40−7.44 (t, 1H), 7.49−7.51 (d, 1H), 8.02−8.05 (t, 2H). GC-MS (EI, 70 eV) m/z (%) = 137 (75) $[M]^+$, 107 (20), 91 (100), 79 (12).

4-Nitrotoluene (**3i**).[20] Light yellow solid; yield 0.116 g, 92%; mp 52−53 °C; purity 99.3% (GC); ^{1}H NMR ($CDCl_3$, 500 MHz) δ = 7.31−7.33 (d, J = 8.5 Hz, 2H), 8.11−8.13 (d, J = 8.5 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 137 (100) $[M]^+$, 107 (32.8), 91 (90), 79 (17.6), 77 (19.6).

3-Nitrobenzoic acid (**3j**).[42] Light yellow solid; yield 0.101 g, 83%; mp 140−142 °C; purity 98.5% (HPLC); ^{1}H NMR (DMSO, 500 MHz) δ = 7.78−7.81 (t, J = 8 Hz, 1H), 8.32−8.34 (t, J = 7.5 Hz, 1H), 8.44−8.46 (m, 1H), 8.601−8.604 (d, J = 1.5 Hz, 1H), 13.6 (br s, 1H); EI-MS = 165.90 [M − H].

4-Nitrobenzoic acid (**3k**).[42] Light yellow solid; yield 0.104 g, 85% yield; mp 235−236 °C; purity 98.8% (HPLC); ^{1}H NMR (DMSO, 400 MHz) δ = 8.17−8.20 (m, J = 9.08, 1.84 Hz, 2H), 8.29−8.32 (m, J = 9.08, 1.88 Hz, 2H), 13.18 (br s, 1H); EI-MS = 165.93 [M − H].

3-Nitrophenol (**3l**).[45,46] White solid; yield 0.105 g, 82%; mp 96−97 °C; purity 98.6% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 5.96 (s, 1H), 7.22−7.19 (m, 1H), 7.41 (t, J = 8.2 Hz, 1H), 7.72 (t, J = 2.0 Hz, 1H), 7.81 (d, J = 8.0 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 139 (100) $[M]^+$, 93 (52.4), 81 (23.2).

4-Nitrophenol (**3m**).[46,47] Light yellow solid; yield 0.106 g, 83%; mp 114−116 °C; purity 99.0% (GC); ^{1}H NMR (DMSO, 500 MHz) δ = 6.065 (s, 1H), 6.935−6.953 (d, J = 9 Hz, 2H); 8.18−8.198 (d, J = 9 Hz, 2H). GC-MS (EI, 70 eV) m/z (%) = 139 (100) $[M]^+$, 93 (31.2), 81 (20), 65 (86.8).

N-(4-Nitrophenyl)acetamide (**3n**).[48] Colorless solid; yield 0.103 g, 86%; mp 209−211; purity 98.7% (GC); ^{1}H NMR (500 MHz, DMSO) δ 2.10 (s, 3H), 7.80−7.79 (d, J = 5 Hz, 2H), 8.18−8.17 (d, J = 5 Hz, 2H), 10.52 (s, 1H). GC-MS (EI, 70 eV) m/z (%) = 180 (33) $[M]^+$, 138 (100), 122 (5.59), 108 (28.4), 92 (26.3).

4-Nitrobenzonitrile (**3o**).[49,50] Light yellow solid; yield 0.110 g, 88%; mp 145−146 °C; purity 99.1% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 7.87−7.91 (m, J = 8.0 Hz, 2H), 8.35−8.38 (m, J = 8.8 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 148 (60) $[M]^+$,118 (10.6), 102 (100), 90 (29.4), 75 (47.5).

1-Nitro-3-(trifluoromethoxy)benzene (**3p**).[51] Pale yellow liquid; yield 0.105 g, 90%; bp 208−210 °C; purity 98.1% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34 (dd, J = 15.4, 9.1 Hz, 2H), 8.28−8.24 (m, 1H), 8.39−8.35 (m, 1H); GC-MS (EI, 70 eV) m/z (%) = 207 (66) $[M]^+$, 177 (28), 161 (13), 95 (100), 92 (27), 75 (27).

1-(4-Nitrophenyl)ethanone (**3q**).[52] Light yellow solid; yield 0.115 g, 94%; mp 76−78 °C; purity 99.2% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 2.69 (s, 3H), 8.11−8.14 (m, J = 8.0, 2.16 Hz, 2H), 8.30−8.34 (m, J = 8.0, 2.24 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 165 (17.8) $[M]^+$, 150 (100), 120 (20.8), 104 (41.6), 92 (24.9), 76 (25.9).

(4-Nitrophenyl)methanol (**3r**).[42] Pale yellow solid; yield 0.104 g, 84%; mp 92−94 °C; purity 99.5% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.00 (br d, 1H), 4.84 (d, J = 5.7 Hz, 2H), 7.54 (dd, J = 8.8 Hz, 2H), 8.22 (dd, J = 8.6 Hz, 2H); GC-MS (EI, 70 eV) m/z (%) = 153 (18) $[M]^+$, 136 (14), 107 (53), 89 (35), 77 (100), 63 (20).

2-Nitrophenol (**3s**).[53] Light yellow solid; yield 0.113 g, 89%; mp 43−44 °C; purity 99.5% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 6.97−7.02 (m, J = 7.24 Hz, 1H), 7.15−7.17 (dd, J = 8.48 Hz, 1H), 7.57−7.61(m, J = 7.28 Hz, 1H), 8.10−8.12 (dd, J = 8.52 Hz, 1H), 10.59 (s, 1H); GC-MS (EI, 70 eV) m/z (%) = 139 (100) $[M]^+$, 122 (6.70), 109 (25.2), 93 (10), 84 (28.8), 65 (39.2), 64 (21.1), 63 (32.7).

2-Nitroaniline (**4a**).[54] Orange solid; yield 0.121 g, 95%; mp 72−73 °C; 99.8% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 6.06 (s, 2H), 6.68−6.72 (m, J = 8.48 Hz, 1H), 6.79−6.82 (dd, J = 8.4 Hz, 1H), 7.34−7.38 (m, J = 8.44 Hz, 1H), 8.1−8.13 (dd, J = 8.64 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 138 (100) $[m]^+$, 108 (19.2), 92 (59.2), 80 (20.4), 65 (88.8).

2,4-Dinitroaniline (**4b**).[55,56] Yellow-orange solid; yield 0.109 g, 89%; purity 99.4% (HPLC); mp 182−183 °C; ^{1}H NMR (DMSO, 400 MHz) δ = 7.09−7.11 (d, J = 9.44 Hz, 1H), 8.09−8.12 (m, J = 9.4, 2.68 Hz, 1H), 8.31−8.33 (br s, 2H), 8.801−8.808 (d, J = 2.64 Hz, 1H); EI-MS = 182.09 [M − H].

2-Methyl-4-nitroaniline (**4c**).[57,58] Yellow solid; yield 0.117 g, 87%; mp 130−132 °C; 99.3% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 2.23 (s, 3H), 3.93 (s, 2H), 7.13−7.15 (d, J = 8.12 Hz, 1H), 7.48−7.49 (d, J = 2.24 Hz, 1H), 7.51−7.54 (dd, J = 8.16 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 152 (89) $[M]^+$, 122 (10.57), 106 (77.49), 94 (21.94), 77 (83.1).

2-Methoxy-4-nitroaniline (**4d**).[59,60] Yellow solid; yield 0.110 g, 90%; mp 140−141 °C; purity 99.3% (GC); ^{1}H NMR (500 MHz, DMSO) δ 3.86 (s, 3H), 6.43 (s, 2H), 6.64 (d, J = 8.8 Hz, 1H), 7.56 (d, J = 2.2 Hz, 1H), 7.73 (dd, J = 8.8, 2.3 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 168 (100) $[M]^+$, 153 (40), 122 (29), 107 (16), 95 (37), 92 (13).

2,6-Dichloro-4-nitroaniline (**4e**).[61] Yellow solid; yield 0.108 g, 92%; mp 189−190 °C; purity 99.1% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 5.17 (s, 2H), 8.16 (s, 2H); GC-MS (EI, 70 eV) m/z (%) = 208 (54) $[M]^+$, 178 (54.8), 160 (51.6), 135 (17.2), 124 (100), 90 (28.4), 63 (30.8).

2-Cyano-4-nitroaniline (**4f**).[62,63] Light yellow solid; yield 0.113 g, 90%; mp 210−211 °C; purity 99.0% (GC); ^{1}H NMR (DMSO, 400 MHz) δ = 6.85−6.87 (d, J = 9.4 Hz, 1H), 7.38 (s, 2H), 8.06−8.09 (m, J = 9.36, 2.68 Hz, 1H), 8.30−8.31 (d, J = 2.68 Hz, 1H). GC-MS (EI, 70 eV) m/z (%) = 163 (97.6) $[M]^+$, 147 (4.6), 133 (70.4), 117 (63.2), 90 (100), 78 (13.2), 63 (56).

2-Bromo-6-cyano-4-nitroaniline (**4g**).[64] Yellow solid; yield 0.106 g, 93%; mp 183−184 °C, purity 98.7% (HPLC); ^{1}H NMR (DMSO, 400 MHz) δ = 7.42 (s, 2H), 8.42−8.44 (m, J = 2.56 Hz, 2H). GC-MS (EI, 70 eV) m/z (%) = 243 (19.79) $[M]^+$, 241 (19.93), 211 (17.90), 195 (9.04), 168-(6.01), 143 (1.23), 116 (36.98), 103 (3.06), 88 (14.45), 77 (7.04), 65 (11.95), 52 (10.63), 40 (100).

4-Nitro-N-phenylaniline (**4h**).[65,66] Yellow solid; yield 0.099 g, 85%; mp 132−134 °C; purity 99.2% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.30 (s, 1H), 6.97−6.93 (m, 2H), 7.18 (t, J = 7.4 Hz, 1H), 7.22 (d, J = 7.6 Hz, 2H), 7.42−7.37 (m, 2H), 8.15−8.11 (m, 2H); GC-MS (EI, 70 eV) m/z (%) = 214 (65) $[M]^+$, 184 (26), 167 (61), 142 (12), 77 (24).

N-Methyl-2-nitroaniline (**4k**).[67,68] Brown-orange solid; yield 0.111 g, 89%; mp 34−35 °C; purity 99.7% (GC); ^{1}H NMR ($CDCl_3$, 400 MHz) δ = 2.95 (s, 3H), 6.56−6.60 (m, J = 8.36 Hz, 1H), 6.76−6.78 (m, J = 8.72 Hz, 1H), 7.37−7.41 (m, J = 8.0, 1.52 Hz, 1H), 7.97 (br s, 2H), 8.09−8.11 (m, J = 8.6, 1.6 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 152 (51) $[M]^+$, 106 (33.6), 105 (53.2), 77 (100), 51 (41).

4-Chloro-2-nitroaniline (**4l-a**).[69] Orange solid; mp 96−97 °C; purity 99.6% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.79 (d, J = 8.9 Hz, 1H), 7.32 (dd, J = 8.9, 2.5 Hz, 1H), 8.13 (d, J = 2.4 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 172 (100) $[M]^+$, 142 (92), 114 (17), 101 (19), 90 (48).

5-Chloro-2-nitroaniline (**4l-b**).[70] Yellow solid; mp 130−131 °C; purity 99.4% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.13 (s, 2H), 6.68 (dd, J = 9.1, 2.2 Hz, 1H), 6.83 (d, J = 2.1 Hz, 1H), 8.08 (d, J = 9.1 Hz, 1H); GC-MS (EI, 70 eV) m/z (%) = 172 (88) $[M]^+$, 174 (28), 142 (100), 101 (30), 114 (30), 90 (63), 78 (13).

N-(2-Nitrophenyl)acetamide (**4m**).[71] Pale yellow solid; yield 0.104 g, 87%; mp 92−94 °C; purity 99.5% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.32−2.27 (m, 3H), 7.18 (dd, J = 8.5, 1.3 Hz, 1H), 7.67−7.61 (m, 1H), 8.20 (d, J = 8.4, 1.5 Hz, 1H), 8.78−8.74 (m, 1H), 10.33 (s, 1H); GC-MS (EI, 70 eV) m/z (%) = 180 (26) $[M]^+$, 138 (79), 92 (46), 65 (21), 43 (100).

4-Chloro-N^1-phenylbenzene-1,2-diamine (**4n**).[72,73] Orange solid; yield 0.102 g, 90%; mp 58−60 °C; purity 99.1% (GC); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.17 (d, J = 9.2 Hz, 1H), 7.33−7.26 (m, 3H), 7.46−7.42 (m, 2H), 8.21 (d, J = 2.5 Hz, 2H), 9.45 (s, 1H); GC-MS (EI, 70 eV) m/z (%) = 248 (100) $[M]^+$, 214 (31), 201 (59), 167 (85), 139 (26), 77 (44).

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b00582.

^{1}H NMR and MS spectra for **3a**−**3s**, **4a**−**4h**, and **4k**−**4n** (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We are thankful to the Institute of Chemical Technology and UGC-CAS for providing financial assistance, to Panjab University for recording ^{1}H NMR spectra, and to MS Indoco Remedies Ltd, Rabale Navi Mumbai, and IIT SAIF for recording MS spectra.

■ REFERENCES

(1) Hwang, S. H.; Kim, N. K.; Koh, K. N.; Kim, S. H. *Dyes Pigm.* **1998**, *39*, 359−369.
(2) Koh, J.; Kim, S.; Kim, J. P. *Color. Technol.* **2004**, *120*, 241−246.
(3) Manabe, S.; Ito, Y. *Chem. Pharm. Bull.* **2001**, *49*, 1234−1235.
(4) Takekoshi, T. *Polym. J.* **1987**, *19*, 191−202.
(5) Luckenbach, T.; Epel, D. *Environ. Health Perspect.* **2005**, *113*, 17−24.
(6) Nash, E. G.; Nienhouse, E. J.; Silhavy, T. A.; Humbert, D. E.; Mish, M. J. *J. Chem. Educ.* **1970**, *47*, 705.
(7) Belciug, M.-P.; Ananthanarayanan, V. S. *J. Med. Chem.* **1994**, *37*, 4392−4399.
(8) Ju, K.-S.; Parales, R. E. *Microbiol. Mol. Biol. Rev.* **2010**, *74*, 250−272.
(9) Mikite, G.; Jakucs, E.; Kis-Tamás, A.; Darvas, F.; Lopata, A. *Pestic. Sci.* **1982**, *13*, 557−562.
(10) Gilbert, E. E.; Leccacorvi, J. R. *Propellants, Explos., Pyrotech.* **1976**, *1*, 89−90.
(11) Yan, G.; Yang, M. *Org. Biomol. Chem.* **2013**, *11*, 2554−2566.
(12) Golan, E.; Rozen, S. *J. Org. Chem.* **2003**, *68*, 9170−9172.
(13) Kol, M.; Rozen, S. *J. Chem. Soc., Chem. Commun.* **1991**, *3*, 567−568.
(14) Rozen, S.; Bar-Haim, A.; Mishani, E. *J. Org. Chem.* **1994**, *59*, 1208−1209.
(15) Murray, R. W.; Jeyaraman, R.; Mohan, L. *Tetrahedron Lett.* **1986**, *27*, 2335−2336.
(16) Zabrowski, D. L.; Moormann, A. E.; Beck, K. R., Jr. *Tetrahedron Lett.* **1988**, *29*, 4501−4504.
(17) Murray, R. W.; Rajadhyaksha, S. N.; Mohan, L. *J. Org. Chem.* **1989**, *54*, 5783−5788.
(18) Emmons, W. D. *J. Am. Chem. Soc.* **1957**, *79*, 5528−5530.
(19) Emmons, W. D. *J. Am. Chem. Soc.* **1954**, *76*, 3470−3472.
(20) Liu, J.; Li, J.; Ren, J.; Zeng, B.-B. *Tetrahedron Lett.* **2014**, *55*, 1581−1584.
(21) Webb, K. S.; Seneviratne, V. *Tetrahedron Lett.* **1995**, *36*, 2377−2378.
(22) Firouzabadi, H.; Amani, N. I. K. *Green Chem.* **2001**, *3*, 131−132.
(23) McKillop, A.; Tarbin, J. A. *Tetrahedron Lett.* **1983**, *24*, 1505−1508.
(24) Das, S. S.; Nath, U.; Deb, D.; Das, P. J. *Synth. Commun.* **2004**, *34*, 2359−2363.
(25) Reddy, K. R.; Maheswari, C. U.; Venkateshwar, M.; Kantam, M. L. *Adv. Synth. Catal.* **2009**, *351*, 93−96.
(26) Jayachandran, B.; Sasidharan, M.; Sudalai, A.; Ravindranathan, T. *J. Chem. Soc., Chem. Commun.* **1995**, 1523−1524.
(27) Krohn, K.; Küpke, J.; Rieger, H. *J. Prakt. Chem./Chem.-Ztg.* **1997**, *339*, 335−339.
(28) Tollari, S.; Vergani, D.; Banfi, S.; Porta, F. *J. Chem. Soc., Chem. Commun.* **1993**, 442−444.
(29) Stuehr, D. J.; Marletta, M. A. *J. Org. Chem.* **1985**, *50*, 694−696.
(30) Dewkar, G. K.; Nikalje, M. D.; Sayyed Ali, I.; Paraskar, A. S.; Jagtap, H. S.; Sudalai, A. *Angew. Chemie Int. Ed.* **2001**, *40*, 405−408.
(31) Winkler, R.; Richter, M. E. A.; Knüpfer, U.; Merten, D.; Hertweck, C. *Angew. Chem., Int. Ed.* **2006**, *45*, 8016−8018.
(32) Lee, J.; Simurdiak, M.; Zhao, H. *J. Biol. Chem.* **2005**, *280*, 36719−36727.
(33) Lee, J.; Zhao, H. *Angew. Chem.* **2006**, *118*, 638−641.
(34) James, A. P.; Sankey, J. P.; Johnstone, R. A. W.; McCarron, M.; Trenbirth, B. *Chem. Commun.* **1998**, 429−430.
(35) Patil, V. V.; Shankarling, G. S. *Beilstein J. Org. Chem.* **2014**, *10*, 921−928.
(36) Parker, W. E.; Witnauer, L. P.; Swern, D. *J. Am. Chem. Soc.* **1957**, *79*, 1929−1931.
(37) Henson, O. E. *Appl. Environ. Microbiol.* **1981**, *42*, 656−660.
(38) Jecs, E.; Kreicberga, J.; Kampars, V.; Jurgis, A.; Rutkis, M. *Opt. Mater. (Amsterdam, Neth.)* **2009**, *31*, 1600−1607.
(39) Thiel, W.; Mayer, R.; Jauer, E.-A.; Modrow, H.; Dost, H. *J. Prakt. Chem.* **1986**, *328*, 497−514.
(40) Choi, J.; Aggarwal, M. D.; Wang, W. S.; Penn, B. G.; Frazier, D. O. *Proc. SPIE* **1999**, *3793*, 55−63.
(41) Xia, R.; Xie, M.-S.; Niu, H.-Y.; Qu, G.-R.; Guo, H.-M. *Green Chem.* **2014**, *16*, 1077−1081.
(42) Yang, H.; Li, Y.; Jiang, M.; Wang, J.; Fu, H. *Chem. - Eur. J.* **2011**, *17*, 5652−5660.
(43) Manna, S.; Maity, S.; Rana, S.; Agasti, S.; Maiti, D. *Org. Lett.* **2012**, *14*, 1736−1739.
(44) González, M. P.; Toropov, A. A.; Duchowicz, P. R.; Castro, E. A. *Molecules* **2004**, *9*, 1019−1033.
(45) Thakur, K. G.; Sekar, G. *Chem. Commun.* **2011**, *47*, 6692−6694.
(46) Xiao, Y.; Xu, Y.; Cheon, H.-S.; Chae, J. *J. Org. Chem.* **2013**, *78*, 5804−5809.
(47) Ramana, M. M. V; Malik, S. S.; Parihar, J. A. *Tetrahedron Lett.* **2004**, *45*, 8681−8683.
(48) Rasheed, S.; Rao, D. N.; Reddy, A. S.; Shankar, R.; Das, P. *RSC Adv.* **2015**, *5*, 10567−10574.
(49) Yadav, A. K.; Srivastava, V. P.; Yadav, L. D. S. *RSC Adv.* **2014**, *4*, 4181−4186.
(50) Kawagoe, Y.; Moriyama, K.; Togo, H. *Eur. J. Org. Chem.* **2014**, *2014*, 4115−4122.
(51) Feiring, A. E. U.S. Patent 4157344, 1979.
(52) Cai, M.; Zheng, G.; Ding, G. *Green Chem.* **2009**, *11*, 1687−1693.
(53) Zolfigol, M. A.; Khazaei, A.; Moosavi-Zare, A. R.; Zare, A.; Kruger, H. G.; Asgari, Z.; Khakyzadeh, V.; Kazem-Rostami, M. *J. Org. Chem.* **2012**, *77*, 3640−3645.
(54) Guha, N. R.; Bhattacherjee, D.; Das, P. *Tetrahedron Lett.* **2014**, *55*, 2912−2916.
(55) Harland, P. A.; Hodge, P.; Maughan, W.; Wildsmith, E. *Synthesis* **1984**, *1984*, 941−943.
(56) Yang, Y.-L.; Rajagopal, B.; Liang, C.-F.; Chen, C.-C.; Lai, H.-P.; Chou, C.-H.; Lee, Y.-P.; Yang, Y.-L.; Zeng, J.-W.; Ou, C.-L.; Lin, P.-C. *Tetrahedron* **2013**, *69*, 2640−2646.
(57) Rys, P.; Steinegger, W. J. *J. Am. Chem. Soc.* **1979**, *101*, 4801−4806.
(58) Takahashi, T.; Yoshimura, M.; Suzuka, H.; Maegawa, T.; Sawama, Y.; Monguchi, Y.; Sajiki, H. *Tetrahedron* **2012**, *68*, 8293−8299.
(59) Van Erp, H. *J. Prakt. Chem.* **1930**, *127*, 20−38.
(60) Burnley, J.; Carbone, G.; Moses, J. E. *Synlett* **2013**, *24*, 652−656.
(61) Mahajan, T.; Kumar, L.; Dwivedi, K.; Agarwal, D. D. *Synth. Commun.* **2012**, *42*, 3655−3663.
(62) Taylor, E. C.; Knopf, R. J.; Cogliano, J. A.; Barton, J. W.; Pleiderer, W. *J. Am. Chem. Soc.* **1960**, *82*, 6058−6064.

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883

(63) Mąkosza, M.; Białecki, M. *J. Org. Chem.* **1998**, *63*, 4878−4888.
(64) Mrozik, H. H.; Bochis, R. J. German Patent DE 2300447 A1, 1973; *Chem. Abstr.* 1973, *79*, 115333j
(65) Singh, R.; Allam, B. K.; Raghuvanshi, D. S.; Singh, K. N. *Tetrahedron* **2013**, *69*, 1038−1042.
(66) Zhang, Y.; César, V.; Lavigne, G. *Eur. J. Org. Chem.* **2015**, *2015*, 2042−2050.
(67) Gale, D. J.; Wilshire, J. F. K. *Aust. J. Chem.* **1972**, *25*, 2145−2154.
(68) Windisch, M. P.; Jo, S.; Kim, H.-Y.; Kim, S.-H.; Kim, K.; Kong, S.; Jeong, H.; Ahn, S.; No, Z.; Hwang, J. Y. *Eur. J. Med. Chem.* **2014**, *78*, 35−42.
(69) Wang, H.; Wen, K.; Nurahmat, N.; Shao, Y.; Zhang, H.; Wei, C.; Li, Y.; Shen, Y.; Sun, Z. *Beilstein J. Org. Chem.* **2012**, *8*, 744−748.
(70) Claridge, R. P.; Millar, R. W.; Sandall, J. P. B.; Thompson, C. *Tetrahedron* **1999**, *55*, 10243−10252.
(71) Srivastava, V. P.; Yadav, A. K.; Yadav, L. D. S. *Synlett* **2014**, *25*, 665−670.
(72) Day, M.; Peters, A. T. *J. Soc. Dyers Colour.* **1967**, *83*, 137−143.
(73) Dale, B. J.; Jones, D. W.; Peters, A. T. *J. Soc. Dyers Colour.* **1974**, *90*, 101−104.

DOI: 10.1021/acs.joc.5b00582
J. Org. Chem. 2015, 80, 7876−7883