Sc(OTf)$_3$ catalyzed carbon-carbon and carbon-heteroatom bond forming reactions: a review

Bubun Banerjee

Department of Chemistry, Indus International University, V.P.O. Bathu, Distt. Una, Himachal Pradesh-174301, India
Email: banerjeebubun@gmail.com

Received 09-05-2016
Accepted 11-08-2016
Published on line 12-04-2016

Abstract

In recent years scandium(III) trifluoromethanesulfonate [Sc(OTf)$_3$] has emerged as an efficient, mild, commercially available, inexpensive, water tolerant Lewis acidic catalyst in the formation of both carbon-carbon and carbon-heteroatom bonds, and thereby the formation of various biologically promising organic compounds. The present review summarizes the latest developments on Sc(OTf)$_3$-catalyzed organic transformations especially carbon-carbon and carbon-heteroatom bond forming reactions reported during the last decade.

Keywords: Lewis acid catalysis, scandium triflate, heterocycles

DOI: https://doi.org/10.24820/ark.5550190.p009.868
Table of Contents

1. Introduction
2. Carbon-Carbon Bond-forming Reactions
   2.1 Friedel-Crafts alkylation of aromatic compounds with alkenes
   2.2 Synthesis of 1,2-dihydroindane derivatives
   2.3 Synthesis of α-(trimethylsilyloxy)nitriles
   2.4 Synthesis of 4-substituted tetrahydroisoquinolines
   2.5 Synthesis of primary homoallylic alcohols
   2.6 Synthesis of 3-propargylated indoles
   2.7 Synthesis of octahydro-1H-pyrrolo[3,2-c]pyridines and octahydropyrano[4,3-b]pyrroles
   2.8 Synthesis of resorcin[4]arene octaalkyl ethers
   2.9 Synthesis of indolemethane derivatives
3. Carbon-Nitrogen Bond-forming Reactions
   3.1 Synthesis of primary amides
   3.2 Synthesis of aryl hydrazides
   3.3 Synthesis of β-amino alcohols
   3.4 Synthesis of N-substituted pyrroles
   3.5 Synthesis of 1-pyridylimidazo[1,5-a]pyridines
   3.6 Synthesis of 5-substituted 1H-tetrazoles
4. Simultaneous Carbon-Carbon and Carbon-Nitrogen Bond-forming Reactions
   4.1 Synthesis of benzimidazole-imidazo[1,2-a]pyridines
   4.2 Synthesis of imidazo[1,2-c]pyrazolo[3,4-d]pyrimidines
   4.3 Synthesis of functionalized pyrazoles
   4.4 Synthesis of N-substituted 1,4-dihydropyridines
   4.5 Synthesis of 2,3-dihydro-1H-1,5-benzodiazepines
   4.6 Synthesis of 3,4-dihydropyrimidin-2(1H)-ones
   4.7 Synthesis of α-amino amidines
5. Carbon-Oxygen Bond-forming Reactions
   5.1 Synthesis of esters
   5.2 Synthesis of 2,6-dioxabicyclo[3,2,1]octane derivatives
   5.3 Synthesis of sugar fused pyranopyran derivatives
   5.4 Synthesis of 3,4-dihydro-4-amino-2-methoxy-2-methyl-2H-1-benzopyrans
   5.5 Synthesis of 2,4-dimethoxy-2-methylchromans
   5.6 Synthesis of coumarins
   5.7 Synthesis of octahydro-2H-chromen-4-ols
6. Carbon-Sulfur Bond-forming Reactions
   6.1 Synthesis of 2,3-unsaturated thioglycosides
7. Sulfur-Sulfur Bond-forming Reactions
   7.1 Synthesis of thiosulfonates
8. Other Reactions
   8.1 Deprotection of tert-butyl aryl sulfonamides
9. Conclusions
1. Introduction

Carbon-carbon and carbon-heteroatom bond-forming reactions are the important tools of organic synthesis to afford structurally varied bioactive organic compounds.\(^1\)\(^-\)\(^3\) Catalysts play an obvious role in such reactions and thus they find wide application. But the screening of suitable catalysts plays a crucial role among the other significant parameters during such chemical praxis.

The last decade has seen a great development in the use of triflate salts as catalysts for organic transformations.\(^4\) Among triflate salts, the applications of scandium(III) trifluoromethanesulfonate [Sc(OTf)\(_3\), scandium triflate] as a Lewis acid catalyst have increased rapidly in the variety of organic transformations that can be effected.\(^5\)-\(^17\) The catalytic applicability of this mild catalyst is well documented in the literature, especially in cycloaddition reactions,\(^18\) Diels-Alder,\(^19\) Ugi,\(^20\) and Michael reactions.\(^21\) Though the majority of the developed methods are based upon the ability of scandium to activate C=X π-bonds toward nucleophilic additions, more recently it has been found that scandium(III) can also activate C-X σ-bonds.\(^22\)

In 1993, Kobayashi et al.\(^{23}\) first demonstrated the use of Sc(OTf)\(_3\) as a promising Lewis acid catalyst in organic synthesis. Sc(OTf)\(_3\) is now commercially available and can be prepared easily from scandium oxide (Sc\(_2\)O\(_3\)) and aqueous trifluoromethanesulfonic acid (TfOH).\(^7\) In general, most of the traditional Lewis acids are deactivated in the presence of water, but Sc(OTf)\(_3\) is stable in an aqueous environment and can efficiently catalyze organic transformations in aqueous media. Moreover, Sc(OTf)\(_3\) is well tolerated and worked efficiently as a Lewis acid catalyst in several other organic solvents. As the size of the scandium (Sc\(^{3+}\)) ion is smaller than those of the rare-earth elements forming triflate salts, Sc(OTf)\(_3\) is a much more efficient Lewis acid catalyst than its congeners. Because of all these benefits the use of this unique catalyst has increased rapidly in organic synthesis especially in carbon-carbon and carbon-heteroatom bond forming reactions.\(^24\)

The present communication focuses on the catalytic application of Sc(OTf)\(_3\) as a mild Lewis acid in organic synthesis, leading to carbon-carbon and carbon-heteroatom bond forming reactions, with up-to-date literature reported on this subject during the last decade.

The following Sections describe the catalytic applicability of scandium(III) triflate in organic synthesis.

2. Carbon-Carbon Bond-forming Reactions

2.1 Friedel-Crafts alkylation of aromatic compounds with alkenes
Scandium(III) triflate catalyzed Friedel-Crafts alkylation of aromatic compounds (1) with alkenes (2) to form the corresponding alkylated products (3) was demonstrated by Song et al.\(^{25}\) (Scheme 1) in 1,3-dialkylimidazolium salts as hydrophobic ionic liquid solvents.
Scheme 1. Scandium(III) triflate catalyzed Friedel-Crafts alkylation.

2.2 Synthesis of 1,2-dihydroindane derivatives
Alajarin et al.\textsuperscript{26} designed a new carbon-carbon bond forming reaction leading to adjacent quaternary carbons to prepare 1,2-dihydroindane derivatives (5, 7) in the presence of scandium(III) triflate as catalyst by the reaction of activated acetalic C-H bonds with benzylidenemalonate fragments (4, 6) as electrophilic hydride acceptors. In this strategy both cyclic as well as acyclic acetal functions underwent smooth conversion to give the desired products (Scheme 2).

Scheme 2. Scandium (III) triflate catalyzed synthesis of 1,2-dihydroindane derivatives.
2.3 Synthesis of α-(trimethylsilyloxy)nitriles
Park et al.\textsuperscript{27} reported an environmentally benign, highly reactive Sc(OTf)\textsubscript{3} catalyzed cyanosilylation of carbonyl compounds (8) with trimethylsilyl cyanide (9) to prepare the corresponding α-(trimethylsilyloxy)carbonitriles (10) in [bmim][SbF\textsubscript{6}] at room temperature (Scheme 3). They also successfully recovered and reused the ionic liquid containing Sc(OTf)\textsubscript{3} for several reaction cycles without any loss of catalytic activity.

![Scheme 3](image)

**Scheme 3.** Sc(OTf)\textsubscript{3} catalyzed cyanosilylations of carbonyl compounds.

2.4 Synthesis of 4-substituted tetrahydroisoquinolines
Tummanapalli et al.\textsuperscript{28} demonstrated a novel, scandium(III) triflate catalyzed, facile, straightforward synthesis of 4-substituted tetrahydroisoquinolines (12) via intramolecular ring expansion of aziridines (11) in 1,2-dichloroethane at 90 °C (Scheme 4).

![Scheme 4](image)

**Scheme 4.** Scandium(III) triflate catalyzed synthesis of 4-substituted tetrahydroisoquinolines.
2.5 Synthesis of primary homoallylic alcohols

Sultana et al. developed a simple protocol for the synthesis of primary homoallylic alcohols (15) from the reaction of alkenes (13) and paraformaldehyde (14) using scandium triflate as catalyst at room temperature (Scheme 5).

\[
\text{Scheme 5. } \text{Sc(OTf)}_3\text{-catalyzed synthesis of primary homoallylic alcohols.}
\]

2.6 Synthesis of 3-propargylated indoles

Yadav and his group (Scheme 6) described a facile and efficient alkylation of indoles (16) with propargyl alcohols (17) to produce 3-propargylated indoles (18) in excellent yields using scandium triflate as catalyst in 1,2-dichloroethane at 80 °C.

\[
\text{Scheme 6. Scandium(III) triflate catalyzed alkylation of indoles with propargyl alcohols.}
\]

2.7 Synthesis of octahydro-1H-pyrrolo[3,2-c]pyridines and octahydropyrano[4,3-b]pyrroles

Reddy et al. (Scheme 7) developed a new method for the synthesis of octahydro-1H-pyrrolo[3,2-c]pyridines (22) and octahydropyrano[4,3-b]pyrroles (23) selectively by means of intramolecular aza-Prins and Prins cyclization of aldehydes (19) and bis-homoallyl (20) and heteroallyl (21) derivatives respectively.

2.8 Synthesis of resorcin[4]arene octaalkyl ethers
Morikawa et al.\textsuperscript{32} demonstrated a simple and straightforward cyclocondensation of 1,3-dialkoxybenzenes (24) with 1,3,5-trioxane (25) to produce resorcin[4]arene octaalkyl ethers (26) in good yields using catalytic amount of Sc(OTf)_3 in acetonitrile at 80 °C (Scheme 8).


2.9 Synthesis of indolemethane derivatives
Kerr and his group\textsuperscript{33} developed an expedient and efficient method for the synthesis of indolemethane derivatives (29) from the reaction of indolylmethyl Meldrum’s acids (27) with a variety of nucleophiles (28) via the nucleophilic displacement of the Meldrum’s acid moiety in the presence of catalytic scandium triflate at 50 °C in acetonitrile as solvent (Scheme 9).
Scheme 9. Scandium(III) triflate catalyzed synthesis of indolemethane derivatives.

3. Carbon-Nitrogen Bond-forming Reactions

3.1 Synthesis of primary amides
Allam et al.\textsuperscript{34} described a versatile microwave-assisted synthetic protocol for the one-pot synthesis of primary amides (31) from aldehydes (19) and hydroxylamine hydrochloride (30) using scandium(III) triflate as a catalyst in water (Scheme 10).

\[
R \text{-CHO} + \text{NH}_2\text{OH.HCl} \xrightarrow[10 \text{ mol\% Sc(OTf)}_3]{\text{MW, Na}_2\text{CO}_3, \text{H}_2\text{O}}^{135 \text{ °C, 15-40 min}} R\text{CONH}_2
\]

R = substituted phenyl, allyl, alkyl

Representatives

\[
\begin{align*}
31\text{a, 89\%} & & 31\text{b, 92\%} & & 31\text{c, 90\%}
\end{align*}
\]
3.2 Synthesis of aryl hydrazides
Yadav et al. reported a Sc(OTf)₃ catalyzed electrophilic amination of arenes (32) with diethyl azodicarboxylate (33) in dichloromethane at ambient temperature to afford the corresponding arylhydrazides (34) in high yields with high regioselectivity (Scheme 11).

\[
\text{R} + \text{C}_2\text{H}_5\text{OOC}-\text{N} = \text{N}-\text{COOC}_2\text{H}_5 \xrightarrow{5 \text{ mol\% Sc(OTf)}_3} \text{HN-\text{COOC}_2\text{H}_5} \\
\text{CH}_2\text{Cl}_2, \text{rt}, 15-360 \text{ min} \\
16 \text{ entries, 68-95\%}
\]

R = OCH₃, 1,3,5-(OCH₃)₃, 1,2-(OCH₃)₂, 1,2-(CH₃)₂, OH, piperonyl, naphthyl, anthracenyl

Representatives

![Scheme 11. Sc(OTf)₃ catalyzed electrophilic amination of arenes.](image)

3.3 Synthesis of β-amino alcohols
Placzek et al. reported a simple, straightforward, efficient method for the synthesis of β-amino alcohols (38, 39, 40) via ring opening of epoxides (36, 37) with amines (35) in the presence of a catalytic amount of Sc(OTf)₃ at room temperature under solvent-free conditions (Scheme 12).

3.4 Synthesis of N-substituted pyrroles
Chen et al. developed a simple and efficient method for the synthesis of N-substituted pyrroles (43) by the Paal-Knorr condensation of various amines (42) with 1,4-diketones (41) using a catalytic amount of Sc(OTf)₃ under neat conditions at ambient temperature (Scheme 13). They also successfully recovered and reused the catalyst without significant loss in catalytic activity.
Scheme 12. Scandium(III) triflate catalyzed synthesis of β-amino alcohols.

Scheme 13. Scandium(III) triflate catalyzed synthesis of N-substituted pyrroles.
3.5 Synthesis of 1-pyridylimidazo-[1,5-a]-pyridines
Kottawar et al. (Scheme 14)\textsuperscript{38} described a facile, mild and highly efficient protocol for the synthesis of 1-(2-pyridyl)imidazo[1,5-a]pyridines (45) from the reaction of various aromatic aldehydes (19) with di-2-pyridyl ketone (44) in presence of ammonium acetate in ethanol using scandium(III) triflate as catalyst.

\begin{center}
\begin{tikzpicture}
  \node (a) at (0,0) {Ar-CHO};
  \node (b) at (1,0) {44};
  \node (c) at (2,0) {5 mol\% Sc(OTf)\textsubscript{3}};
  \node (d) at (3,0) {NH\textsubscript{4}OAc/EtOH};
  \node (e) at (4,0) {75 °C, 30-60 min};
  \node (f) at (5,0) {10 entries, 80-94\%};
  \node (g) at (6,0) {Ar \text{= C}_6\text{H}_5, 4-OCH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 4-CH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 2-Cl-C\textsubscript{6}H\textsubscript{4}, 4-NO\textsubscript{2}-C\textsubscript{6}H\textsubscript{4}, 3-OCH\textsubscript{3}, 4-OH-C\textsubscript{6}H\textsubscript{4}, 2-OH-C\textsubscript{6}H\textsubscript{4}, 3-OH-C\textsubscript{6}H\textsubscript{4}, 4-OH-C\textsubscript{6}H\textsubscript{4}.};
  \node (h) at (0,1) {19};
  \node (i) at (1,1) {Ar-C};
  \node (j) at (2,1) {5\% Sc(OTf)\textsubscript{3}};
  \node (k) at (3,1) {NH\textsubscript{4}OAc/EtOH};
  \node (l) at (4,1) {75 °C, 30-60 min};
  \node (m) at (5,1) {10 entries, 80-94\%};
  \node (n) at (6,1) {Ar \text{= C}_6\text{H}_5, 4-OCH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 4-CH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 2-Cl-C\textsubscript{6}H\textsubscript{4}, 4-NO\textsubscript{2}-C\textsubscript{6}H\textsubscript{4}, 3-OCH\textsubscript{3}, 4-OH-C\textsubscript{6}H\textsubscript{4}, 2-OH-C\textsubscript{6}H\textsubscript{4}, 3-OH-C\textsubscript{6}H\textsubscript{4}, 4-OH-C\textsubscript{6}H\textsubscript{4}.};
\end{tikzpicture}
\end{center}


3.6 Synthesis of 5-substituted 1H-tetrazoles
Several 5-substituted 1H-tetrazoles (48) were synthesized by Coca et al.\textsuperscript{39} (Scheme 15) \textit{via} the [2+3] cycloaddition of sodium azide (47) with aryl nitriles, aliphatic nitriles, and vinyl nitriles (46) under the influence of microwave irradiation of 1 h at 160 °C in a 3:1 isopropanol / water mixture using scandium(III) triflate as catalyst.

\begin{center}
\begin{tikzpicture}
  \node (a) at (0,0) {R-CN};
  \node (b) at (1,0) {46};
  \node (c) at (2,0) {20 mol\% Sc(OTf)\textsubscript{3}};
  \node (d) at (3,0) {MW, 160 °C, 1 h};
  \node (e) at (4,0) {3:1 isopropanol/H\textsubscript{2}O};
  \node (f) at (5,0) {17 entries, 25-100\%};
  \node (g) at (0,1) {47};
  \node (h) at (1,1) {R \text{= C}_6\text{H}_5, 4-C\textsubscript{6}H\textsubscript{4}-CO, 2-Cl-C\textsubscript{6}H\textsubscript{4}, 4-CH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 4-OCH\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 4-CF\textsubscript{3}-C\textsubscript{6}H\textsubscript{4}, 4-Cl-C\textsubscript{6}H\textsubscript{4}, 4-Br-C\textsubscript{6}H\textsubscript{4}, 1-naphthyl};
  \node (i) at (0,2) {48a, 99\%};
  \node (j) at (1,2) {48b, 80\%};
  \node (k) at (2,2) {48c, 76\%};
\end{tikzpicture}
\end{center}

Scheme 15. Scandium(III) triflate catalyzed synthesis of 5-substituted 1H-tetrazoles.
4. Simultaneous Carbon-Carbon and Carbon-Nitrogen Bond-forming Reactions

4.1 Synthesis of benzimidazolyl imidazo[1,2-α]pyridines

Maiti et al.\textsuperscript{40} developed a microwave irradiated novel environmentally benign, one-pot three-component reaction protocol for the synthesis of biologically interesting benzimidazolyl-imidazo[1,2-α]pyridines (51) employing variously substituted benzimidazole-linked amino pyridines (49), aldehydes (19), and isocyanides (50) in presence of catalytic amount of scandium(III) triflate under solvent-free conditions (Scheme 16).

\[
\begin{align*}
\text{H}_2\text{N} & \quad + \quad \text{R}^2\text{-CHO} \quad + \quad \text{R}^3\text{-NC} \\
\text{N} & \quad + \quad \text{Sc(OTf)}_3 \\
\text{N} & \quad \quad \quad \text{MW, 135 °C, neat, 5-10 min} \\
& \quad \quad \quad \text{26 entries, 72-90\%}
\end{align*}
\]

\( \text{R}^3 = \text{C}_6\text{H}_{11}, \text{C}_6\text{H}_5\text{CH}_2, \text{C}_6\text{H}_9, \text{C(CH}_3)_2, \text{C(CH}_3)_3 \)

\( \text{R}^2 = \text{C}_6\text{H}_5, \text{2-NO}_2\text{-C}_6\text{H}_4, \text{2-F-C}_6\text{H}_4, \text{4-NO}_2\text{-C}_6\text{H}_4, \text{4-CH}_3\text{-C}_6\text{H}_4, \text{4-OCH-C}_6\text{H}_4, \text{4-OH-C}_6\text{H}_4, \text{C}_6\text{H}_{11}, \text{3,4-O-CH}_2\text{-O-C}_6\text{H}_3, \text{2-furyl} \)

**Scheme 16.** Synthesis of benzimidazolyl imidazo[1,2-α]pyridines.

4.2 Synthesis of imidazo[1,2-c]pyrazolo[3,4-e]pyrimidines

A facile, one-pot three-component scandium triflate catalyzed condensation reaction between aminopyrazolo[3,4-d]pyrimidine (52), aldehyde (19), and isocyanide (50) was developed by Agrebi et al.\textsuperscript{41} for the synthesis of a series of fluorescent imidazo[1,2-c]pyrazolo[3,4-e]pyrimidines (53) in good to excellent yields at 150 °C (Scheme 17).

### 4.3 Synthesis of functionalized pyrazoles

Kumari et al.\(^{42}\) reported an efficient, facile, straightforward, microwave irradiated rapid, and environmentally benign scandium triflate catalyzed synthesis of functionalized pyrazoles (56) by the reaction of phenyl hydrazine (54), aldehydes (19) and ethyl acetoacetate (55) under neat conditions (Scheme 18).

Scheme 18. Scandium triflate catalyzed synthesis of functionalized pyrazoles.
4.4 Synthesis of N-substituted 1,4-dihydropyridine derivatives
Kikuchi et al.\textsuperscript{,}\textsuperscript{43} developed a facile and straightforward method for the synthesis of N-substituted 1,4-dihydropyridine derivatives (59) from the reaction of imines (57) with ethyl propiolate (58) using catalytic amount of scandium(III) triflate in toluene or benzotrifluoride under reflux conditions (Scheme 19).

![Reaction scheme]

Scheme 19. Scandium(III) triflate catalyzed synthesis of 1,4-dihydropyridines.

4.5 Synthesis of 2,3-dihydro-1H-1,5-benzodiazepines
De et al.\textsuperscript{,}\textsuperscript{44} demonstrated a mild, simple and efficient method for the synthesis of 2,3-dihydro-1H-1,5-benzodiazepines (61) with good yields from the reaction of o-phenylenediamines (60) and ketones (8) in the presence of a catalytic amount of Sc(OTf)\textsubscript{3} under neat conditions at room temperature (Scheme 20).

4.6 Synthesis of 3,4-dihydropyrimidin-2(1H)-ones
De and his group\textsuperscript{,}\textsuperscript{45} developed another scandium(III) triflate catalyzed protocol for the synthesis of 3,4-dihydropyrimidin-2(1H)-ones (63) via the three component Biginelli reaction of aldehyde (19), β-ketoester (55), and urea (62a) or thiourea (62a) in acetonitrile under reflux conditions (Scheme 21).
Scheme 20. Scandium(III) triflate catalyzed synthesis of 2,3-dihydro-1H-1,5-benzodiazepines.

\[
\begin{align*}
\text{R-CHO} & + \text{H}_2\text{C}=\text{C(}\text{OCH}_2\text{CH}_3) + \text{H}_2\text{N-NH}_2 & \xrightarrow{5 \text{ mol\% Sc(OTf)}_3} & \text{C}_2\text{H}_5\text{OOC}\text{R} \\
\text{19} & \text{55} & \text{NH} & \text{63} \\
\text{Representatives} & & & \\
\text{R} = \text{C}_6\text{H}_5, 4\text{-OCH}_3\text{C}_6\text{H}_4, 4\text{-ClC}_6\text{H}_4, 4\text{-NO}_2\text{C}_6\text{H}_4, 3\text{-OHC}_6\text{H}_4, 4\text{-N(CH}_3)_2\text{C}_6\text{H}_4, \text{furfuryl, C}_9\text{H}_{19} \\
\text{63a, 76\%} & \text{63b, 91\%} & \text{63c, 85\%} & \text{63d, 90\%}
\end{align*}
\]

Scheme 21. Scandium(III) triflate catalyzed synthesis of 3,4-dihydropyrimidin-2(1H)-ones.

4.7 Synthesis of α-amino amidines
α-Amino amidines (64) were synthesized by Keung et al. via a simple, efficient and straightforward three-component reaction of amines (35), aldehydes (19), and isonitrile (50) using scandium(III) triflate as catalyst in methanol at room temperature (Scheme 22).
Scheme 22. Scandium(III) triflate catalyzed synthesis of \(\alpha\)-amino amidines.

5. Carbon-Oxygen Bond-forming Reactions

5.1 Synthesis of esters
Atkinson et al.\(^47\) demonstrated a scandium(III) triflate catalyzed protocol for the synthesis of esters (66) from the reaction of various primary amides (31) and alcohols (65) in \(n\)-heptane at 100 \(\degree\)C (Scheme 23).

Scheme 23. Scandium(III) triflate catalyzed synthesis of ester using primary amides.

5.2 Synthesis of 2,6-dioxabicyclo[3.2.1]octane derivatives.
Reddy et al. (Scheme 24)\(^48\) demonstrated an efficient straight forward strategy for the synthesis of aryl and alkyl substituted 2,6-dioxabicyclo[3.2.1]octane derivatives (68) via an intramolecular Prins cyclization of...
aldehydes (19) with pent-4-ene-1,2-diol (67) in the presence of 5 mol% scandium triflate and 15 mol% p-toluenesulfonic acid in dichloroethane at 80 °C.

$$\begin{align*}
\text{R-CHO} & + \text{HO}_\text{OH} \rightarrow \text{O}_\text{O} \\
19 & + 67 \rightarrow 68 \\
& \text{CICH}_2\text{CH}_2\text{Cl}, 80 ^\circ\text{C}, 3-5 \text{ h} \\
& 12 \text{ entries, 71-89\%}
\end{align*}$$

R = C\text{H}_6, 4-\text{CH}_3\text{C}_6\text{H}_4, 4-\text{NO}_2\text{C}_6\text{H}_4, \text{cyclohexyl}, 4-\text{C}\text{(CH}_3\text{)}_3\text{C}_6\text{H}_4,
4-\text{OCH}_3\text{C}_6\text{H}_4, 3,5-(\text{CH}_3)_2\text{C}_6\text{H}_3, 3-\text{ClC}_6\text{H}_4, 4-\text{BrC}_6\text{H}_4

Representatives

68a, 78%  
68b, 85%  
68c, 87%

Scheme 24. Scandium(III) triflate catalyzed synthesis of 2,6-dioxabicyclo[3.2.1]octanes.

5.3 Synthesis of sugar fused pyranopyran derivatives

Tandem ene-Prins cyclization between an aldehyde (19) and O-prenyl derivative of a sugar aldehyde (69) was successfully coupled by Reddy et al. (Scheme 25) using a catalytic amount of scandium triflate (10 mol %) at ambient temperature in dichloromethane to produce a novel series of sugar fused pyranopyran derivatives (70) in good to excellent yields with high enantioselectivity.

5.4 Synthesis of 3,4-dihydro-4-amino-2-methoxy-2-methyl-2H-1-benzopyrans

Yadav and his group (Scheme 26) demonstrated a simple, facile and efficient protocol for the diastereoselective synthesis of 3,4-dihydro-4-amino-2-methoxy-2-methyl-2H-1-benzopyrans (73) with good yields from the reaction of 2,2-dimethoxypropane (71) with a variety of o-hydroxybenzaldimines (72) in the presence of a catalytic amount of scandium triflate at ambient temperature.

$$\begin{align*}
\text{R-CHO} & + \text{HO}_\text{OH} \rightarrow \text{O}_\text{O} \\
19 & + 67 \rightarrow 68 \\
& \text{CICH}_2\text{CH}_2\text{Cl}, 80 ^\circ\text{C}, 3-5 \text{ h} \\
& 12 \text{ entries, 71-89\%}
\end{align*}$$

R = C\text{H}_6, 4-\text{CH}_3\text{C}_6\text{H}_4, 4-\text{NO}_2\text{C}_6\text{H}_4, \text{cyclohexyl}, 4-\text{C}\text{(CH}_3\text{)}_3\text{C}_6\text{H}_4,
4-\text{OCH}_3\text{C}_6\text{H}_4, 3,5-(\text{CH}_3)_2\text{C}_6\text{H}_3, 3-\text{ClC}_6\text{H}_4, 4-\text{BrC}_6\text{H}_4

Representatives

68a, 78%  
68b, 85%  
68c, 87%

Scheme 26. Synthesis of 3,4-dihydro-4-amino-2H-1-benzopyrans.

5.5 Synthesis of 2,4-dimethoxy-2-methyl chromans
Yadav and his group (Scheme 27)\textsuperscript{51} also reported a novel facile, straight forward, efficient procedure for the synthesis of a new class of 2,4-dimethoxy-2-methyl chromans (75) in high yields via an unusual cyclocondensation of \( o \)-hydroxybenzaldehydes (74) with 2,2-dimethoxypropane (71) using a catalytic amount of scandium triflate at room temperature.

Scheme 27. Synthesis of 2,4-dimethoxy-2-methylidihydrobenzopyrans.

5.6 Synthesis of coumarins
Jung et al.\textsuperscript{52} demonstrated the application of scandium(III) triflate as an efficient catalyst for the synthesis of coumarins (76) via the Pechmann condensation of a variety of phenols (65) and \( \beta \)-ketoesters (55) under neat conditions at 80 °C (Scheme 28).
Scheme 28. Scandium(III) triflate catalyzed synthesis of coumarins.

5.7 Synthesis of octahydro-2H-chromen-4-ols
Yadav et al. (Scheme 29)\textsuperscript{53} demonstrated a tandem ene-Prins cyclization between (R)-citronellal (77) and aldehydes (19) using Sc(OTf)\textsubscript{3} as a catalyst at ambient temperature to furnish octahydro-2H-chromen-4-ols (78) in good to excellent yields with high cis-selectivity.

Scheme 29. Scandium(III) triflate catalyzed synthesis of octahydro-2H-chromen-4-ols.
6. Carbon-Sulfur Bond-forming Reactions

6.1 Synthesis of 2,3-unsaturated thioglycosides

Another scandium(III) triflate catalyzed method was developed by Yadav et al. (Scheme 30)\textsuperscript{54} for the selective synthesis of 2,3-unsaturated thioglycosides (81) with good yields via the thioglycosidation of 3,4,6-tri-O-acetyl or benzoyl-D-glycals (79) with various thiols (80) in dichloromethane at room temperature.

![Scheme 30. Scandium(III) triflate catalyzed synthesis of 2,3-unsaturated thioglycopyranosides](image)

7. Sulfur-Sulfur Bond-forming Reactions

7.1 Synthesis of thiosulfonates

Sc(OTf)\textsubscript{3}-catalyzed sulfenylation of sodium sulfinates (82) with N-(organothio)succinimides (83) in ionic liquids and water mixture as cosolvent was demonstrated by Liang et al. (Scheme 31)\textsuperscript{55} to afford thiosulfonates (84) in moderate to excellent yields at ambient temperature. They also successfully recovered and reused the ionic liquid containing Sc(OTf)\textsubscript{3} for several reaction cycles without any significant loss of catalytic activity.

![Scheme 31. Scandium(III) triflate catalyzed synthesis of thiosulfonates](image)
8. Other Reactions

8.1. Deprotection of tert-butyl aryl sulfonamides

Mahalingam et al. developed a mild and high-yielding method for removal of a variety of tert-butyl protecting group from the N-substituted aryl sulfonamides (85) to form the corresponding sulfonamides (86) utilizing Sc(OTf)₃ as catalyst in nitromethane at ambient temperature (Scheme 32).

\[
\text{Scheme 32. Scandium(III) triflate catalyzed deprotection of tert-butyl aryl sulphonamides.}
\]

9. Conclusions

The present review offers an up-to-date literature on the latest developments of Sc(OTf)₃-catalyzed organic transformations specially carbon-carbon and carbon-heteroatom bond forming reactions reported during the last decade. Therefore the present review will surely make some impacts on the on-going developments of triflate salts catalyzed organic transformations as it is one of the thrusting areas for today’s organic methodologists worldwide.

10. Acknowledgements

The author is thankful to the Indus International University, Una, Himachal Pradesh, India for support and the Kartha Education Society, Mumbai, India for financial help. Special thanks are due to Mr. Hridaynath Bhattacharjee, Research Scholar, Department of Chemistry, University of Saskatchewan, Saskatoon, Canada, for his able assistance throughout.

References

   [http://dx.doi.org/10.1021/cr00022a004](http://dx.doi.org/10.1021/cr00022a004)
   [http://dx.doi.org/10.1021/jo100524b](http://dx.doi.org/10.1021/jo100524b)
   [http://dx.doi.org/10.1016/S0040-4039(03)00580-X](http://dx.doi.org/10.1016/S0040-4039(03)00580-X)
   [http://dx.doi.org/10.1021/jo402511b](http://dx.doi.org/10.1021/jo402511b)
    [http://dx.doi.org/10.1021/jo500076c](http://dx.doi.org/10.1021/jo500076c)
    [http://dx.doi.org/10.1039/B512195G](http://dx.doi.org/10.1039/B512195G)
    [http://dx.doi.org/10.1039/b919666h](http://dx.doi.org/10.1039/b919666h)
    [http://dx.doi.org/10.1021/ol050093y](http://dx.doi.org/10.1021/ol050093y)
    [http://dx.doi.org/10.1021/ol802329y](http://dx.doi.org/10.1021/ol802329y)
    [http://dx.doi.org/10.1021/ol9009893](http://dx.doi.org/10.1021/ol9009893)
    [http://dx.doi.org/10.1248/cpb.54.1611](http://dx.doi.org/10.1248/cpb.54.1611)
    [http://dx.doi.org/10.1016/S0040-4039(01)00629-3](http://dx.doi.org/10.1016/S0040-4039(01)00629-3)
    [http://dx.doi.org/10.1016/S0040-4039(01)02008-1](http://dx.doi.org/10.1016/S0040-4039(01)02008-1)
    [http://dx.doi.org/10.1016/S0040-4039(02)01671-4](http://dx.doi.org/10.1016/S0040-4039(02)01671-4)
    [http://dx.doi.org/10.1021/jo800745a](http://dx.doi.org/10.1021/jo800745a)
    [http://dx.doi.org/10.1021/ja067234o](http://dx.doi.org/10.1021/ja067234o)
   [http://dx.doi.org/10.1016/S0040-4039(00)79220-3](http://dx.doi.org/10.1016/S0040-4039(00)79220-3)

   [http://dx.doi.org/10.1002/1099-0690(199901)1999:1<15::AID-EJOC15>3.0.CO;2-B](http://dx.doi.org/10.1002/1099-0690(199901)1999:1<15::AID-EJOC15>3.0.CO;2-B)

   [http://dx.doi.org/10.1039/b005335j](http://dx.doi.org/10.1039/b005335j)

   [http://dx.doi.org/10.1002/adsc.201000812](http://dx.doi.org/10.1002/adsc.201000812)

   [http://dx.doi.org/10.1039/b900254e](http://dx.doi.org/10.1039/b900254e)

   [http://dx.doi.org/10.1016/j.tetlet.2014.10.047](http://dx.doi.org/10.1016/j.tetlet.2014.10.047)

   [http://dx.doi.org/10.1016/j.tetlet.2007.04.056](http://dx.doi.org/10.1016/j.tetlet.2007.04.056)

   [http://dx.doi.org/10.1016/j.tetlet.2010.04.093](http://dx.doi.org/10.1016/j.tetlet.2010.04.093)

   [http://dx.doi.org/10.1016/j.tetlet.2006.04.015](http://dx.doi.org/10.1016/j.tetlet.2006.04.015)

   [http://dx.doi.org/10.1021/jo4017524](http://dx.doi.org/10.1021/jo4017524)

   [http://dx.doi.org/10.1016/j.tetlet.2011.08.150](http://dx.doi.org/10.1016/j.tetlet.2011.08.150)

   [http://dx.doi.org/10.1246/cl.2002.318](http://dx.doi.org/10.1246/cl.2002.318)


   [http://dx.doi.org/10.1080/00397910902788158](http://dx.doi.org/10.1080/00397910902788158)

   [http://dx.doi.org/10.1080/00397911.2014.957775](http://dx.doi.org/10.1080/00397911.2014.957775)

   [http://dx.doi.org/10.1021/co400010y](http://dx.doi.org/10.1021/co400010y)

   [http://dx.doi.org/10.1016/j.tetlet.2013.06.136](http://dx.doi.org/10.1016/j.tetlet.2013.06.136)


   [http://dx.doi.org/10.1016/j.tetlet.2007.11.003](http://dx.doi.org/10.1016/j.tetlet.2007.11.003)
[http://dx.doi.org/10.1016/j.tetlet.2005.01.113](http://dx.doi.org/10.1016/j.tetlet.2005.01.113)

[http://dx.doi.org/10.1080/00397910500213781](http://dx.doi.org/10.1080/00397910500213781)

[http://dx.doi.org/10.1016/j.tetlet.2003.11.051](http://dx.doi.org/10.1016/j.tetlet.2003.11.051)

[http://dx.doi.org/10.1016/j.tetlet.2014.10.124](http://dx.doi.org/10.1016/j.tetlet.2014.10.124)

[http://dx.doi.org/10.1016/j.tetlet.2012.04.029](http://dx.doi.org/10.1016/j.tetlet.2012.04.029)


[http://dx.doi.org/10.1016/S0040-4039(01)00736-5](http://dx.doi.org/10.1016/S0040-4039(01)00736-5)

[http://dx.doi.org/10.1016/S0040-4039(00)01322-8](http://dx.doi.org/10.1016/S0040-4039(00)01322-8)

[http://dx.doi.org/10.1080/00397910802369513](http://dx.doi.org/10.1080/00397910802369513)

[http://dx.doi.org/10.1016/j.tetlet.2010.03.100](http://dx.doi.org/10.1016/j.tetlet.2010.03.100)

[http://dx.doi.org/10.1081/SCC-120016313](http://dx.doi.org/10.1081/SCC-120016313)

[http://dx.doi.org/10.1016/j.tetlet.2012.09.132](http://dx.doi.org/10.1016/j.tetlet.2012.09.132)

[http://dx.doi.org/10.1081/SCC-20048949](http://dx.doi.org/10.1081/SCC-20048949)

**Author’s Biography**

**Bubun Banerjee** was born in Mamudpur, Burdwan, West Bengal, India in 1987. He received his B.Sc degree in Chemistry from St. Xavier’s College, Kolkata under the University of Calcutta in 2008 and obtained his M.Sc.
with Organic specialization from the University of Delhi in 2010. After qualifying the UGC-CSIR NET Examination in 2010 he did his Ph.D. under the supervision of Prof. (Dr.) Goutam Brahmachari at the Visva-Bharati University, Santiniketan, West Bengal, India. Presently he is working as an Assistant Professor of Chemistry in the Department of Chemistry, Indus International University, Bathu, Una, Himachal Pradesh, India. His research interests focus on the development of novel synthetic methodologies for biologically active compounds with special emphasis on greener aspects.

This paper is dedicated to Prof. (Dr.) Goutam Brahmachari who is pictured above.