A Platinum Open Access Journal
for Organic Chemistry

Review

Free to Authors and Readers

DOAJ Seal

Arkivoc **2025** (1) 202512462

Acid-catalyzed cyclotrimerization of acetophenones to 1,3,5-triphenylbenzenes: a short review

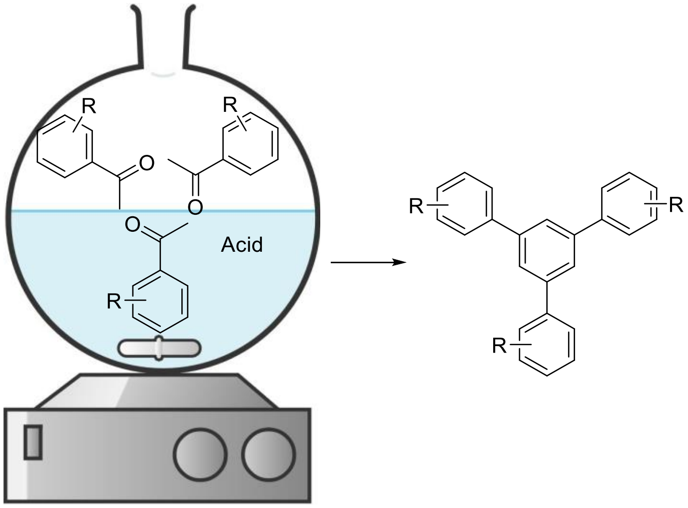
Ishmael B. Masesane* and Dumisile G. Matsala

Department of Chemistry, University of Botswana, Private Bag 0022, Gaborone, Botswana
Email: masesane@ub.ac.bw

Received 08-26-2025 **Accepted** 10-02-2025 **Published on line** 11-04-2025

Abstract

This review collates literature procedures that use Brønsted and Lewis acids to catalyze the cyclotrimerization of acetophenones to 1,3,5-triphenylbenzenes. The review revealed that procedures involving sulphonic acid-catalysis tolerated halo and methyl substituents on the benzene ring of acetophenone but intermittently tolerate methoxy and nitro substituents. Cyclotrimerization procedures catalyzed by heteropoly acids (HPAs) tolerated halo, methyl and methoxy substituents on the benzene ring of acetophenone. Lewis acid-catalyzed procedures discussed in this review were found to tolerate halo, methyl and methoxy substituents on the aromatic ring of acetophenone and intermittently tolerate nitro substituents.



Keywords: Acetophenone, Brønsted acid, Lewis acid, cyclotrimerization, 1,3,5-triphenylbenzene

Cite as *Arkivoc* **2025** (1) 202512462
DOI: https://doi.org/10.24820/ark.5550190.p012.462

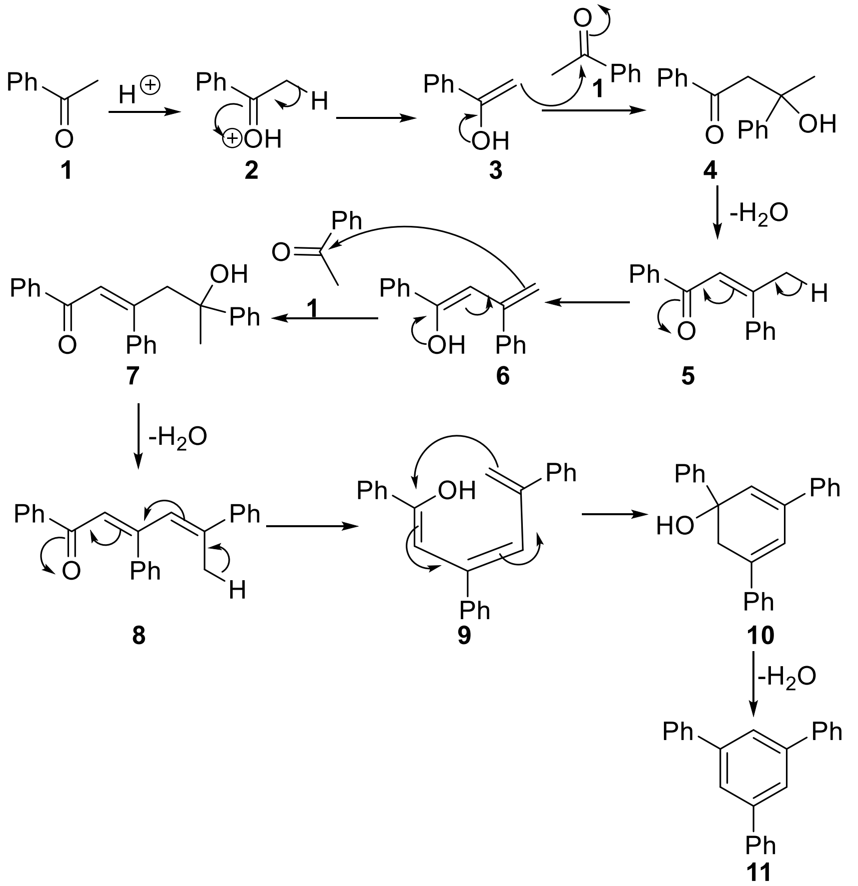
Table of Contents

1. Introduction

Over the years, synthetic organic chemists have become increasingly interested in the Brønsted acids[1-11] or Lewis[12-15]-catalyzed cyclotrimerization of acetophenone and its derivatives. This interest stems from the remarkable properties of the resulting 1,3,5-triphenylbenzene products, particularly their semiconducting, electrochemical, and optical characteristics.[11,12,14,17-20] These organic semiconducting materials are gaining popularity as alternatives to traditional inorganic semiconductors, mainly because they can be used to create devices that are not only cost-effective but also flexible, lightweight, and suitable for large-area applications.[17] Given their versatile properties, 1,3,5-triphenylbenzenes have found their way into various practical applications, from organic light-emitting diodes (OLEDs) to photovoltaic devices and chemical sensors.[4,11,16-18,20] Naturally, this wide range of applications has sparked significant interest in developing new and improved methods for synthesizing these compounds. The Brønsted acids-catalyzed cyclotrimerization reactions of acetophenones are the most studied and the proposed mechanism of this type of reaction is discussed below.

The mechanism of the Brønsted acid-catalyzed cyclotrimerization of acetophenone is thought to proceed as summarized in Scheme 1.[5] It involves protonation of acetophenone (**1**) to give oxonium intermediate **2**, which loses a proton to form enolate **3**. Enolate **3** then reacts with a second molecule of acetophenone (**1**) to give β-hydroxyketone **4**. Intermediate **4** undergoes a dehydration reaction to give α,β-unsaturated ketone **5**, which tautomerizes to give enol **6**. Enol **6** reacts with a third molecule of **1** to give hydroxyketone **7**, which loses water to give diene **8**. Diene **8** undergoes tautomerization to triene **9**, which in turn undergoes a 6π-electron electrocyclic reaction to give cyclodiene **10**. Cyclodiene **10** ultimately loses water to give 1,3,5-triphenylbenzene **11**.

This review will discuss the effect of different Brønsted and Lewis acids on the yields of the literature procedures for the cyclotrimerization of acetophenones. The literature procedures' tolerance of different substituents of the benzene ring of acetophenone will be highlighted. To our best knowledge, such a review has never been reported, and this article will be a valuable reference for chemists and material scientists interested in the cyclotrimerization reaction of acetophenones and the resultant 1,3,5-triphenylbenzenes.



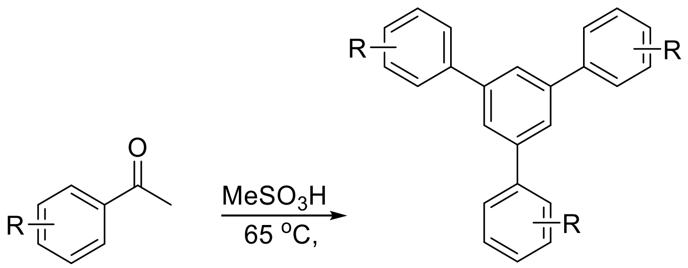
Scheme 1. Mechanism of the cyclotrimerization of acetophenone.

2. Brønsted Acids-catalysed Cyclotrimerization of Acetophenones

Brønsted acids have been used extensively as catalysts for the cyclotrimerization of acetophenones to 1,3,5-triphenylbenzenes. The Brønsted acids which have been employed in the cyclotrimerization reaction are sulphonic acids, heteropolyacids (HPA) and organic acids and these will be discussed in the subsequent sections of this paper.

2.1 Sulphonic acids-catalysed cyclotrimerization of acetophenones

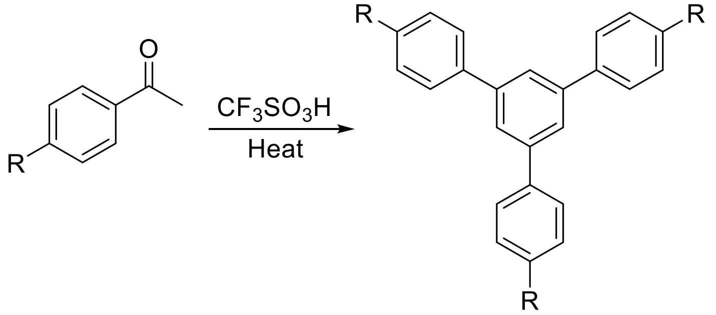
Sulphonic acids have been the most used Brønsted acids for promoting the cyclotrimerization of acetophenone and derivatives to give the corresponding 1,3,5-triphenylbenzenes. Even our serendipitous introduction to cyclotrimerization of acetophenones involved the sulphonic acid $MeSO_3H$. Our attempted $MeSO_3H$-catalyzed condensation of benzaldehyde, acetophenone and secondary amines as a synthetic route to 4-aminochromenes gave a complex mixture of products from which 1,3,5-triphenybenzene was isolated.[1] Subsequently, we proved that 1,3,5-triphenylbenzene was a product of trimerization of acetophenone by heating a mixture of acetophenone (**1**) and $MeSO_3H$ at 65 ^{o}C to give cyclotrimer **11** in 95% yields. Haloacetophenone derivatives **12**, **13** and **14** underwent the cyclotrimerization reaction to give the corresponding cyclotrimers **17**, **18** and **19** in good yields of 79-95%. In contrast, methoxyacetophenone derivatives **15** and **16** cyclotrimerized under the same reaction conditions to give cyclotrimers **20** and **21** respectively in low yields of 40-48%, scheme 2.[1] The conclusion from these results was that the cyclotrimerization reactions' yields are adversely affected by the electron donating methoxy group on the benzene rings of the acetophenone substrates.



1 (R = H)	**11** (95%)
12 (R = 2-Cl)	**17** (98%)
13 (R = 3-Br)	**18** (79%)
14 (R = 4-Br)	**19** (85%)
15 (R = 2-OCH_3)	**20** (48%)
16 (R = 3,4-diOCH_3)	**21** (40%)

Scheme 2. Matsala and Masesane $MeSO_3H$-mediated trimerization of acetophenones.

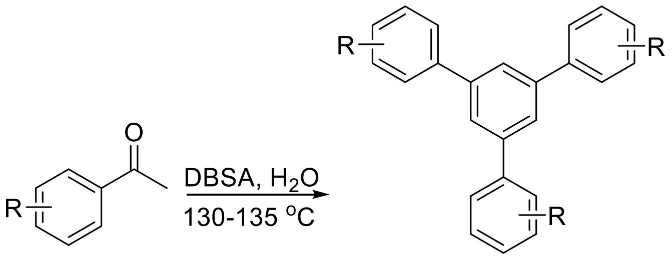
In a comparative approach, Kim and Beckerbauer used a stronger sulphonic acid CF_3SO_3H to catalyze the cyclotrimerization of bromoacetophenone **14** to give trimer **19** in close to quantitative yield of 97%, scheme 3.[2] This yield is significantly higher than that achieved when the less acidic $MeSO_3H$ was used by Matsala and Masesane. In addition, methylacetophenone **22** underwent the cyclotrimerization reaction to give cyclotrimer **23** in 67%.[2] In this procedure, the electron withdrawing bromo group is tolerated more than the electron donating methyl group on the benzene ring of the acetophenone substrate.



14 (R = Br)	**19** (97%)
22 (R = CH_3)	**23** (67%)

Scheme 3. Kim and Beckerbauer's CF_3SO_3H-catalyzed cyclotrimerization of acetophenones.

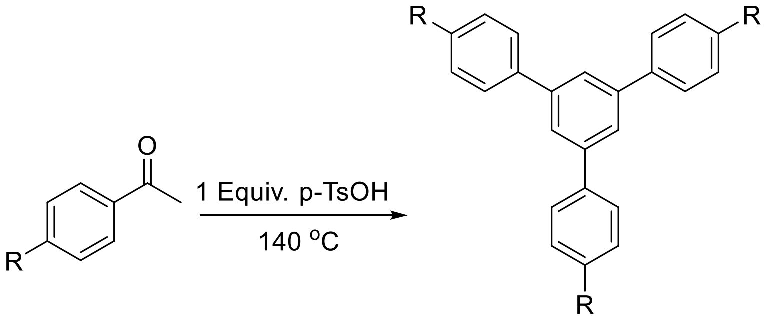
The cyclotrimerization reactions described thus far were performed without a solvent and in excess acid. Phatangare and co-workers have reported the cyclotrimerization of acetophenone (**1**) in the presence of stoichiometric amount of the more organic *p*-dodecylbenzenesulphonic acid (DBSA) and water as a solvent to give cyclotrimer **11** in 94%.[3] This yield was comparable to the one achieved in the $MeSO_3H$-catalysed reaction discussed earlier. Methylacetophenones **22**, **24** and **25** also underwent the DBSA-mediated cyclotrimerization reactions to give the corresponding cyclotrimers **23**, **29** and **30** in 90, 84 and 76% yields respectively. It is instructive to note 2-methylacetophenone (**25**) gave the lowest yield and 4-methylacetophenone (**22**) gave the highest yield. Similarly, 2-chloroacetophenone **12**, 3-chloroacetopheneone **27** and 4-chloroacetophenone **28** cyclotrimerized to the corresponding cyclotrimers **17**, **32** and **33** in 72, 77 and 87% yields respectively, scheme 4.[3] These observations can be attributed to reduction in steric hindrance around the carbonyl group as one moves from *o*- through *m*- to *p*-substituted acetophenones. Methoxyacetophenone **26** participated in the cyclotrimerization reaction to give cyclotrimer **31** in a low yield of 45%, consistent with the $MeSO_3H$-mediated cyclotrimerization discussed earlier. Phatangare and co-workers' reaction conditions were tolerated by chloro and methyl substituents on the benzene ring of acetophenone but were less tolerated by the methoxy substituent.



1 (R = H)	**11** (94%)
22 (R = 4-CH_3)	**23** (90%)
24 (R = 3-CH_3)	**29** (84%)
25 (R = 2-CH_3)	**30** (76%)
26 (R = 4-OCH_3)	**31** (45%)
12 (R = 2-Cl)	**17** (72%)
27 (R = 3-Cl)	**32** (77%)
28 (R = 4-Cl)	**33** (87%)

Scheme 4. Phatangare and co-workers' DBSA-mediated trimerization of acetophenones

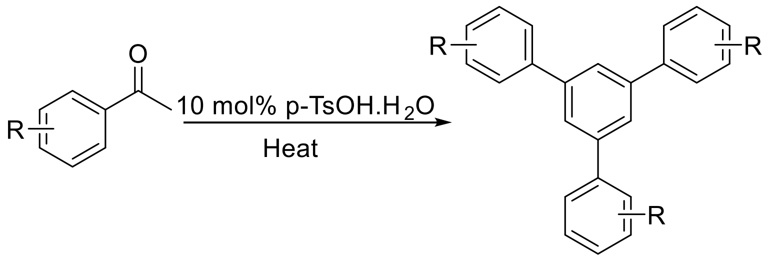
Gao and co-workers on the other hand described the use of p-TsOH to catalyze the cyclotrimerization of acetophenones, scheme 5.[4] When a mixture of acetophenone (**1**) and p-TsOH was heated, cyclotrimer **11** was isolated in 88% yield. Surprisingly, methoxyacephenone **26** underwent the trimerization reaction under these conditions to give the corresponding trimer **31** in very good yield of 95%. This is in sharp contrast to the results achieved in the previous discussions when $MeSO_3H$, CF_3SO_3H and DBSA were used to facilitate the cyclotrimerization reaction. It is not clear to what the discrepancy of yields of the $MeSO_3H$ and p-TsOH-mediated cyclotrimerization of methoxyacetophenones should be attributed. The two acids are relatively similar in acidity. Haloacetophenone **34** when exposed to the reaction conditions gave cyclotrimer **35** in 80% yield.[4]



1 (R = H)	**11** (88%)
26 (R = OCH_3)	**31** (95%)
34 (R = F)	**35** (80%)

Scheme 5. Gao and co-workers' *p*-TsOH mediated cyclotrimerization of acetophenones.

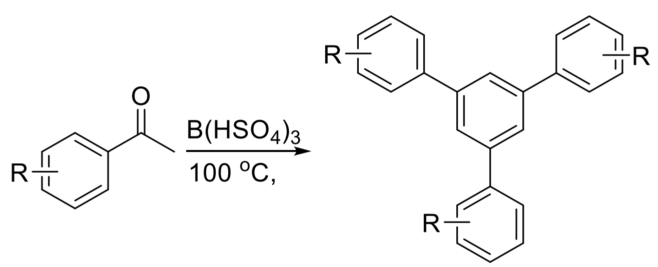
In their approach to TsOH-catalyzed trimerization of acetophenones, Zhao and co-workers treated acetophenone (**1**) with catalytic amount of *p*-TsOH.H_2O and heated the mixture to give trimer **11** in 91% yield, scheme 6.[5] Under these reaction conditions, methylacetophenones **22**, **24** and **25** cyclotrimerized to give the corresponding cyclotrimers **23**, **29** and **30** in 87, 85 and 70% yields respectively. Subjection of methoxyacetophenone **26** to Zhao and co-workers' reaction conditions resulted in the formation of cyclotrimer **31** in 68% yield. Exposure of chloroacetophenones **12**, **27** and **28** to catalytic amount of p-TsOH.H_2O gave the corresponding cyclotrimers **17**, **32** and **33** in 61, 71 and 74% yields respectively.[5] It is noteworthy that 4-nitroacetophenone failed to undergo the cyclotrimerization reaction when subjected to the Zhao and co-workers' reaction conditions. *P*-TsOH under Zhao and co-workers' conditions again proved to be a reliable catalyst for the cyclotrimerization of methoxyacetophenones.



1 (R = H)	**11** (91%)
22 (R = 4-CH_3)	**23** (87%)
24 (R = 3-CH_3)	**29** (85%)
25 (R = 2-CH_3)	**30** (70%)
26 (R = 4-OCH_3)	**31** (68%)
12 (R = 2-Cl)	**17** (61%)
27 R = 3-Cl)	**32** (71%)
28 (R = 4-Cl)	**33** (74%)

Scheme 6. Zhao and Co-workers' TsOH.H_2O-catalyzed cyclotrimerization of acetophenones.

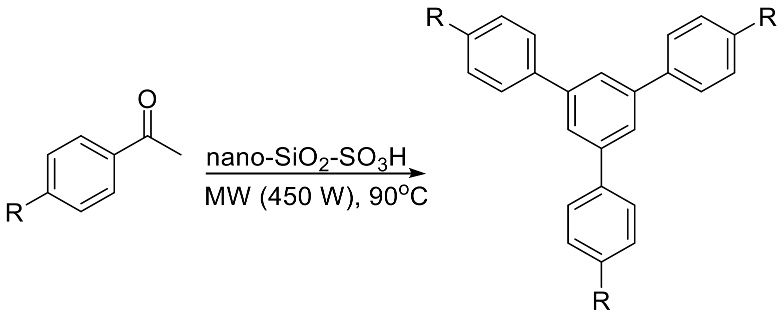
Safaei and co-workers have carried out extensive studies on the cyclotrimerization of acetophenone and its derivatives using the solid and reusable $B(HSO_4H)_3$ as the catalyst.[6] Heating a mixture of acetophenone (**1**) in the presence of 20 mol% of $B(HSO_4)_3$ gave trimer **11** in 94% yield. Methylacetophenones **22** and **24** also participated in the cyclotrimerization reaction to give the corresponding trimers **23** and **29** in 90 and 91% yields respectively. Under these conditions, even substrate **26** with an electron donating methoxy group underwent the cyclotrimerization reaction to give trimer **31** in good yield of 86%. Steric hinderance played no significant part in the $B(HSO_4)_3$-catalysed reaction since 2-chloro, 3-chloro and 4-chloroacetophenones **12**, **27** and **28** underwent the cyclotrimerization reaction to give the corresponding cyclotrimers **32**, **33** and **28** in 91, 92 and 92% respectively. 4-Nitroacetophenone **36** also cyclotrimerized when heated in the presence of $B(HSO_4)_3$ to give trimer **37** in 92%.[6] $B(HSO_4)_3$ proved to be a very effective catalyst for the cyclotrimerization of acetophenones with either electron-withdrawing chloro and nitro substituents or electron-donating methyl and methoxy substituents.



1 (R = H)	**11** (94%)
22 (R = 4-CH_3)	**23** (91%)
24 (R = 3-CH_3)	**29** (90%)
26 (R = 4-OCH_3)	**31** (86%)
12 (R = 2-Cl)	**17** (91%)
27 (R = 3-Cl)	**32** (92%)
28 (R = 4-Cl)	**33** (92%)
36 (R = 4-NO_2)	**37** (92%)

Scheme 7. Safaei and co-workers' $B(HSO_4)_3$-catalyzed cyclotrimerization of acetophenones.

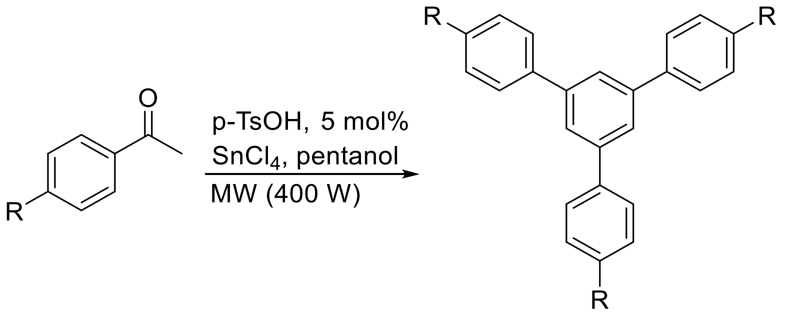
Ghanbaripour and co-workers relied on the nano-silica-supported sulphuric acid under microwave irradiation to effect the cyclotrimerization of acetophenone (**1**) to give cyclotrimer **11** in 97% yield, scheme 8.[7] Substituted acetophenones **22**, **26** and **28** were also subjected to Ghanbaripour and co-workers' reaction conditions to give the cyclotrimers **23**, **31** and **33** respectively in yields between 82% and 89%. Clearly, these reactions conditions are tolerated by methyl, methoxy and chloro substituents on the benzene ring of acetophenone.



1 (R = H)	**11** (97%)
22 (R = CH_3)	**23** (87%)
26 (R = OCH_3)	**31** (82%)
28 (R = Cl)	**33** (89%)

Scheme 8. Ghanbaripour and co-workers' nano-SiO_2-SO_3H-catalyzed cyclotrimerization of acetophenones.

Another cyclotrimerization procedure which involved microwave irradiation was reported by Jing and co-workers, scheme 9.[8] The procedure involved treatment of a solution of acetophenone (**1**) in pentanol with molar equivalent p-TsOH, catalytic amount of $SnCl_4$ and irradiation of the mixture with microwaves for 3 minutes to give cyclotrimer **11** in 86% yield. The Jing and co-workers' reaction conditions were applied to acetophenones **22**, **26** and **28** to give cyclotrimers **23**, **31** and **33** respectively in 80-88% yields.[8] These results are consistent with the those discussed above when nano-SiO_2-SO_3H was used as a catalyst under microwave irradiation. It is therefore instructive to note that sulphonic acid-catalyzed cyclotrimerization reactions under microwave irradiation tolerate electron-donating methyl and methoxy substituents and electron-withdrawing halo substituents on the benzene ring of acetophenone.

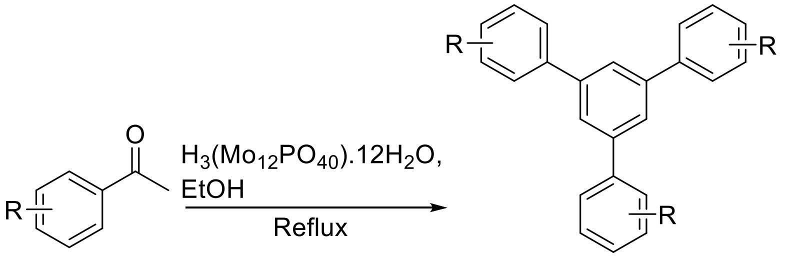


1 (R = H)	**11** (86%)
22 (R = CH$_3$)	**23** (84%)
26 (R = OCH$_3$)	**31** (88%)
28 (R = Cl)	**33** (80%)

Scheme 9. Jing and co-workers' p-TsOH/SnCl$_4$-catalyzed cyclotrimerization of acetophenones.

2.2 HPA-catalyzed cyclotrimerization of acetophenones

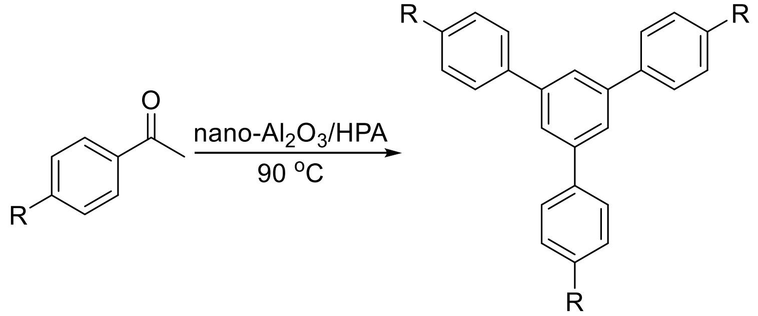
In addition to sulphonic acids, heteropoly acids (HPAs) have been reported as effective Brønsted acid catalysts for the cyclotrimerization of acetophenones. Phatangare and co-workers for example described the heteropoly acid (HPA) phosphomolybdic acid ($H_3Mo_{12}PO_{40}.12H_2O$)-catalysed cyclotrimerization of acetophenone (**1**) in ethanol and under reflux to give cyclotrimer **11** in 87%, scheme 10.[9] Methylacetophenone **22**, **24** and **25** underwent the phosphomolybdic acid-catalyzed cyclotrimerization reactions to give the corresponding trimers **23**, **29** and **30** in 88, 72 and 68% yield respectively, scheme 10. (ref) This trend is consistent with results achieved in the DBSA-catalyzed cyclotrimerization reactions described earlier. Exposure of methoxyacetophenones **26** and **38** to these reaction conditions led to cyclotrimerization reactions to give the corresponding cyclotrimers **31** and **39** in 90 and 75% yields respectively. Surprisingly, acetophenone **36** with an electron-withdrawing nitro group underwent the cyclotrimerization reaction to give trimer **37** in the lowest yield of 30%.[9] This HPA-catalyzed procedure tolerates acetophenone substrates with methyl or methoxy substituents on the benzene ring but give low yields for a substrate with a nitro substituent.



1 (R = H)	**11** (87%)
22 (R = 4-CH$_3$)	**23** (88%)
24 (R = 3-CH$_3$)	**29** (72%)
25 (R = 2-CH$_3$)	**30** (68%)
26 (R = 4-OCH$_3$)	**31** (90%)
38 (R = 3-OCH$_3$)	**39** (75%)
36 (R = 4-NO$_2$)	**37** (30%)

Scheme 10. Phatangare and co-workers' HPA-catalyzed trimerization of acetophenones.

Tayebee and co-workers used a different HPA $H_5PW_{10}V_2O_{40}$ supported on nano-Al_2O_3 to catalyze the cyclotrimerization of acetophenone (**1**) to give cyclotrimer **11** in 85% yield, scheme 11.[10] Under these conditions, acetophenones **22**, **26** and **40** with electron donating substituents underwent the cyclotrimerization reaction to give the corresponding trimers **23**, **31** and **33** in 82, 60 and 77% yields respectively. Further, chloroacetophenone **28** and nitroacetophenone **36** were subjected to HPA-catalyzed reaction to give cylotrimers **33** in 93% and trimer **37** in 68% respectively. Tayebee and co-workers' reaction conditions were also tolerated by a hydroxyl group and subjection of hydroxyacetophenone **40** to these conditions gave cyclotrimer **41** in 77%.[10]

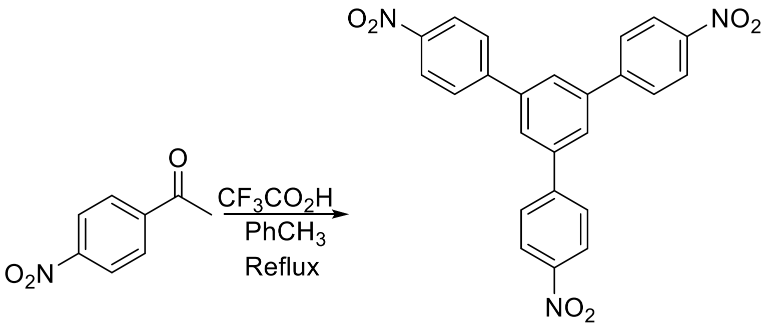


1 (R = H)	**11** (85%)
22 (R = 4-CH_3)	**23** (82%)
26 (R = 4-OCH_3)	**31** (60%)
28 (R = 4-Cl)	**33** (93%)
36 (R = 4-NO_2)	**37** (68%)
40 (R = 4-OH)	**41** (77%)

Scheme 11. Tayebee and co-workers' nano-Al_2O_3/HPA catalyzed trimerization of acetophenones.

2.3 Organic acid-catalyzed cyclotrimerization of acetophenones

The sulphonic acid and HPA-catalyzed approaches discussed in the earlier sections of this report suggest that the cyclotrimerization of acetophenones requires strong Brønsted acids. It was therefore anticipated that few examples of organic acid-catalyzed cyclotrimerization of acetophenones will be found in the literature since organic acids are weak acids. Indeed, only one example by Kasprzak and co-workers used the organic acid CF_3CO_2H to catalyze the cyclotrimerization of substrate **36** with a strong electron-withdrawing nitro group in toluene as the solvent and under reflux to give cyclotrimer **37** in 86% yield, scheme 12.[11] Cyclotrimer **37** was elaborated into triferrocenyl-substituted 1.3.5-triphenylbenzene, a potential molecule for organic electronics due to its aggregation-induced emission effect and high fluorescence quantum yields.[11]

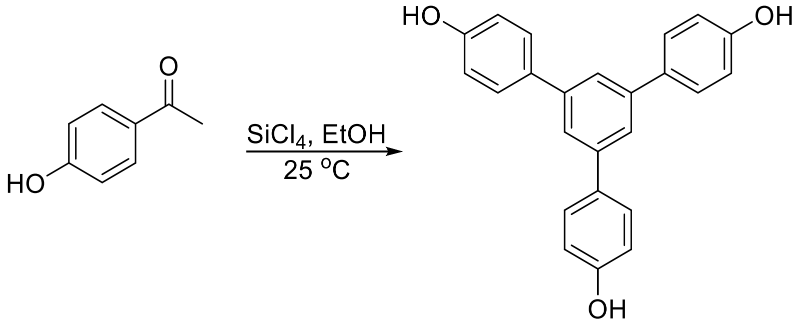


36 **37** (86%)

Scheme 12. Kasprzak and co-workers CF_3CO_2H-catalyzed cyclotrimerization of 4-nitroacetophenone.

3. Lewis Acid-catalysed Cyclotrimerization of Acetophenones

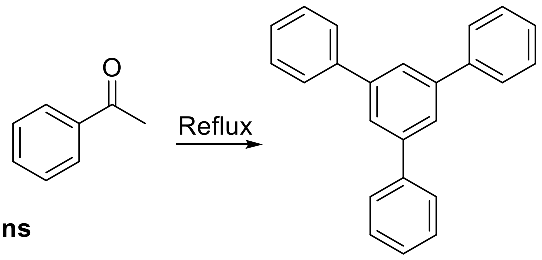
In addition to the use of Brønsted acids described in section 2 of this paper, a few Lewis acids have been reported as effective catalysts for the cyclotrimerization of acetophenones to afford 1,3,5-triphenylbenzenes. Award and Jber for example relied on the oxophilicity of Silicon and effected the cyclotrimerization of hydroxyacetophenone **40** using $SiCl_4$ as the Lewis acid at room temperature to give the corresponding cyclotrimer **41** in excellent of 98%, scheme 13.[12] The tolerance of this procedure to a free hydroxy group is worth noting. It is appropriate to acknowledge that the $SiCl_4$-catalyzed cyclotrimerization afforded cyclotrimer **41** in significantly higher yield when compared to the HPA-catalyzed reaction presented earlier in scheme 11.



40 **41** (98%)

Scheme 13. Award and Jber's $SiCl_4$-catalysed cyclotrimerization of 4-hydroxyacetophenone

Ono and co-workers on the other hand screened various Lewis acids as catalysts for the cyclotrimerization of acetophenone (**1**).[13] They found $Bi(OTf)_3.4H_2O$ to be an effective catalyst for the cyclotrimerization of acetophenone (**1**) to give cyclotrimer **11** in 80%, scheme 14. Other Lewis acids that showed promising activity included $(CH_3)_3SiOTf$ and $TiCl_3OTf$ which catalyzed the cyclotrimerization of acetophenone (**1**) to cyclotrimer **11** in 43 and 14% yields respectively.[13]

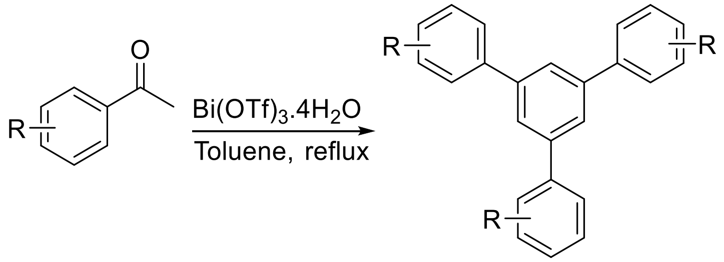


Reaction conditions	
$(CH_3)_3SiOTf$, toluene **1**	**11** (43%)
$TiCl_3OTf$, toluene	(14%)
$Bi(OTf)_3.4H_2O$, toluene	(80%)

Scheme 14. Ono and co-workers' screening of Lewis acids as catalysts for cyclotrimerization of acetophenone.

The results of the screening reactions described above set the stage for the extension of the $Bi(OTf)_3.4H_2O$-catalysed cyclotrimerization to substituted acetophenones. In the event, methylacetophenone **22** when subjected to the action of the Bi(III) catalyst gave cyclotrimer **23** in 82% yield scheme 15.[13] The position of the methy group did not significantly affect the yield of the reactions since methylacetophenone **24** was successfully cyclotrimerized under the same reaction conditions to give cyclotrimer **29** in 78%. Chloroacetophenones **27** and

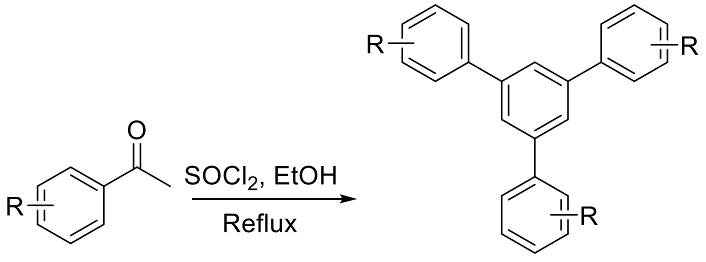
28 also underwent the Bi(OTf)$_3$.4H$_2$O-catalyzed cyclotrimerization reaction to give the corresponding cyclotrimers **32** and **33** in 80 and 73% respectively.[13]



22 (R = 4-CH$_3$) **23** (82%)
24 (R = 3-CH$_3$) **29** (78%)
27 (R = 3-Cl) **32** (80%)
28 (R = 4-Cl) **33** (73%)

Scheme 15. Ono and co-workers' Bi(OTf)$_3$.4H$_2$O-catalyzed cyclotrimerization of acetophenones.

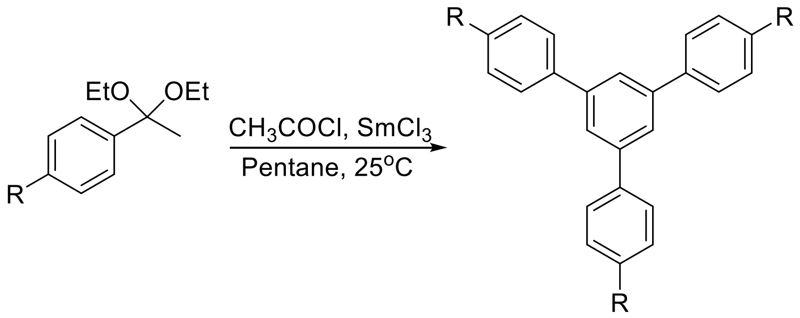
In another study directed towards the Lewis acid-catalyzed cyclotrimerization of acetophenones, Hu and co-workers employed SOCl$_2$ to facilitate the conversion of acetophenone (**1**) to trimer **11** in 85% yield, scheme 16.[14] Methylacetophenone **22** and methoxyacetophenone **26** cyclotrimerized under the influence of SOCl$_2$ to give the corresponding cyclotrimers **23** and **31** in 84 and 78% yields respectively. SOCl$_2$ also facilitated the cyclotrimerization of bromoacetophenones **13** and **14** to give cyclotrimers **18** (75%) and **19** (81%) respectively. SOCl$_2$ showed little activity when it was tested on nitroacetophenone **36** and only traces of the corresponding cyclotrimer **37** were detected.[14]



1 (R = H) **11** (85%)
22 (R = 4-CH$_3$) **23** (84%)
26 (R = 4-OCH$_3$) **31** (78%)
13 (R = 3-Br) **18** (75%)
14 (R = 4-Br) **19** (81%)
36 (R = 4-NO$_2$) **37** (trace)

Scheme 16. Hu and co-workers' SOCl$_2$-catalyzed cyclotrimerization of acetophenones.

Cheng and co-workers have described the use of SmCl$_3$ to catalyze the cyclotrimerization of acetophenone diethyl ketal **42** to cyclotrimer **11** in 85% yield, scheme 16.[15] Ketals **43** and **44** were efficiently cyclotrimerized under the catalytic activity of SmCl$_3$ to give the corresponding cyclotrimers **23** and **31** in 83 and 88% yields respectively. SmCl$_3$ also catalyzed the cyclotrimerization of ketal **45** to give cyclotrimer **33** in 67% and ketal **46** to give cyclotrimer **37** in 40% yield.[15] In general, Lewis acid-catalyzed cyclotrimerization reactions exhibited a wider tolerance for methoxy groups when compared to the Brønsted acid-catalyzed reactions.



42 (R = H)	**11** (85%)
43 (R = CH$_3$)	**23** (83%)
44 (R = OCH$_3$)	**31** (88%)
45 (R = Cl)	**33** (67%)
46 (R = NO$_2$)	**37** (40%)

Scheme 17. Cheng and co-workers' SmCl$_3$-catalysed cyclotrimerization of protected acetophenones.

4. Conclusions

This review has revealed that both Brønsted and Lewis acids are efficient catalysts for the cyclotrimerization of acetophenones to 1,3,5-triphenylbenzene. Brønsted acids that have been used to catalyze the cyclotrimerization of acetophenones include sulphonic acids, HPA and organic acids. In general, the discussed Brønsted acid-catalyzed cyclotrimerization procedures tolerate methyl and halo substituents on aromatic ring of acetophenones to give high yields of the corresponding 1,3,5-triphenylbenzene products but intermittently tolerate methoxy and nitro substituents. The review further revealed that Lewis-acid-catalyzed cyclotrimerization procedures tolerated methyl, halo and methoxy substituents on the benzene ring of acetophenone.

Acknowledgements

The authors are grateful to the Department of Chemistry, University of Botswana for providing facilities and resources that allowed for this review to be written.

References

1. Matsala, D. G.; Masesane, I. B. *Arkivoc* **2023**, *viii*, 202312068.
   https://doi.org/10.24820/ark.5550190.p012.068
2. Kim, Y. H.; Beckerbauer, R. *Macromolecules* **1994**, *27*, 1968-1971.
   https://doi.org/10.1021/ma00085a048
3. Phatangare, K.; Padalkar, V.; Murugan, K.; Chaskar, A. *Curr. Chem. Lett.* **2012**, *1*, 133–138.
   http://dx.doi.org/10.5267/j.ccl.2012.5.001
4. Gao, Q.; Bao, F.; Feng, X.; Pan, Y.; Wang, H.; Li, D. A*rkivoc* **2013**, *iii*, 49-60.
   https://doi.org/10.3998/ark.5550190.0014.305
5. Zhao, Y.; Li, J.; Li, C.; Yin, K.; Ye, D.; Ji, X. *Green Chem*., **2010**, *12*, 1370–1372.
   https://doi.org/10.1039/C0GC00158A
6. Safaei, H. R.; Davoodi, M.; Shekouhy, M. *Synth. Commun.* **2013**, *43*, 2178–2190.

https://doi.org/10.1080/00397911.2012.696300

7. Ghanbaripour, R.; Mohammadpoor-Baltork, I.; Moghadam, M.; Khosropour, A. R.; Tangestaninejad, S.; Mirkhani, V. *J. Iran Chem. Soc*. **2012**, *9*, 791–798. https://doi.org/10.1007/s13738-012-0089-0
8. Jing, X.; Xu, F.; Zhu, Q.; Ren, X.; Yan, C.; Wang, L.; Wang, J. *Synth. Commun.* **2005**, *35*, 3167–3171. https://doi.org/10.1080/00397910500283370
9. Phatangare, K.; Padalkar, V.; Mhatre, D.; Patil. K.; Chaskar, A. *Synth. Commun.* **2009**, *39*, 4117–4121. https://doi.org/10.1080/00397910902885533
10. Tayebee, R.; Savoji, K.; Razi, M. K.; Maleki. B. *RSC Adv*. **2016**, *6*, 55319-55326. https://doi.org/10.1039/C6RA07141D
11. Kasprzak, A.; Guńka, P. A.; Kowalczyk, A.; Nowicka, A. M. *Dalton Trans*. **2020**, *49*, 14807-14814. https://doi.org/10.1039/D0DT02948C
12. Awad, L. I.; Jber, N. R. *Int. J. Drug Deliv. Technol.* **2019**; *9*, 295-302. https://doi.org/10.25258/IJDDT.9.2.28
13. Ono, F.; Ishikura, Y.; Tada, Y.; Endo, M.; Sato, T. *Synlett* **2008**, *15*, 2365-2367. https://doi.org/10.1055/s-2008-1078012
14. Hu, H.; Zhang, A.; Ding, L.; Lei, X.; Zhang, L. *J. Chem. Res*. **2007**, 720-721. https://doi.org/10.3184/030823407X275946
15. Cheng, K.; Ding, Z.; Wu, S. *Synth. Commun.* **1997**, *27*, 11-15. https://doi.org/10.1080/00397919708004800
16. Alshubramy, M. A.; Alamry, K. A.; Hussein, M. A. *RSC Adv*. **2023**, *13*, 14317-14339. https://doi.org/10.1039/D3RA01336G
17. Kaliramna, S.; Aryan, Dhayal, S. S.; Kumar, N. *Optical Materials* **2024**, *149*, 115087. https://doi.org/10.1016/j.optmat.2024.115087
18. Kosińska, A. I.; Nisiewicz, M. K.; Nowicka, A. M.; Kasprzak, A. *ChemPlusChem* **2021**, *86*, 820–826. https://doi.org/10.1002/cplu.202100137
19. Vishnoi, P.; Kaleeswaran, D.; Murugavel, R. *RSC Adv*. **2018**, *8*, 17535–17550.
20. Abdollahi, S.; Mostaghni, F. *International Journal of Materials and Chemistry* **2012**, *2*, 128-131. https://doi.org/10.5923/j.ijmc.20120204.02

Authors' Biographies

Ishmael B. Masesane was born in Tutume, Botswana. He was awarded B. Sc. (Chemistry and Biology) and M. Sc. (Natural Products Chemistry) by the University of Botswana in 1996 and 1998 respectively. In 2004, he was awarded a Ph.D. (organic synthesis) by the University of Durham, UK. Ishmael was employed by the University of Botswana as a Staff Development Fellow after completion of his B.Sc. degree and as a lecturer after completion of his M.Sc. degree. He is currently a Professor of Chemistry at the University of Botswana. He is also the President of the Botswana Academy of Science, a Fellow of the Royal Society of Chemistry and a former Executive Board member of Commonwealth Chemistry. To date, he has published 62 journal articles and 4 book chapters in the broad areas of Natural Products Chemistry and Organic Synthesis.

Dumisile G. Matsala is a national of Botswana with a strong academic background in chemistry. She was awarded a B.Sc. in Biology and Chemistry (Double Major) by the University of Botswana in 2020 and subsequently pursued an M.Sc. in Chemistry at the same institution under the supervision of Prof. Ishmael B. Masesane, which she completed in 2024. She is also an active member of the Organization for Women in Science for the Developing World (OWSD) – Botswana Chapter. Her professional interests include organic synthesis, renewable energy applications and advancing science education.