Indium(III) Chloride Catalyzed Allylation of *gem*-Diacetates: A Facile Synthesis of Homoallyl Acetates

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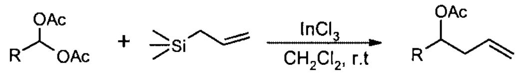
Indium(III) chloride is found to catalyze efficiently the allylation of *gem*-diacetates with allyltrimethylsilane at room temperature to afford the corresponding homoallylic acetates in high yields with good regioselectivity.

Lewis acid promoted carbon–carbon bond forming reactions are of great interest because of their unique reactivity and selectivity. Among various Lewis acid catalyzed C–C bond forming reactions, the allylation of carbonyl compounds or their equivalents with allylsilanes is one of the most useful synthetic reactions[1] in organic synthesis. *gem*-Diacetates are ambident substrates containing two types of reactive carbon centers, the carbon atom of a protected aldehyde function and the carbonyl group in the ester moieties. In general, carbon nucleophiles will predominantly attack the former center and displace one of the acyloxy groups affording substitution products in good yields.[2,3] Even though, *gem*-diacetates are readily available from the corresponding aldehydes, these compounds have received little attention as substrates[4] for nucleophilic substitution reactions. Generally, the homoallylic acetates are prepared from the addition of allylsilane to aldehydes followed by in situ acylation with acetic anhydride[5] but these procedures involve longer reaction times and produce a mixture of products containing the homoallylic alcohol, diacetate and double-allylated product along with desired homoallylic acetates. Further, most of these Lewis acids are moisture sensitive and they decompose or deactivate under quenching conditions.

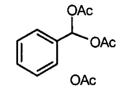
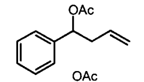
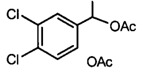
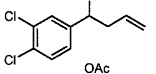
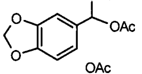
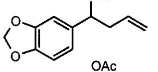
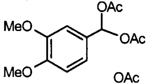
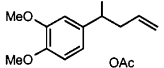
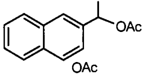
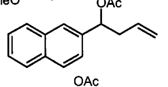
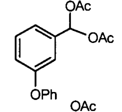
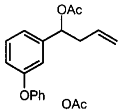
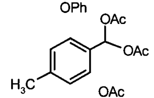
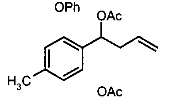
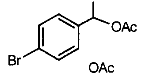
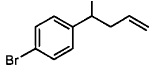
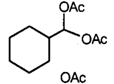
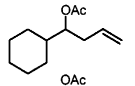
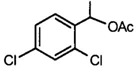
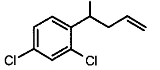
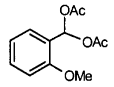
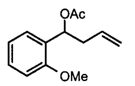
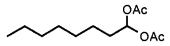
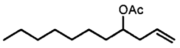
Recently, indium(III) halides have received special attention as mild Lewis acids in various tranformations[6] such as Mukaiyama aldol reactions, Diels–Alder reactions, Mannich reactions, Prins-type cyclizations, and Michael reactions in both aqueous and non-aqueous media. Unlike, traditional Lewis acids such as $TiCl_4$, $SnCl_4$, $BF_3{\cdot}OEt_2$ and $AlCl_3$, indium(III) chloride is stable and reusable in water. These unique properties inherent to $InCl_3$ prompted us to explore this catalyst for the mono substitution of *gem*-diacetates with allyltrimethylsilane.



Scheme 1

In this communication, we wish to report a mild and highly efficient procedure for the allylation of *gem*-diacetates (acylal) with allyltrimethylsilane using indium(III) chloride as the catalyst (Scheme 1). The reaction of benzylidene 1,1-diacetate with allyltrimethylsilane in the presence of 10% indium(III) chloride gave the homoallylic acetate in 90% yield. Similarly, several aldehyde acylals were reacted with allyltrimethylsilane to give the corresponding homoallylic acetates in high yields.[7] The reactions proceeded smoothly at ambient temperature and completed within 5–10 h of reaction time. The results as summarized in Table 1 clearly reveal the scope and generality of the reaction with respect to various diacetates. The reactions underwent quite cleanly without any side reactions and the mono-allylated products were obtained in 70–90% yield. However, in the case of acylals derived from electron rich aldehydes, bis-allylated products were isolated in 10–15% along with desired homoallylic acetates. This is because of the low nucleophilicity of allylsilanes and low electrophilicity of electron rich aldehydes which requires strong Lewis acids for activation. Strong Lewis acids promoted carbocation formation becomes increasingly facile as the aromatic aldehyde increases

Table 1: $InCl_3$ catalyzed allylation of *gem*-diacetates with allyltrimethyl silane

Entry	Substrate (1)	Product[a] (2)	Reaction time /h	Yield[b] /%
a			6	90
b			8	92
c			5	79[c]
d			5	75[c]
e			10	90
f			8	81
g			7	92
h			6	87
i			10	65
j			6	90
k			8	75[c]
l			10	70

[a]All products were characterized by ^1H NMR, IR, and Mass spectra. [b]Isolated yields after purification. [c]10-15% bis-allylated products were isolated.

in electron density that results in di-allylation. Further, the reaction of aldehydes with allyltrimethylsilane and acetic anhydride in the presence of 15% indium(III) chloride in dichloromethane led directly to homo-allylic acetates in high yields.[7b] Both activated and unactivated aldehyde acylals were converted into the corresponding homoallylic acetates in 70–90% yield. However, in the case of aliphatic aldehyde acylals, moderate yields of products were obtained after a long reaction time (8–10 h) due to their intrinsic lower reactivity. The ketone acylals did not work under the present reaction conditions. Among various solvents such as CH_3NO_2, CH_2Cl_2, CH_3CN, and H_2O used for this transformation, CH_3NO_2 and CH_2Cl_2 are found to be effective interms of conversion and reaction time. Although this reaction proceeds smoothly in commercial grade dichloromethane, the reaction was unsuccessful in water. Further, we have examined the catalytic activity of various Lewis acids such as $InCl_3$, $YbCl_3$, $BF_3{\cdot}OEt_2$, $TaCl_5$, and YCl_3 in the allylation reaction. Among these catalysts, $InCl_3$ is found to be the most effective.

In conclusion, we have developed a new and efficient procedure for the allylation of *gem*-diacetates with allyltrimethylsilane using indium(III) chloride. The method offers several advantages like mild reaction conditions, greater selectivity, high yields of products, regeneration of the catalyst, and simple experimental/product isolation procedures which makes it a useful and attractive process for the preparation of homoallyl acetates.

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7 General Procedure: a) Conversion of *gem*-diacetate to homoallylic acetate: a mixture of diacetate (5 mmol) allyltrimethylsilane (6 mmol) and $InCl_3$ (10% w/w of diacetate) in dichloromethane (15 mL) was stirred at room temperature for an appropriate time (Table 1). After completion of the reaction, as indicated by TLC, the reaction mixture was diluted with water (20 mL) and extracted twice with dichloromethane (2 × 15 mL). The combined organic layers were dried over anhydrous Na_2SO_4, concentrated in vacuo, and purified by column chromatography on silica gel (Merck, 100–200 mesh; ethyl acetate–hexane, 1:9) to afford pure homoallylic acetate.

b) Conversion of aldehyde to homoallylic acetate: A mixture of aldehyde (5 mmol), allyltrimethylsilane (6 mmol), acetic anhydride (5 mmol) and $InCl_3$ (15% w/w of aldehyde) in dichloromethane or nitromethane (15 mL) was stirred at room temperature for 5–8h. After completion of the reaction as indicated by TLC, the reaction mixture was neutralized with aqueous $NaHCO_3$ solution and extracted twice with dichloromethane (2 × 15mL). The combined organic layers were dried over anhydrous Na_2SO_4, concentrated in vacuo and purified by column chromatography on silica gel (Merck, 100–200 mesh; ethyl acetate–hexane, 1:9) to afford pure homoallylic acetates in 75–85% yield.

Representative data for compound **2a**: ^1H NMR ($CDCl_3$): δ 2.05 (s, 3H), 2.55 (m, 2H), 5.05 (m, 2H), 5.65 (m, 1H), 5.80 (t, 1H, J = 6.8Hz), 7.30 (m, 5H). IR (KBr): ν 3050, 2980, 1740, 1620, 1580, 1230, 970 cm^{-1}.