Tetrahedron Letters xxx (xxxx) xxx

Contents lists available at ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Acid activated montmorillonite K-10 mediated intramolecular acylation: Simple and convenient synthesis of 4-chromanones

Ayisha F. Begum [a], Kalpattu K. Balasubramanian [b], Bhagavathy Shanmugasundaram [a,*]

[a] Department of Chemistry, B. S. Abdur Rahman Crescent Institute of Science and Technology, Chennai, Tamilnadu 600048, India
[b] Department of Chemistry, Indian Institute of Technology Madras, Chennai, Tamilnadu 600036, India

ARTICLE INFO

Article history:
Received 4 June 2021
Revised 10 August 2021
Accepted 25 August 2021
Available online xxxx

Keywords:
Montmorillonite K-10
Aryloxypropionic acid
Friedal-Crafts acylation
Intramolecular cyclisation
Clay catalyst

ABSTRACT

3-Aryloxyproionic acids undergo intramolecular cyclization in the presence of AA.Mont.K-10 in toluene under reflux for 30–45 min in good to excellent yields. Phenyl ring bearing various substituents at the ortho, meta, para positions undergo this cyclization reaction. This method involves simple work up and amenable for large scale preparations. The heterogeneous acid treated catalyst can be regenerated and used for up to three cycles with minimum loss of activity.

Contents

Introduction

The 2,3-dihydro-1-benzopyran-4-ones commonly known as chroman-4-ones or 4-chromanones are privileged motifs in medicinal chemistry for drug discovery.[1] They are also present in large number of natural products as such or in modified forms.[2] Thus, it is of no surprise that they continue to attract the attention of synthetic organic chemists. Chroman-4-ones are versatile building blocks as they provide rapid access to chromans, chromenes and chromanols.[2] The derivatives of 4-chromanones are very well known to exhibit pharmacological properties like anti-inflammatory, anti-bacterial, anti-oxidant, anti-tumor, anti-HIV and Alzheimer's.[3] Chroman-4-one derivatives such as eriodictyol, a catheccholic flavanone is used as taste-modifying agents,[4] 12-oxocalanolide A is an effective anti-HIV agent.[3] *Trans*-dihydroquercetin and hesperetin are drugs under clinical trials for treating diabetes and as cholesterol lowering agent.[5]

A variety of methods are known for the synthesis of 4-chromanones, albeit most of them require harsh reaction conditions and the criteria for atom economy are seldom met.[6] The most typical approach towards synthesis of 4-chromanones is *via* intramolecular cyclisation of 3-aryloxypropionic acids in the presence of reagents such as P_2O_5,[7] $HO(HPO_3)_nH$,[8] CH_3SO_3H,[9] TFAA,[10] CF_3SO_3H,[11] HF,[12] $Yb(OTf)_3$,[13] $AlCl_3$,[14] *etc.* Most of these methods suffer from one disadvantage or the other such

* Corresponding author.
E-mail address: bhagavathy@crescent.education (B. Shanmugasundaram).

https://doi.org/10.1016/j.tetlet.2021.153372
0040-4039/

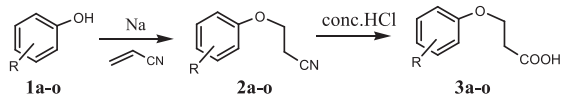
as stoichiometric amount or more of the reagents, inert conditions, poor atom economy and problems of waste disposal as well mounting the cost. The use of CH_3SO_3H and TFA reagents involve tedious workup and are not suitable for large scale reactions either because of cumbersome work up or due to its corrosive nature. Also, some of the reagents used for the cyclisation cannot be easily reused or recovered. This intramolecular acylation reaction is found to be inefficient and quite challenging for substrates in which the phenyl ring contains electronegative groups resulting in yields as low as 10%.[15] These considerations motivated us to explore the use of modified inexpensive heterogeneous catalysts for the cyclisation of 3- aryloxypropionic acids which would exhibit good substrate scope and which can be recovered and reused.

Montmorillonite K-10 (Mont.K-10) is a well-known green heterogeneous reusable catalyst for a wide range of organic reactions due to its ease of work-up, in-expensive and milder reaction conditions.[16] Acid activated montmorillonite clays are also found to be much more effective than the commercially available clays.[17] Although Mont.K-10 has been used in various acylation reactions,[18] its utility has not yet been explored towards the synthesis of 4-chromanones. In this report, we describe the use of acid activated Mont.K-10 for the intramolecular cyclisation of 3-aryloxypropionic acids towards the synthesis of 4-chromanones.

3-Aryloxypropionic acids **3a**-**3o** can be synthesised in two steps from the respective phenols (Scheme 1) according to literature reports. Oxa-Michael addition of phenols **1a-o** to acrylonitrile in the presence of sodium yielded the 3-aryloxypropane nitrile **2a-o**.[19] Subsequent hydrolysis of the crude 3-aryloxypropane nitrile with conc.HCl afforded the desired 3-aryloxypropionic acids **3a-o** in moderate to very good yields.[20]

Our initial work on the intramolecular cyclization reaction of 3-aryloxypropionic acids using TfOH/TFA[11] & PPA[21] led to chromanones;[11] but in very low yields; especially with electron withdrawing substituents **3i, 3f** and disubstituents **3h.** Hence, we turned our attention to explore the use of acidic heterogeneous catalysts like Mont.K-10,[22] Nafion-H,[23] TiO_2[24] and $ZrOCl_2$[25] for this transformation as these catalysts are known to bring about aromatic acylation reactions. It is to be noted that although Friedel-Crafts acylation reactions are known using Mont.K-10, its application towards synthesis of chromanone has not been reported so far.

To begin with, we screened the above-mentioned heterogeneous catalysts for the intramolecular cyclisation of 3-phenoxypropionic acid **3a** varying the reaction conditions and the results are summarised in Table 1. Treatment of the 3-phenoxypropionic acid **3a** with thermally activated Mont.K-10 in toluene afforded the corresponding chromanone **4a** albeit in very low yields (Table 1, ***Entry 2***) and with only 50% conversion. Heating it for longer time and increasing the quantity of the Mont.K-10 catalyst were not fruitful. Cyclisation with Nafion-H films did afford the product, but here again the reaction was incomplete and further heating it longer time with additional catalyst also had



1a,**2a**,**3a** R = H
1b,**2b**,**3b** R = 4-Me
1c,**2c**,**3c** R = 2-Me
1d,**2d**,**3d** R = 3-Me
1e,**2e**,**3e** R = 4-OMe
1f,**2f**,**3f** R = 2-OMe
1g,**2g**,**3g** R = 4-OEt
1h,**2h**,**3h** R = 3,5-$(CH_3)_2$
1i,**2i**,**3i** R = 2-Cl
1j,**2j**,**3j** R = 4-Cl
1k,**2k**,**3k** R = 4-Br
1l,**2l**,**3l** R = 3-Br
1m,**2m**,**3m** R = 4-F
1n,**2n**,**3n** R = 1-naphthyl
1o,**2o**,**3o** R = 2-naphthyl

Scheme 1. Synthesis of 3-aryloxypropionic acids **3a-o.**

no significant effect (Table 1, ***Entry 4***). Heating the acid **3a** with TiO_2 and $ZrOCl_2$ too were not successful as it led to only mixture of products (Table 1, ***Entry 5–7***). Mont.K-10 and Nafion-H were completely inert when the cyclisation was done at room temperature (Table 1, ***Entry 1,3***). Based on these findings, we chose montmorillonite K-10 for further investigation focussing our attention to improve its catalytic efficiency by treating it with sulphuric acid. For convenience, all AA mentioned further stands for "Acid Activated".

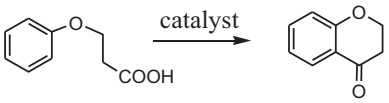
Literature reports reveal that Bronsted acid treated clays exhibit significant enhancement in the catalytic activity due to their increased acidity.[26] To increase the acidity of the Mont.K-10, H_2SO_4 and HCl were employed. Acidification of the Mont.K-10 clay was carried out with 0.5 N, 5 N and 36 N (conc.) of H_2SO_4 as per known method.[27] Intramolecular cyclisation of **3a** with the catalyst prepared from 36 N afforded the corresponding chromanone **4a** in just 30 min and in good yields (Table 1, ***Entry 10***), whilst the AA.Mont.K-10 prepared from 0.5 N and 5 N sulphuric acid solution behaved similar to the thermally activated Mont.K-10 showing only a slight increase in the reaction conversion rate. It is found that this acid treated clay should be washed with water until the pH of the washing is ~ 2–3 as excessive washing of the clay reduces its acidity. Drying of AA.Mont.K-10 at three different temperatures *i.e.* 100 °C, 250 °C and 500 °C for 6 h when examined, it is found that the AA.Mont.K-10 dried at 100 °C gave quantitative yields of the chromanone **4a** upon cyclization of the acid **3a**; whilst the AA.Mont.K-10 dried at higher temperature (250 °C & 500 °C) did not lead to any product formation.

Performing this reaction under neat conditions without the use of any solvents were also not satisfactory as it required longer time and the yields was also not reproducible (Table 1, ***Entry 8 & 11***). It was interesting to observe that conc. HCl treated clay was equally efficient for this intramolecular cyclisation of the acid **3a** (Table 1, ***Entry 13***). The desired chromanone **4a** could also be obtained in few minutes by refluxing the acid **3a** at higher temperatures with high boiling solvents like nitrobenzene and decalin (Table 1, ***Entry 14–15***), but isolation of the chromanone **4a** with these high boiling solvents posed problems of purification by vacuum distillation or chromatographic separation, and hence this was not pursued further.

Subsequently, use of microwaves in the presence of the AA.Mont.K-10 was explored for the cyclisation of the acid **3a**. Cyclisation of **3a** with the thermally activated commercial Mont.K-10 under microwave irradiation at 120 °C led to the formation chromanone **4a**, but the reaction was incomplete (Table 2, ***Entry 1***). Once again, the use of excess of the AA.Mont.K-10 and irradiating for longer time leads to only decomposition. Interestingly the cyclization reaction was successful and went to completion in 5 min when irradiated at 200 °C using the thermally activated Mont.K-10 (Table 2, ***Entry 2***). It is also observed that the H_2SO_4 treated Mont.K-10 and HCl treated Mont.K-10 under microwave irradiation led to facile cyclization of the acid **3a** to **4a** (Table 2, ***Entry 3–4***) in just 30 s at 200 °C. Strangely, microwave irradiation of **3a** using the acid treated Mont.K-10 when carried out at 120 °C (Table 2, ***Entry 5–6***) did afford the chromanone **4a**, but in low yields due to incomplete reaction. Performing the reaction with increasing the irradiation time at 120 °C led to only charring of the reaction mass and hence microwave reactions were not satisfactory for this AA.Mont.K-10 promoted transformation. These experiments reveal that the temperature is one of the crucial factors like that of acidity for this intramolecular cyclization of the aryloxypropionic acids.

From our optimisation studies, the amount of the AA.Mont.K-10 required for the cyclization of **3a** to **4a** was found to be 300–500% by weight. Use of lesser quantity of the AA.clay *i.e.* 100–200% by weight considerably slowed the rate of reaction requiring longer

Table 1
Cyclisation of acid **3a** to chromanone **4a** under different conditions,



3a **4a**

S. No	catalyst[a)]	Rxn conditions[b)]	Time	Yield[c)](%)
1	Mont.K-10	CH_2Cl_2, rt	48 h	no rxn.
2	Mont.K-10	toluene, 110 °C	24 h	20[e)]
3	Nafion-H	CH_2Cl_2, rt	24 h	no rxn.
4	Nafion-H	toluene, 110 °C	24 h	30[e)]
5	TiO_2	toluene, 110 °C	24 h	-[d)]
6	$ZrOCl_2{\cdot}8H_2O$	toluene, 110 °C	24 h	-[d)]
7	$ZrOCl_2$ anhydr.	toluene, 110 °C	24 h	-[d)]
8	Mont. K-10	neat	24 h	20[e)]
9	H_2SO_4 act. Mont.K-10	CH_2Cl_2, rt	24 h	no rxn.
10	H_2SO_4 act. Mont.K-10	toluene, 110 °C	30 min	95
11	H_2SO_4 act. Mont.K-10	Neat, 110 °C	2 h	87
12	HCl act. Mont.K-10	CH_2Cl_2, rt	24 h	no rxn.
13	HCl act. Mont.K-10	toluene, 110 °C	30 min	90
14	H_2SO_4 act. Mont.K-10	nitrobenzene,210 °C	5 min	-[f)]
15	H_2SO_4 act. Mont.K-10	decalin, 190 °C	10 min	-[f)]

[a)]300% *w/w* of the catalyst; [b)]microwave-5 bar, 200 °C; [c)]yield after hexane wash of the crude; [d)]mixture of compounds; [e)]incomplete reaction; [f)]product not isolated.

Table 2
Microwave assisted intramolecular cyclisation of acid **3a** to chromanone **4a.**

S. No	Catalyst[a)]	Temp. (°C)	Rxn time	Yield[b)](%)
1	Mont.K-10	120	20 min	55[c)]
2	Mont.K-10	200	5 min	60
3	H_2SO_4 act. Mont.K-10	200	30 *sec*	90
4	HCl act. Mont.K-10	200	35 secs	85
5	H_2SO_4 act.Mont.K-10	120	>30 min	55[c)]
6	HCl act. Mont.K-10	120	>45 min	45[c)]

time of about 3 to 6 h to go to completion. Adding excess of the acid treated clay by>500% by weight did not noticeably show any enhancement in yield.

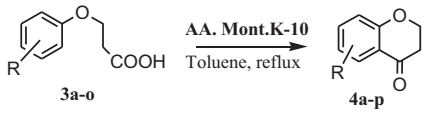
Heating the acid **3a** with 300% by weight of the H_2SO_4 treated Mont.K-10 (AA.Mont.K-10) in toluene at 110 °C was found to be the best condition to afford the chromanone **4a** in excellent yields. Various substituted 3-phenoxypropionic acids **3b**-**3o** too underwent facile cyclization with AA.Mont.K-10 to afford the respective chromanone **4b**-**4o** in good yields (Table 3). All the chromanones Table 3 **4a**-**4o** could be obtained in pure form by hexane wash of the crude and did not require any column purification except during isomer separation.

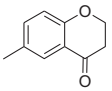
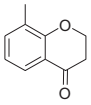
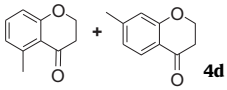
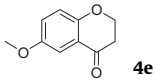
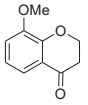
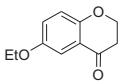
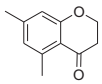
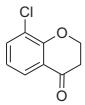
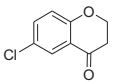
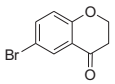
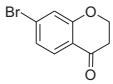
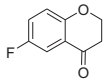
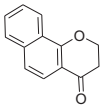
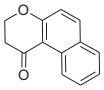
Synthesis of chromanones *viz.* **4b**-**4h, 4p** from acids **3b**-**3h** (Table 3) possessing electron donating groups was achieved in very good yields in about 25–30 min by the optimised reaction conditions. The 3-(3,5-dimethylphenoxy)propionic acid **3h** underwent this cyclisation smoothly and afforded the chromanone **4h** in very good yield. But the 6-ethoxychromanone **4g** was obtained only in moderate yield. Extending the reaction time for the formation of **4g** led only to a mixture of products and hence, the reaction was arrested in about 20 min to obtain the clean product and the unreacted starting material could be recovered. Cyclisation of 3-(3-methylphenoxy)-propionic acid **3d** was not regioselective and yielded the isomeric chromanones **4d** and **4p** in almost equal amounts.

Extending this cyclisation to 3-aryloxypropionic acids containing deactivating groups like halogen was also successful. Cyclisation of 3-(haloaryloxy)propionic acids **3i-3m** in the presence of the AA.Mont.K-10 afforded the chromanones **4i-4m** in moderate to good yields. Unlike the bromo- and fluoro substitutents (**4k**, **4l**, **4m**), the chloro substituted phenoxypropionic acids **3i** and **3j** afforded the corresponding chromanones **4i** and **4j** in relatively lower yields due to incomplete reaction. Here too, prolonging the duration led to complex mixture of products. Surprisingly cyclisation of the 3-(3-bromophenoxy)propionic acid **3l** using this catalyst afforded only the corresponding 7-bromochromanone **4l** with no trace of the corresponding 5-bromochromanone. This probably could be attributed to the steric hindrance of the bromine atom. As expected 3-(1-naphthoxy)propionic acid **3n** and 3-(2-naphthoxy)propionic acid **3o** too cyclised smoothly to yield the respective naphthochromanones **4n** and **4o**, respectively. It is observed that our AA.Mont.K-10 catalyst does convert the naphthoxypropio nitrile **2n** and **2o** directly to afford the respective chromanones **4n** and **4o**, whilst other nitriles **3a**-**3m** were found to be inert. All these chromanones were characterised thoroughly and the spectral data were in accordance with the literature.[28]

Inspired by the highly encouraging results, we proceeded to look at the morphology of the AA.Mont.K-10 catalyst. It was characterised by IR, SEM and BET data and compared with the commercial thermally activated Mont.K-10. The IR spectrum clearly showed flattening of the hydroxyl band in the AA.Mont.K-10 in comparison with that of the commercial Mont.K-10 as observed in literature.[29] This is possible because in the case of AA.Mont. K-10 the protons can penetrate into the clay layers resulting in dehydroxylation with the characteristic absorption bands attributed to vibrations of OH groups. SEM images of AA.mont.K-10 and thermally activated commercial Mont.K-10 reveals the structure of the AA.mont.K-10 to be as sponge shaped nano-structure, while

Table 3
Synthesis of 4-Chromanones **4a-p.**

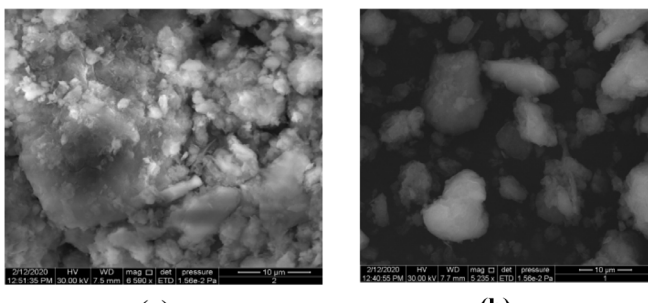


 **4a**(30 min., 95%) 95%)	 **4b** (25 min., 92%) (25 min., 92%)	 **4c** (30 min., 85%) (30 min., 85%)
 **4d** **4p** (30 min., 45% + 55%) **4p**(30 min., 45% + 55%)[a]	 **4e** (30 min., 90%) (30 min., 90%)	 **4f** (30 min., 85%) (30 min., 85%)
 **4g** (20 min., 55%)[b] (20 min., 55%)[b]	 **4h** (30 min., 90%) (30 min., 90%)	 **4i** (45 min., 65%)[b] (45 min., 65%)[b]
 **4j**(45 min., 62%)[b] 62%)[b]	 **4k** (40 min., 75%) (40 min., 75%)	 **4l** (30 min., 85%) (30 min., 85%)
 **4m** (45 min., 75%) (45 min., 75%)	 **4n** (30 min., 80%) (30 min., 80%)	 **4o** (25 min., 85%) (25 min., 85%)

[a])separated by column chromatography; [b])reaction incomplete.

the commercial Mont.K-10 is seen as large thick dense flakes[30] (Fig. 1).

BET adsorption isotherms carried out under N_2 atmosphere reveal that the commercial Mont.K-10 (Fig. 2) has a surface area of 42 m^2g^{-1} with pore size of 8.2 nm and its pore volume of 0.13 ccg^{-1}. It is known that acid treated clays leads to structural transformation with an increase in the volume and pore diameters and



(a) **(b)**

Fig. 1. SEM image 10 μm **(a)** comm. Mont.K-10 and **(b)** AA.Mont.K-10.

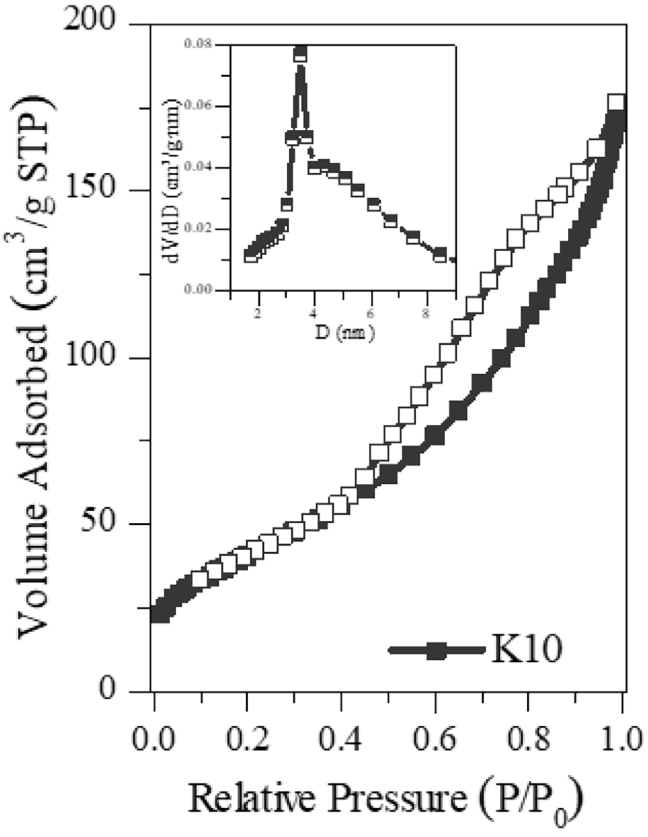


Fig. 2. N_2 adsorption desorption isotherm of commercial Mont.K-10. Inset shows the BJH pore size distribution from the desorption branch.

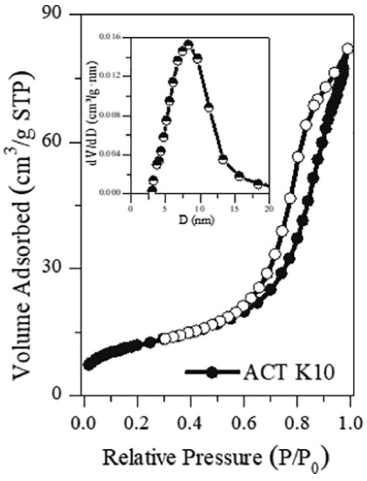


Fig. 3. N_2 adsorption desorption isotherm of AA.Mont.K-10 clay. Inset shows the BJH pore size distribution from the desorption branch.

hence, the particle size distribution too changes due to the rise in micro- and mesoporosity.[26] The BET adsorption isotherms of our AA.mont.K-10 reveal that it has an enhanced surface area of 148 m^2g^{-1}, its pore diameter is 3.5 nm and an increase in the pore volume of the clay is 0.99 ccg^{-1} (Fig. 3). The increase in surface area and pore volume of the AA.mont.K-10 as compared to that of the normal Mont.K-10 proves its nanostructure and hence this could be attributed to its higher reactivity towards the intramolecular cyclization reaction of the 3-aryloxypropionic acids to chromanones.

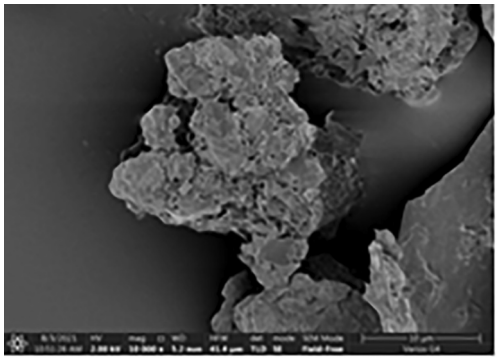


Fig. 4. SEM image 10 μm of recovered AA.Mont.K-10.

The intramolecular cyclization of 3-phenoxypropionic acid **3a** to chromanone **4a** is known to be facilitated by the use of strong protic acidic like triflic acid or trifluoroacetic acid. Most of the chemical reactions brought out by Mont.K-10 clay are based on its surface acidity [31]. Hence the AA.Mont.K-10 should facilitate the intramolecular cyclization similar to that of the protic acids and Lewis acids catalysed reactions due to their increased surface acidity. This intramolecular cyclization is found to be feasible only upon heating as only the high temperature conditions allows easy diffusion of the H^+ ions of the AA.Mont.K-10 to the substrates. Cyclisation proceeds by the protonation of carboxyl group to generate the acyl cation followed by intramolecular cyclization facilitated by the phenolic oxygen at the *ortho* position.

To rule out the possibility of homogeneous catalysis of the leached H_2SO_4,[32] we performed a control reaction by treating the acid **3a** with varying amounts of conc.H_2SO_4 (10 μL, 50 μL and 100 μL) under similar reaction conditions, but in the absence of AA.Mont.K-10.[32] By arresting the reaction in 30 min, it was found that in the case of the reaction with 10 μL of conc.H_2SO_4 the reaction was only 20% complete, while with 50 μL the reaction showed just 25% increase in chromanone with rest being the starting acid **3a** as observed from their ^{1}H NMR of the crude product. Increasing the concentration of H_2SO_4 to 100 μL did not lead to completion of the reaction and the ^{1}H NMR of its crude showed only 33% increase in chromanone formation along with other unidentified impurities and the acid **3a**. Allowing the reaction (10 μL) for longer hours resulted in extensive impurities and with still some minor amounts of the starting acid **3a**. These studies clearly indicate that the residual acid in the catalyst is not just enough to promote the cyclisation reaction.

Recycle studies using the AA.Mont.K-10 when performed for the cyclization of the acid **3a** to the chromanone **4a** showed that the AA.Mont.K-10 can be recycled only once for this cyclization reaction and that too with only moderate yields. Second recycling of the AA.Mont.K-10 does lead to the cyclization reaction, but the reaction does not go to completion proving that the catalytic efficiency is found to decline over reuse. The IR spectrum of the recovered AA.Mont.K-10 reveals the presence of excessive hydroxyl groups unlike the commercial and the AA.Mont.K-10. Whilst, its SEM image (Fig. 4) does appear as dense flake structure like that of commercial Mont.K-10, but with changes in its morphology which could be attributed to leaching during acid activation. To our utmost satisfaction, we observed that regeneration of the AA.Mont.K-10 by treating with sulphuric acid restored its activity for the cyclization reaction of 3-phenoxypropionic acids up to 3 cycles.

As to our knowledge, this is the first report on the AA.Mont.K-10 mediated cyclization of 3-aryloxypropionic acids **3** to chromanones **4**. The present study provides a highly convenient and efficient route for the intramolecular cyclization of various 3-aryloxypropionic acids to the respective chromanones. The AA.Mont.K-10 is in-expensive, easy to prepare, easy-to-handle, low toxicity, *eco*-friendly, amenable for scale-up preparations and does not require any Dean-Stark trap. Since the reaction is clean, there is no need for column chromatographic purification. Further application of the AA.Mont.K-10 and cation impregnated AA.Mont.K-10 towards aromatic acylation of other carbocycles and heterocycles is under progress.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank Prof. N. Sridhar, department of chemical engineering IIT Madras for NMR, Prof. Anju Chadha, department of biotechnology, IIT Madras for microwave instrument, Prof. G. Sekar and Prof. P. Selvam of department of chemistry, IIT Madras for valuable discussions. The authors also thank Crescent seed money scheme for funding analytical data.

Appendix A. Supplementary data

^{1}H NMR of all the known phenoxy acids **3a**-**3o**; ^{1}H and ^{13}C NMR of all the known chromanones **4a**-**4p** are provided in the supplementary material. IR, SEM, BJH data for the AA.Mont.K-10 are provided. Supplementary data to this article can be found online at https://doi.org/10.1016/j.tetlet.2021.153372.

References

[1] P. Gwynn, Ellis, *The Chemistry of Heterocyclic compounds*, John Wiley & Sons, 2009.
[2] A. Gaspar, M.J. Matos, J. Garrido, E. Uriarte, F. Borges, Chem. Rev. 114 (2014) 4960–4992, https://doi.org/10.1021/cr400265z.
[3] a) Ze-Qi Xu, Buckheit, R. W.; Stup, T. L.; Flavin, M. T.; Khilevich, A.; Rizzo, J. D.; Zembower, D. E. Bioorg. Med. Chem. Lett. 1998, 8, 2179-2184. DOI:10.1016/s0960-894x(98)00380-1;
(b). Zheng, X.; Hu, Y.; Liu, J.; Ouyang, K. Bioorg. Med. Chem. Lett. 2005, 15, 4531-4535. DOI:10.1016/j.bmcl.2005.07.003
[4] J.P. Ley, G. Krammer, G. Reinders, I.L. Gatfield, H.-J. Bertram, J. Agr. Food Chem. 53 (2005) 6061–6066, https://doi.org/10.1021/jf0505170.
[5] http://www.drugbank.ca/drugs.
[6] (a) J.H. Park, S.U. Lee, S.H. Kim, S.Y. Shin, J.Y. Lee, C.-G. Shin, Y.S. Lee, Arch. Pharm. Res. 31 (1) (2008) 1–5, https://doi.org/10.1007/s12272-008-1111-z;
(b) S. Emami, Z. Ghanbarimasir, Eur. J. Med. Chem. 93 (2015) 539–563, https://doi.org/10.1016/j.ejmech.2015.02.048;
(c) L. Jalili-Baleh, E. Babaei, S. Abdpour, S. Nasir Abbas Bukhari, A. Foroumadi, A. Ramazani, M. Khoobi, Eur. J. Med. Chem. 2018, 152, 570-589. DOI:10.1016/j.ejmech.2018.05.004..
[7] a) M.T. Bogert, H.C. Breneman, J. Hand, Am. Chem. Soc. 25 (1903) 372–380, https://doi.org/10.1021/ja02006a005;
b) M. Busch, Ber. 25 (1892) 2853.
[8] J.R. Price, Fortschr. Chem. org. Nat. 13 (1956) 330.
[9] (a) F. Camps, J. Coll, A. Messeguer, M.A. Pericas, S. Ricart, W.S. Bowers, D.M. Soderlund, Synthesis (1980) 725–727;
(b) D. Huckle, I.M. Lockhart, M. Wright, J. Med. Chem. 12 (1969) 277–279.
[10] (a) Zhong, Y.-L.; Boruta, D. T.; Gauthier, D. R.; Askin, D. Tet. Lett. 2011, 52, 4824-4826.;
(b) C. Galli, Synthesis. 4 (1979) 303–304.
[11] H.M. Colquhoun, D.F. Lewis, D.J. Williams, Org. Lett. 3 (2001) 2337–2340, https://doi.org/10.1021/ol010097.
[12] (a) V.K. Srivastav, S. Singh, A. Gulati, K. Shanker, Ind. J. Chem. 26B (1987) 652–656;
(b) N.M. Naik, K.R.J. Desai, Inst. Chem. (India). 61 (1989) 227–228.
[13] E. Fillion, A.M. Dumas, B.A. Kuropatwa, N.R. Malhotra, T.C. Sitler, J. Org. Chem. 71 (2006) 409–412, https://doi.org/10.1021/jo052000t.
[14] P.F. Wiley, J. Am. Chem. Soc. 73 (1951) 4205–4209, https://doi.org/10.1021/ja01153a048.
[15] T. Patonay, A. Vasas, A. Kiss-Szikszai, A.M.S. Silva, J.A.S. Cavaleiro, Aust. J. Chem. 63 (2010) 1582–1593, https://doi.org/10.1071/ch10295.

[16] (a) B.K.G. Theng, The Chemistry of Clay-Organic Reactions, Adam Hilger Ltd, London, 1974;
(b) L.J. Krstic, S. Sukdolak, S. Solujic, J. Serb. Chem. Soc. 67 (2002) 325–329, https://doi.org/10.2298/JSC0205325K.
[17] (a) T.S. Li, T.S. Jin, Chin. J. Org. Chem. 16 (1996) 385;
(b) Navjeet Kaur, Dharma Kishore, J. Chem. Pharm. Res. 4 (2012) 991–1015.
[18] (a) G. Sartori, R. Maggi, Chem. Rev. 106 (2006) 1077–1104, https://doi.org/10.1021/cr040695c;
(b) T.S. Li, A.X. Li, J. Chem. Soc., Perkin Trans. 1 (1998) 1913–1918, https://doi.org/10.1039/A802051E.
[19] A.H. Cook, K.J. Reed, J. Chem. Soc. (1945) 920–921, https://doi.org/10.1039/jr9450000920.
[20] (a) G.B. Bachman, H.A. Levine, J. Am. Chem. Soc. 70 (1948) 599–601, https://doi.org/10.1021/ja01182a046;
(b) Woods, L.L. J. Am. Chem. Soc. 1952, 74, 3959-3959. DOI:10.1021/ja01135a526.
[21] (a) C.D. Hurd, S. Hayao, J. Am. Chem. Soc. 76 (1954) 5065–5069, https://doi.org/10.1021/ja01649a016;
(b) S. Kumar, J.K. Makrandi, Eur. J. Chem. 9 (2012) 1251–1256, https://doi.org/10.1155/2012/324907.
[22] D. Kumar, B. Jyoti, S. Pollov, Cat. Rev. 57 (2015) 257–305, https://doi.org/10.1080/01614 940.2014.1003504.
[23] G.A. Olah, T. Mathew, M. Farnia, P.G.K. Surya, Synlett. 7 (1999) 1067–1068.
[24] P.M. Afzal, K. Manjula, V. Puttaramegowda Jayashankara, Synth. React. Inorg. Metal-Org. Nano-Metal Chem. 36 (2006) 321–324, https://doi.org/10.1080/155331706 00651389.
[25] R. Ghosh, S. Maiti, A. Chakraborty, Tet. Lett. 46 (2005) 147–151, https://doi.org/10.1016/j.tetlet.2004.10.164.
[26] C.N. Rhodes, D.R. Brown, Cat. Lett. 24 (1994) 285–291, https://doi.org/10.1007/bf00811801.
[27] P.J. Wallis, W.P. Gates, A.F. Patti, J.L. Scott, E. Teoh, Green Chem. 9 (2007) 980–986, https://doi.org/10.1039/b701504f.
[28] Relevant references quoted in Supporting Information.
[29] Komadel, P.; Madejova, J. Chapter 7.1 Acid Activation of Clay Minerals. Handbook Clay Sci. 2006, 263-287. DOI:10.1016/s1572-4352(05)01008-1
[30] Y. Jiraskova, J. Bursik, J. Seidlerova, K.M. Kutlakova, I. Safarik, M. Safarikova, O.J. Zivotsky, Nanomat. (2018) 1–14, https://doi.org/10.1155/2018/3738106.
[31] B.S. Kumar, A. Dhakshinamoorthy, K. Pitchumani, Catal. Sci. Technol. 4 (2014) 2378–2396, https://doi.org/10.1039/c4cy00112e.
[32] Based on referee's suggestions we performed this controlled experiment to rule out the possibility of this transformation due to the leached-out acid. The amount of leached out H2SO4 in AA.Mont.K-10 was calculated by obtaining the differences in weight of the AA.Mont.K-10 catalyst before and after the cyclisation reaction. After the reaction was over, the AA.Mont.K-10 was filtered, washed with water, then dried at 100 oC and weighed. The weight loss was 13 mg (i.e.~8 μL) of H2SO4 for 300 mg of the AA.Mont.K-10.