Advanced Synthesis & Catalysis

## Accepted Article

**Title:** "Lewis Acid Catalyzed Reductive Cyclization of 2-Aryloxybenzaldehydes and 2-(Arylthio)benzaldehydes to Unsubstituted 9H-Xanthenes and Thioxanthenes in Diisopropyl Ether"

**Authors:** Shashi Verma, Anamika Prajapati, Manoj Saini, and Ashok Basak



**To be cited as:** *Adv. Synth. Catal.* 10.1002/adsc.202000836

**Link to VoR:** https://doi.org/10.1002/adsc.202000836

10.1002/adsc.202000836

FULL PAPER

DOI: 10.1002/adsc.202((will be filled in by the editorial staff))

# Lewis Acid Catalyzed Reductive Cyclization of 2-Aryloxybenzaldehydes and 2-(Arylthio)benzaldehydes to Unsubstituted 9*H*-Xanthenes and Thioxanthenes in Diisopropyl Ether

Shashi Kant Verma,[a] Anamika Prajapati,[b] Manoj Kumar Saini,[a] Ashok K Basak*[a]

[a]Department of Chemistry, Institute of Science, Banaras Hindu University, Varanasi 221005, India
[b]Department of Chemistry, University of Rajasthan, Jaipur 302004, India

E-mail ID: akbasak.chem@bhu.ac.in

Received: ((will be filled in by the editorial staff))

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/adsc.201######.((Please delete if not appropriate))

**Abstract.** Readily accessible 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes undergo a sequence of reactions leading to a wide variety of unsubstituted 9*H*-xanthenes and thioxanthenes in high yields when heated with a Lewis acid in diisopropyl ether. This reductive cyclization method is compatible with several important functional groups. The method is also applicable for the selective reductive cyclization of the more electron-rich aryl ring of a 2,6-bis(aryloxy)benzaldehyde. The key feature of this transformation is the chemoselective reduction of a transient xanthylium ion in the presence of aldehydic group via intermolecular hydride transfer from diisopropyl ether (solvent).

**Keywords:** 2-Aryloxybenzaldehyde; 2-(arylthio)benzaldehyde; xanthylium ion; hydride transfer; chemoselective reduction; 9*H*-xanthene; reductive cyclization; redox-neutral conditions.

## Introduction

Unsubstituted 9*H*-xanthenes and thioxanthenes (Figure 1) are tricyclic aromatic structural motifs that contain diaryl methylene group. Due to the moderate pKa value (~35) of the methylene protons, relatively stable (due to the presence of two aryl groups) carbanions can be readily obtained by treating with a strong base in suitable solvents. These carbanions were utilized for nucleophilic arylation at C-9 position,[1] addition to styrenes and related olefins,[2] and nucleophilic opening of oxetanes[3] to generate synthetically useful novel molecular entities. In addition, owing to the low C-H bond dissociation energy[4] (76 Kcal/mol) of the methylene group, 9*H*-xanthenes are often utilized as a choice of starting materials for the development of benzylic C-H functionalization reactions[5] such as radical C-H functionalization,[6] electrochemical cross-dehydrogenative coupling,[7] organocatalytic asymmetric cross-dehydrogenative coupling,[8] and Pd-catalyzed C($sp^3$)-H arylation reactions.[9] Using a suitable reagent, unsubstituted 9*H*-xanthenes and thioxanthenes can be converted into 9*H*-xanthylium ion which is subsequently trapped by nucleophiles to generate useful compounds.[10] Despite these synthetic importances, however, only a limited number of methods are reported for the synthesis of these extremely useful substrates. Scheme 1 represents the reported methods for the direct synthesis of unsubstituted 9*H*-xanthene. Klussmann and co-workers reported a $Sc(OTf)_3$-catalyzed one-pot condensation of 2-hydroxybenzaldehydes with cyclohexenones under microwave as well as conventional heating (PhCl reflux, 18-44 h, 12

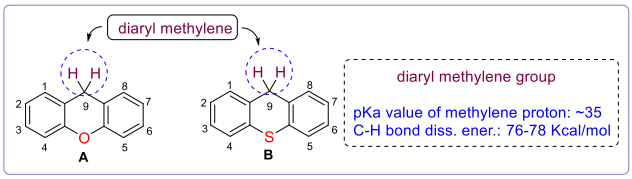
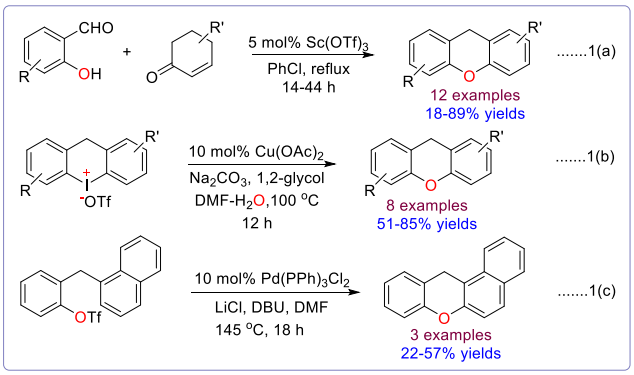



**Figure 1**. Unsubstituted 9*H*-xanthene (A) and thioxanthene (B)

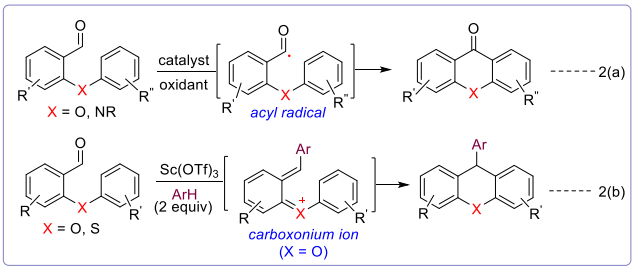
10.1002/adsc.202000836

examples) to obtain unsubstituted 9*H*-xanthenes in 18-89% yields (Scheme 1a).[11] The efficiency of the condensation reaction is dependent on the nucleophilicity of the hydroxyl group of salicylaldehydes and thus, provide poor yield (18%) with 5-chlorosalicylaldehyde due to the presence of the electronegative Cl-atom. Moreover, no example



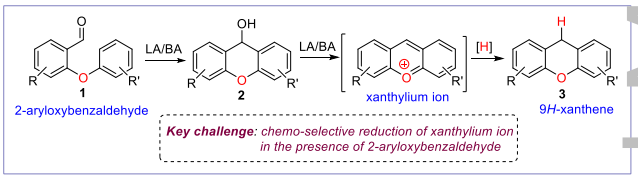

**Scheme 1**. Reported methods for direct synthesis of unsubstituted 9*H*-xanthenes

for the synthesis of 9*H*-thioxanthene was reported in the paper. In a very recent report, Zhu, Wen and co-workers demonstrated a $Cu(OAc)_2$-catalysed base-promoted domino reaction of cyclic diphenyliodonium salts with water to access unsubstituted 9*H*-xanthenes in 51-85% yields (8 examples, 100 °C, 12 h) with limited substrate scope (Scheme 1b).[12] Lastly, Harvey et al. showed that simple polycyclic unsubstituted 9*H*-xanthenes can be synthesized via ligand-free Pd(II)-catalyzed intramolecular cross-coupling reaction of polycyclic aryltriflate esters at high temperature (3 examples, 145 °C, 18 h, 22-57% yields) (Scheme 1c).[13] The lack of a common method for the synthesis of unsubstituted 9*H*-xanthenes as well as thioxanthenes can be attributed to the non-identification of competent starting materials for a common strategy. Thus, in this context, the development of a common method for the synthesis of unsubstituted 9*H*-xanthenes as well as thioxanthenes with wide substrate scope and functional group compatibility is highly desired.




**Scheme 2**. Xanthene derivatives from 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes

On the other hand, 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes are readily accessible in high yields from commercially available 2-fluorobenzaldehydes and phenols/thiophenols via direct aromatic nucleophilic substitution reaction.[14] These substrates were extensively utilized for the synthesis of xanthene derivatives, particularly, xanthones[15] and 9-(hetero)aryl xanthenes.[14,16] 2-Aryloxybenzaldehydes yield xanthones when treated with stoichiometric amount of a suitable oxidant in the presence of a catalyst (Scheme 2a). These xanthones can be reduced into unsubstituted 9*H*-xanthenes under mild conditions.[17] Li et al. and later on Panda et al. demonstrated that 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes undergo domino reaction when treated with 2 equiv of electron rich (hetero)arenes in the presence of suitable Lewis acid catalyst (Scheme 2b).[16a,16b] Despite these advances, to the best of our knowledge, there is no report for the direct synthesis of unsubstituted 9*H*-xanthenes and thioxanthenes from the readily available 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes. Our hypothesis for a one-pot transformation of 2-aryloxybenzaldehyde to unsubstituted 9*H*-xanthene is outlined in Scheme 5. Lewis acid/Bronsted acid (LA/BA) promoted intramolecular Friedel-Crafts (FC) type cyclization would lead to intermediate cyclic alcohol **2** which would get converted into xanthylium ion under the reaction conditions (LA/BA). This transient xanthylium ion could be reduced in-situ to the unsubstituted 9*H*-xanthene **3** by a suitable hydride transfer reagent.[18]




**Scheme 3**. Envision for direct synthesis of unsubstituted 9*H*-xanthene

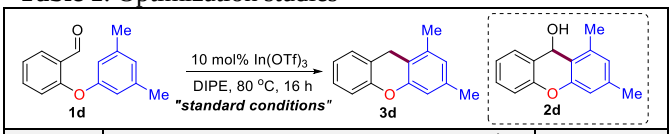
However, finding a hydride transfer reagent compatible with the reaction conditions and effective for the chemoselective reduction of the xanthylium ion in the presence of a highly reactive aryl aldehydic group is the key challenge associated with this one-pot multi-step catalytic conversion plan. For instance, 2-aryloxybenzaldehydes did not yield the anticipated unsubstituted 9*H*-xanthenes and underwent reductive etherification when treated with a Lewis acid in the presence of triethylsilane as the reducing agent.[19] Herein, we report the successful development of a highly effective reductive cyclization of 2-aryloxybenzaldehydes and 2-(arylthio)benzaldehydes using $In(OTf)_3$ as the Lewis acid in diisopropyl ether. The method delivers a wide range of 9*H*-xanthenes and thioxanthenes in excellent yields. In addition, these conditions are also highly effective for the selective reductive cyclization of 2,6-bis(aryloxy)benzaldehydes.

## Results and Discussion

10.1002/adsc.202000836

In recent literature, alkyl ethers, in the presence of suitable Lewis acids/Bronsted acids, have been utilized as traceless hydride transferring agents for highly effective intramolecular[20] as well as intermolecular[21] reduction of transient carbenium ions. For instance, Gagosz, Chiba and co-workers

**Table 1**. Optimization studies

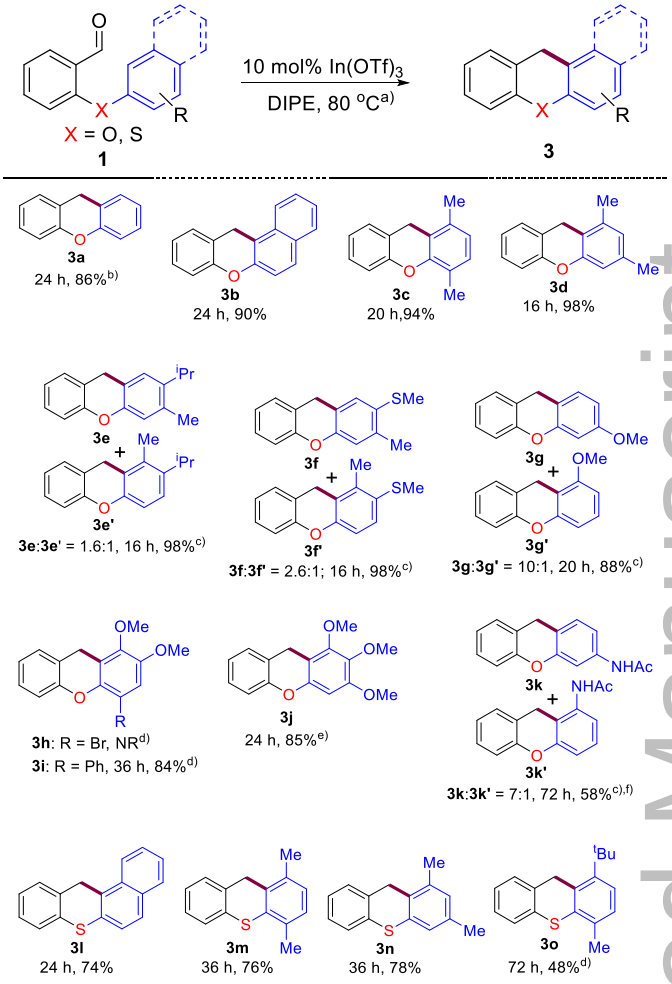



| entry | deviation from standard conditions[a] | yield (%) |
|---|---|---|
| a | none | 98 |
| b | THF instead of DIPE | 75 |
| c | diethyl ether instead of DIPE | 85 |
| d | di-n-butyl ether instead of DIPE | 86 |
| e | 50 °C instead of 80 °C | 65[b] |
| f | $Sc(OTf)_3$ instead of $In(OTf)_3$ | 90 |
| g | $Yb(OTf)_3$ instead of $In(OTf)_3$ | 78[c] |
| h | $InCl_3$ instead of $In(OTf)_3$ | 94 |
| i | TfOH instead of $In(OTf)_3$ | 90[d] |
| j | $HNTf_2$ instead of $In(OTf)_3$ | 92[d] |

[a]All reactions were carried out in 0.30 mmol scale using 10 mol% catalyst in appropriate solvent (0.2M concentration) in a sealed tube. [b]80% conversion after 24 h. [c]80 °C, 36 h. [d]80 °C, 24 h. DIPE = diisopropyl ether.

reported an elegant TsOH catalyzed intramolecular hydrogenation of alkene using benzyl and isopropyl ether as the traceless hydride transferring groups under redox-neutral conditions.[20a] Similarly, Xiong, Chen and co-workers demonstrated that diarylmethyl carbenium ions, generated in situ from diarymethyl alcohols by treating with stoichiometric amount (1.2 equiv) of $BF_3.OEt_2$, can be reduced via intermolecular hydride transfer from the solvent (n-butylether).[21] Inspired by these literature reports, we tested the envisaged reductive cyclization reaction (as shown in Scheme 3) in ethereal solvents in the presence of LA/BA. As shown in Table 1, the reductive cyclization reaction of 2-aryloxybenzaldehyde **1d** furnished xanthene **3d** in nearly quantitative yield (98%) under the optimized standard conditions: 10 mol% $In(OTf)_3$, DIPE (0.2 M), 80 °C, 16 h. Reactions in other ethereal solvents (THF, diethyl ether, di-n-butyl ether) provided inferior results (entries b-d, Table 1). The cyclization reaction at lower temperature (50 °C) was slow and small amount (<10%) of intermediate cyclic alcohol **2d** was observed at that temperature. While $Sc(OTf)_3$ produced xanthene **3d** in 90% yields, $Yb(OTf)_3$ was found to be less effective for this reductive cyclization reaction. 10 mol% $InCl_3$ as catalyst also delivered xanthene **3d** in excellent yield (94%). As anticipated, Bronsted acids (TfOH, $HNTf_2$) also delivered xanthene **3d** in very high yields (entries i-j, Table 1).

Next, to probe the synthetic utility, a variety of 2-aryloxybenzaldehydes, generated from 2-fluorobenzaldehyde and readily available phenols, were subjected to the standards conditions. The results of the reductive cyclization reactions are presented in Scheme 4. Aryl ether derived from electron-neutral phenol underwent reductive cyclization at 95 °C to generate xanthene **3a** in 86% yield. However, 2-naphthol derived aryl ether showed better reactivity and produced xanthene **3b** at 80 °C in 90% yield. 2-Aryloxybenzaldehydes generated from



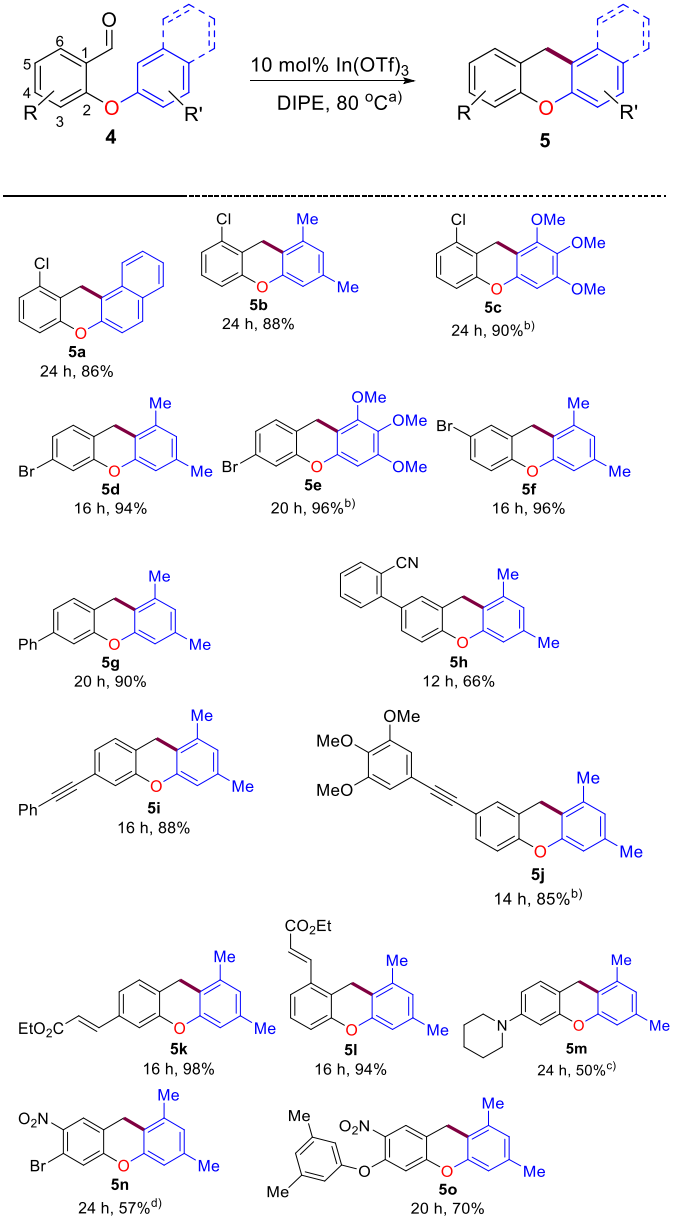

[a]All reactions were carried out in 0.30 mmol scale in sealed tube in anhydrous DIPE in 0.2 M concentration. [b]reaction was carried out at 95 °C. [c]mixture of regioisomers. [d]reaction was carried out at 90 °C. [e]reaction was carried out in DIPE-THF (4:1) mixture. [f]reaction was carried out in DIPE-THF (4:1) mixture at rt. NR = no reaction.

**Scheme 4**: Scope of the reductive cyclization reaction

2,5-dimethylphenol and 3,5-dimethylphenol furnished xanthenes **3c** and **3d** in 94% and 98% yields, respectively. Aryl ether generated from 4-isopropyl-3-methylphenol produced isomeric xanthenes **3e** and **3e´** in excellent yield (98%). Similarly, aryl ether derived from 3-methyl-4-(thiomethyl)phenol and 3-methoxyphenol also resulted into xanthenes (**3f**, **3f´**) and (**3g**, **3g´**) as a mixture of regiomers in high yields. The major regiomer arising out of the cyclization of aryl ethers derived from unsymmetrical phenols is predictable. In general, p-position to an electron-donating group (Me, OMe, NHAc) is the most preferred position for cyclization leading to the formation of the major

10.1002/adsc.202000836

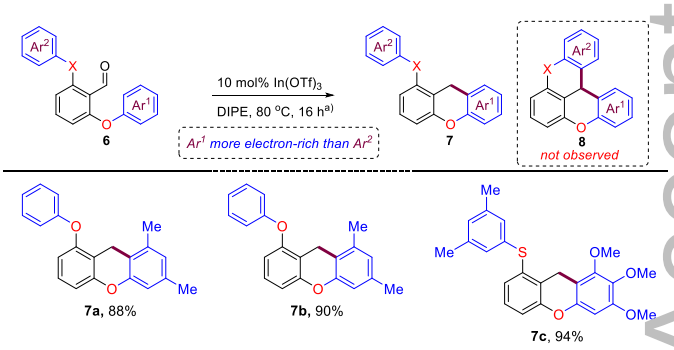
regioisomer. The ratio of regioisomers in favour of the major increases as the size of the electron donating group increases (for example, Me group in **3e** versus OMe group in **3g**). While no reaction was observed with aryl ether derived from 2-bromo-4,5-dimethylphenol even after prolonged heating at 90 °C due to the presence of electron-withdrawing Br-atom, xanthene **3i** could be obtained in 84% yield by heating at 90 °C for 36 hours. 3,4,5-Trimethoxyphenol derived aryl ether provided xanthene **3j** in high yield (85%). Aryl ether derived from *N*-(3-hydroxyphenyl)acetamide underwent reductive cyclization at ambient temperature (30 °C) to generate a mixture of isomeric xanthenes (**3k**, **3k´**) in moderate yield (58%). Next, a few 2-(arylthio)benzaldehydes, obtained from 2-fluorobenzaldehyde and commercially available symmetrical thiophenol, were subjected to the reductive cyclization reaction conditions. Aryl thioether derived from electron-neutral naphthalene-2-thiol underwent reductive cyclization to furnish thioxanthene **3l** in 74% yield. Aryl thioethers generated from 2,5-dimethylbenzenethiol and 3,5-dimethylbenzenethiol provided thioxanthenes **3m** and **3n** in 76% and 78% yields, respectively. Notably, reductive cyclization at the ortho-position to a bulky tert-butyl group was also successful generating thioxanthene **3o** in modest (48%) yield.




a)All reactions were carried out in 0.3 mmol scale in a sealed tube using anhydrous DIPE in 0.2M concentration. b)Reaction was carried out in DIPE-THF (4:1) mixture. dReaction was carried out using 15 mol% $In(OTf)_3$ at 120 °C. d)Reaction was carried out at 90 °C.

**Scheme 5**: Scope of unsubstituted 9*H*-xanthene synthesis

To evaluate the effect of substituents on the reductive cyclization, a series of 2-aryloxybenzaldehydes bearing various substituents on aryl ring containing aldehyde group were subjected to the standard reaction conditions. 2-Aryloxy-6-chlorobenzaldehydes underwent reductive etherification to generate xanthenes **5a**-**5c** in very high yields (Scheme 5). Aryl ethers having Br-atom at 4- and 5-position provided xanthenes **5d**-**5f** in excellent yields. Aryloxybenzaldehyde containing a phenyl group at 4-position provided xanthene **5g** in 90% yield. Similarly, aryl ether containing a phenyl-2-carbonitrile group at 5-position gave corresponding xanthene **5h** in 66% yield. The $In(OTf)_3$-catalyzed reductive cyclization conditions were also compatible with internal alkynes at 4- and 5-position providing xanthenes **5i** and **5j** in 88% and 85% yields, respectively. Aryl ethers having electron-deficient olefin at 4- and 6-position furnished xanthenes **5k** and **5l** in 98% and 94% yields, respectively. Remarkably, the reductive cyclization of aryl ether containing a strong electron-releasing piperidine moiety at 4-position was also successful generating xanthene **5m** in moderate yield (50%). Gratifyingly, aryl ether bearing strong electron-withdrawing $NO_2$-group at 5-position and Br-atom at 4-position

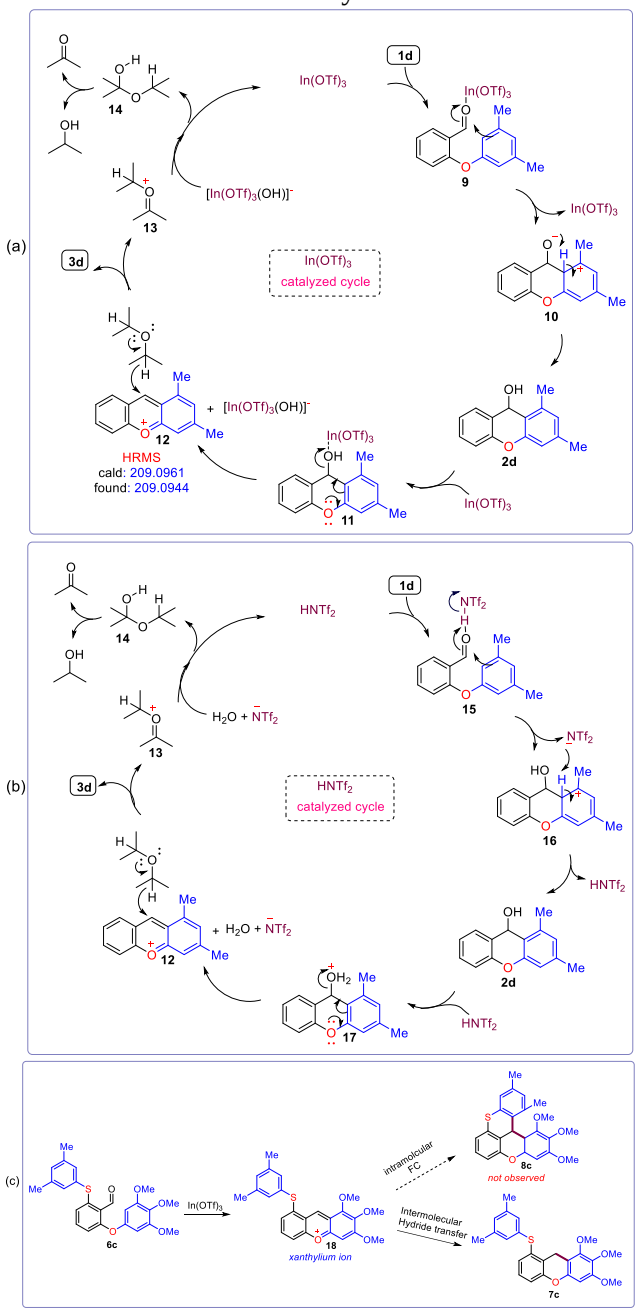



a)All reaction were carried out in 0.30 mmol scale using 10 mol% $In(OTf)_3$ in DIPE (0.2M) at 80 °C.

**Scheme 6**: Selective reductive cyclization of 2,6-bis(aryloxy)benzaldehydes.

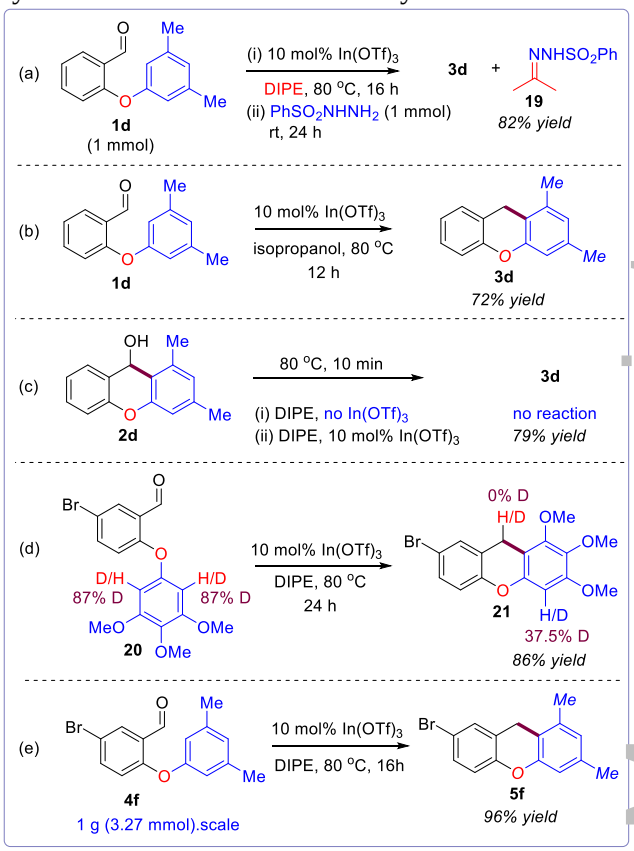
provided xanthene **5n** in 57% yield. Significantly higher yield (70%) of xanthene **5o** was obtained with aryl ether having $NO_2$-group at 5-position and a second aryloxy group at 4-position.

As shown in Scheme 6, the $In(OTf)_3$ catalyzed reductive cyclization reaction could be exploited for the selective cyclization of the more electron-rich aryl ring in 2,6-bis(aryloxy)benzaldehydes obtained from 2-aryloxy-6-chlorobenzaldehydes via direct aromatic nucleophilic substitution reaction (see page S11, Supporting Information). While xanthenes **7a** and **7b** were obtained via selective cyclization of electron-rich aryl ring versus electron-neutral aryl ring, xanthene **7c** was obtained via selective reduction of the more electron-rich aryl ring between the two electron-rich aryl rings. Compound **8**, which would arise when both the aryl rings undergo intramolecular Friedel-Crafts type cyclization reaction with the aldehydic group, was not observed in the above cases. Further studies towards the development of efficient condition for the synthesis of the typical compound **8** are in progress in our laboratory.




**Scheme 7**: Proposed reaction mechanism (a) $In(OTf)_3$-catalyzed cycle (b) $HNTf_2$-catalyzed cycle (c) selective reductive cyclization.

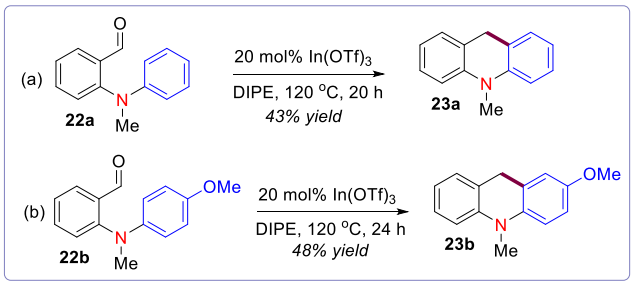
The mechanism of the reductive cyclization reaction catalyzed by a Lewis acid ($In(OTf)_3$) as well as a Bronsted acid ($HNTf_2$) is depicted in Scheme 7. LA/BA promoted intramolecular Friedel-Crafts type cyclization leads to intermediate cyclic alcohol **2d**



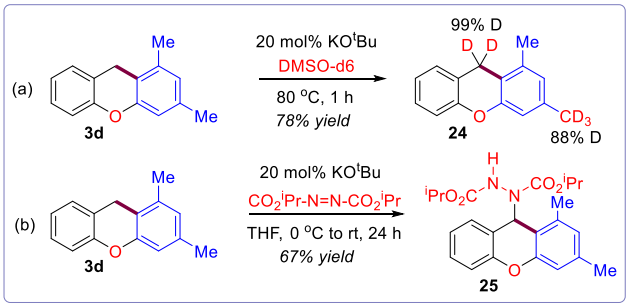

**Scheme 8**: Supporting experiments and gram-scale synthesis.

which then gets converted into xanthylium ion **12**. Chemoselective reduction of **12** via intermolecular hydride transfer from diisopropyl ether (solvent)[21] provides xanthene **3d** and oxocarbenium ion **13**. Hydrolysis of **13** leads to hemiacetal **14** which presumably decomposes under reaction conditions to acetone and isopropanol. Hydride transfer from isopropanol is likely to reduce xanthylium ion **12** to generate acetone and xanthene **3d**. The reductive cyclization of **1d** also occurs in dry isopropanol to furnish xanthene **3d** in good yield (Scheme 8b). These results support the reduction of xanthylium ion **12** via hydride transfer from isopropanol and are in complete agreement with literature report.[18b] The cyclic alcohol **2d** could be synthesized in two steps[15d,22] and when subjected to the standard conditions provided xanthene **3d** within very short time (10 min) in 79% yield (Scheme 8c). This indicates that the formation of the intermediate alcohol **2d** is the slowest step and thus the rate determining step. In the case of xanthylium ion **18** obtained from 2,6-bis(aryloxy)benzaldehyde **6c** (Scheme 7c), intermolecular hydride transfer precess from the solvent (DIPE) outcompetes the intramolecular Friedel-Crafts reaction providing 9*H*-

xanthene **7c** exclusively. This differential reactivity can be attributed to the solvation of the xanthylium ion by DIPE and the energy barrier associated with intramolecular FC reaction forming a strained fused




**Scheme 9**: Synthesis 10-methyl-9,10-dihydroacridines




**Scheme 10**: KOtBu-catalyzed reactions of **3d**

ring **8c**. The formation of acetone was observed by the real-time monitoring of a reaction in NMR tube using $CDCl_3$ as solvent and with added stoichiometric amount of DIPE (see Scheme S1 & Figure S1, page S3, SI). Due to volatile nature of the by-product (acetone), $^1$H NMR of the crude reaction mixture of **1d** appeared exceptionally clean (see crude $^1$H NMR, Figure S5, page S7, SI). As shown in Scheme 8a, acetone can be obtained quantitatively (82% yield) as its *N*-phenylsulfonyl hydrazone derivative **19** by treating the crude reaction mixture of **1d** with *N*-phenylsulfonyl hydrazide at rt for 24 h. The xanthylium ion could be detected by HRMS analysis of aliquot of crude reaction mixture of **1d** at intermediate time (~8 h) interval. Notably, the deuterio-enriched aryl ether **20** prepared from deuterio-enriched phenol[23] also provided xanthene **21** in high yield (86%). To probe the utility in large scale synthesis, 2-aryloxybenzaldehyde **4f** in 1.0 g scale was subjected to the standard reaction conditions. Gratifyingly, no loss in yield and/or reactivity was observed thereby demonstrating the robustness and practicality of this novel transformation. As shown in Scheme 9, the method can also be used for the reductive cyclization of 2-(methyl(phenyl)amino)benzaldehydes[15c] to generate 10-methyl-9,10-dihydroacridines (**23a** & **23b**). However, these reactions are less efficient when compared to the synthesis of unsubstituted 9*H*-xanthenes. KO$^t$Bu-catalyzed selected functionalization reactions presented in Scheme 10 showcase the synthetic utility of the unsubstituted 9*H*-xanthenes. For example, deuterated compound **24** was obtained in 78% yield via KO$^t$Bu catalysed deuteration reaction which is believed to proceed via single-electron-transfer mechanism.[24] Deuterated xanthenes of type **24** are useful for kinetic as well as mechanistic studies.[25] The KO$^t$Bu-catalyzed addition of xanthene **3d** to diisopropyl azodicarboxylate provides a novel method for the generation of C-N bond at 9-position of unsubstituted 9*H*-xanthene (Scheme 10b).[2a]

## Conclusion

In conclusion, a highly efficient, robust and viable reductive cyclization reaction of 2-aryloxybenzaldehydes and 2-(arythio)benzaldehydes to the corresponding unsubstituted 9*H*-xanthenes and thioxanthenes catalyzed by $In(OTf)_3$ in diisopropyl ether has been developed. This novel transformation involves sequence of steps which include an intramolecular Friedel-Crafts type cyclization, xanthylium ion formation and the crucial chemoselective reduction of xanthylium ion via highly effective intermolecular hydride transfer from diisopropyl ether (solvent). The method is compatible with several important functional groups and can be carried in gram-scale. Notably, this method can also be utilized for the selective reductive cyclization of the more electron-rich aryl ring in case of 2,6-bis(aryloxy)benzaldehydes. Most of the reactions are very clean and high yielding and thus the method is poised for further development of one-pot transformations of the resulting 9*H*-xanthenes and thioxanthenes. Further applications of this novel reductive cyclization method are in progress in our laboratory.

## Experimental Section

**General experimental procedure for the synthesis of 9*H*-xanthenes (3a-3o and 5a-5o):**

2-(3,5-dimethylphenoxy)benzaldehyde **1d** (67.9 mg, 0.30 mmol), dry diisopropyl ether (1.5 mL, 0.2M) and $In(OTf)_3$ (17 mg, 0.030 mmol) was charged into a 10 mL pressure tube under nitrogen atmosphere. The pressure tube is then sealed with a Teflon® screw cap and heated in a pre-heated oil bath at 80 °C for 16 h. The reaction mixture was the diluted with ethyl acetate (25 mL), washed with brine (1 x 10 mL), dried over $Na_2SO_4$ and evaporated. The crude product was purified by short silica gel column chromatography using 100% hexanes as eluent to obtained 1,3-dimethyl-9*H*-xanthene **3d** (61.8 mg, 98%) as a white solid.

**General experimental procedure for the synthesis of 8-aryloxy-9*H*-xanthenes (7a-7c):**

2,6-Bis(aryloxy)benzaldehyde (0.30 mmol), dry diisopropyl ether (1.5 mL, 0.2M) and $In(OTf)_3$ (17 mg, 0.030 mmol) were charged into a 10 mL pressure tube under nitrogen atmosphere. The pressure tube is then sealed with a Teflon® screw cap and heated in a pre-heated oil bath at 80 °C for 16 h. The reaction mixture was then diluted with ethyl acetate (25 mL), washed with brine (1 x 10 mL), dried over $Na_2SO_4$ and evaporated. The crude product was purified by short silica gel column chromatography using 0 → 5% gradient mixture of ethyl acetate in hexanes as eluent to obtain 8-aryloxy-9*H*-xanthene **7**.

## Acknowledgements

*Research grant from Council of Scientific and Industrial Research (Grant No. 02(0346)/19/EMR-II), India is gratefully acknowledged. SKV thanks UGC, New Delhi for a research fellowship. AP and MKS thank CSIR, New Delhi for research fellowship*

## References

[1] X. Ji, T. Huang, W. Wu, F. Liang, S. Cao, *Org. Lett*. **2015**, *17*, 5096-5099.

[2] a) Y.-F. Liu, D.-D. Zhai, X.-Y. Zhang, B.-T. Guan, *Angew. Chem. Int. Ed.* **2018**, *57*, 8245-8249; b) X. Ji, Y. Liu, H. Shi, S. Cao, *Tetrahedron* **2018**, *74*, 4155-4159.

[3] D. Quintás, A. García, D. Domínguez, *Tetrahedron Lett*. **2003**, *44*, 9291-9294.

[4] F. G. Bordwell, J.-P. Cheng, A. V. Satish, C. L. Twyman, *J. Org. Chem.* **1992**, *57*, 6542-6546.

[5] a) A. Pintér, A. Sud, D. Sureshkumar, M. Klussmann, *Angew. Chem. Int. Ed.* **2010**, *49*, 5004-5007; b) B. Schweitzer-Chaput, A. Sud, Á. Pintér, S. Dehn, P. Schulze, M. Klussmann, *Angew. Chem. Int. Ed.* **2013**, *52*, 13228-13232; c) Y.-D. Du, Z.-J. Xu, C.-Y. Zhou, C.-M. Che, *Org. Lett.* **2019**, *21*, 895-899; d) H. Wu, C. Su, R. Tandiana, C. Liu, C. Qiu, Y. Bao, J. Wu, Y. Xu, J. Lu, D. Fan, K. P. Loh, *Angew. Chem. Int. Ed.* **2018**, *57*, 10848-10853; e) T. Stopka, L. Marzo, M. Zurro, S. Janich, E. ‑ U. Würthwein, C. G. Daniliuc, J. Alemán, O. G. Mancheño, *Angew. Chem. Int. Ed.* **2015**, *54*, 5049-5053; f) Y. Liu, X. Guan, E. L.-M. Wong, P. Liu, J.-S. Huang, C.-M. Che, *J. Am. Chem. Soc.* **2013**, *135*, 7194-7204; g) Á. Pintér, M. Klussmann, *Adv. Synth. Catal.* **2012**, *354*, 701-711; h) Y. Liu, C.-M. Che, *Chem. Eur. J.* **2010**, *16*, 10494-10501.

[6] a) S. Liua, M. Klussmann, *Chem. Commun.* **2020**, *56*, 1557-1560; b) T. Brandhofer, A. Özdemir, A. Gini, O. G. Mancheño, *Chem. Eur. J.* **2019**, *25*, 4077-4086; c) H. Nishino, H. Kamachi, H. Baba, K. Kurosawa, *J. Org. Chem.* **1992**, *57*, 3551-3557.

[7] a) M.-Y. Lin, K. Xu, Y.-Y. Jiang, Y.-G. Liu, B.-G. Sun, C.-C. Zeng, *Adv. Synth. Catal.* **2018**, *360*, 1665-1672; b) Y.-Z. Yang, R. J. Song, J.-H. Li, *Org. Lett.* **2019**, *21*, 3228-3231; c) K.-J. Li, Y.-Y. Jiang, K. Xu, C.-C. Zeng, B.-G. Sun, *Green Chem.* **2019**, *21*, 4412-4421; d) X. Shao, L. Tian, Y. Wang. *Eur. J. Org. Chem.* **2019**, 4089-4094; e) Y.-Z. Yang, Y.-C. Wu, R.-J. Song, J.-H. Li, *Chem. Commun.* **2020**, *56*, 7585-7588.

[8] a) E. Larionov, M. M. Mastandrea, M. A. Pericás, *ACS Catal.* **2017**, *7*, 7008-7013; b) B. Zhang, S.-K. Xiang, L.-H. Zhang, Y. Cui, N. Jiao, *Org. Lett.* **2011**, *13*, 5212-5215; c) F. Huang, L. Xu, J. Xiao, *Chin. J. Chem.* **2012**, *30*, 2721-2725; d) W. Cao, X. Liu, R. Peng, P. He, L. Lin, X. Feng, *Chem. Commun.* **2013**, *49*, 3470-3472; e) X.-H. Ho, S. Mho, H. Kang, H.-Y. Jang, *Eur. J. Org. Chem.* **2010**, 4436-4441; f) F. Li, D. Tian, Y. Fan, R. Lee, G. Lu, Y. Yin, B. Qiao, X. Zhao, Z. Xiao, Z. *Nat. Commun.* **2019**, *10*, 1774; g) F. Benfatti, M. G. Capdevila, L. Zoli, E. Benedetto, P. G. Cozzi, *Chem. Commun*. **2009**, 5919-5929.

[9] a) G. Shen, L. Zhao, Y. Wang, W. Xia, M. Yang, T. Zhang, *RSC Adv*. **2016**, *6*, 84748-84751; b) J. Zhang, A. Bellomo, N. Trongsiriwat, T. Jia, P. J. Carroll, S. D. Dreher, M. T. Tudge, H. Yin, J. R. Robinson, E. J. Schelter, P. J. Walsh, *J. Am. Chem. Soc.* **2014**, *136*, 6276-6287; c) S.-C. Sha, J. Zhang, P. J. Carroll, P. J. Walsh, *J. Am. Chem. Soc.* **2013**, *135*, 17602-17609; d) J. Zhang, A. Bellomo, A. D. Creamer, S. D. Dreher, P. J. Walsh, *J. Am. Chem. Soc.* **2012**, *134*, 13765-13772.

[10] a) W. Chen, Z. Xie, H. Zheng, H. Lou, L. Liu, *Org. Lett.* **2014**, *16*, 5988-5991; b) W. Muramatsu, K. Nakano, *Org. Lett.* **2015**, *17*, 1549-1552; c) Q. Chen, X. Wang, G. Yu, C. Wen, Y. Huo, *Org. Chem. Front.* **2018**, *5*, 2652-2656.

[11] E. Böβ, T. Hillringhaus, J. Nitsch, M. Klussmann, *Org. Biomol. Chem.* **2011**, *9*, 1744-1748.

[12] D. Zhu, M. Li, Z. Wu, Y. Du, B. Luo, P. Huang, S. Wen, *Eur. J. Org. Chem.* **2019**, 4566-4571.

[13] J.-Q. Wang, R. G. Harvey, *Tetrahedron* **2002**, *58*, 5927-5931.

[14] S. K. Das, R. Singh, G. Panda, *Eur. J. Org. Chem.* **2009**, 4757-4761.

[15] (a) P. Wang, H. Rao,; R. Hua, C.-J. Li, *Org. Lett*. **2012**, *14*, 902-905; b) S. Wertz, D. Leifert, A. Studer, *Org. Lett.* **2013**, *15*, 928-931; c) X.-A. Li, H.-L. Wang, S.-D. Yang, *Org. Lett.* **2013**, *15*, 1794-1797; d) H. Rao, X. Ma, Q. Liu, Z. Li, S. Cao, C.-J. Li, *Adv. Synth. Catal.* **2013**, *355*, 2191-2196; e) H. Li, C. Liu, Y. Zhang, Y. Sun, B.Wang, W. Liu, *Org. Lett.* **2015**, *17*, 932-935; f) J. Tang, S.Zhao, Y. Wei, Z. Quana, C Huo, *Org. Biomol. Chem.* **2017**, *15*, 1589-1592; (g) J. B. Singh, K. Mishra, T. Gupta, R. M. Singh, *ChemistrySelect* **2017**, *2*, 1207-1210; h) H. Bao, X. Hu, J. Zhang, Y. Liu, *Tetrahedron* **2019**, *75*, 130533; (i) Z. Zheng, L. Dian, Y. Yuan, D. Zhang-Negrerie, Y. Du, K. Zhao, *J. Org. Chem.* **2014**, *79*, 7451-7458.

[16] a) H. Li, J. Yang, Y. Liu, Y. Li, *J. Org. Chem.* **2009**, *74*, 6797-6801; b) R. Singh, G. Panda, *Org. Biomol. Chem.* **2010**, *8*, 1097-1105; c) T. Yildiz, H. B. Küçük, *RSC Adv.* **2017**, *7*, 16644-16649; d) T. Yildiz, *Synth. Commun.* **2018**, *48*, 2177-2188.

10.1002/adsc.202000836

[17] S. C. A. Sousa, T. A. Fernandes, A. C. Fernandes, *Eur. J. Org. Chem.* **2016**, 3109-3112.

[18] a) X.-Q. Zhu, Z. Dai, A. Yu; S. Wu, J.-P. Cheng, *J. Phys. Chem B* **2008**, *112*, 11694-11707; b) Y. Lu, J. Bradshaw, Y. Zhao, W. Kuester, D. Kabotso, *J. Phys. Org. Chem.* **2011**, *24*, 1172-1178; c) F. Liu, X. Zhu, *Eur. J. Org. Chem.* **2014**, 7329-7332.

[19] A. Prajapati, M. Kumar, R. Thakuria, A. K. Basak, *Tetrahedron Lett.* **2019**, *60*, 150955.

[20] a) D. A. Gandamana, B. Wang, C. Tejo, B. Bolte, F. Gagosz, S. Chiba, *Angew. Chem. Int. Ed.* **2018**, *57*, 6181-6185; b) B. Wang, D. A. Gandamana, F. Gagosz, S. Chiba, *Org. Lett.* **2019**, *21*, 2298-2301; c) B. Wang, D. Gandamana, D. F. L. Rayo, F. Gagosz, S. Chiba, *Org. Lett.* **2019**, *21*, 9179-9182; d) A. Bauer, N. Maulide, *Org. Lett.* **2018**, *20*, 1461-1464; e) D. A. Gandamana, F. Gagosz, S. Chiba, *Tetrahedron* **2020**, *76*, 131272.

[21] J. Li, Q. Liu, H. Shen, R. Huang, X. Zhang, Y. Xiong, C. Chen, *RSC Adv*. **2015**, *5*, 85291-85295.

[22] H. Blake, R. Mortezaali, B. Hammann, M. Razzaghi, S. Kashfolgheta, Y. Lu, *Chem. Commun.* **2012**, *48*, 11337-11339.

[23] For the preparation of deuterium enriched phenol, see: Y. Sawama, A. Nakano, T. Matsuda, T. Kawajiri, T. Yamada, H. Sajiki, *Org. Process Res. Dev.* **2019**, *23*, 648-653.

[24] Y. Hu, L. Liang, W.-t. Wei, X. Sun, X.-j. Zhang, M. Yan, *Tetrahedron* **2015**, *71*, 1425-1430.

[25] a) A. Lewandowska-Andralojc, D. C. Grills, J. Zhang, R. M. Bullock, A. Miyazawa, Y. Kawanishi, E. Fujita, *J. Am. Chem. Soc.* **2014**, *136*, 3572-3578; b) M. A. Ehudin, D. A. Quist, K. D. Karlin, *J. Am. Chem. Soc.* **2019**, *141*, 12558-12569.

10.1002/adsc.202000836

FULL PAPER

# Lewis Acid Catalyzed Reductive Cyclization of 2-Aryloxybenzaldehydes and 2-(Arylthio)benzaldehydes to Unsubstituted 9*H*-Xanthenes and Thioxanthenes in Diisopropyl Ether

*Adv. Synth. Catal.* **Year**, *Volume*, Page – Page

Shashi Kant Verma, Anamika Prajapati, Manoj Kumar Saini, Ashok K. Basak*