Vol. 13 (núm. 1) pp. 93-102
Enero-Junio de 2022

Ciencia en Desarrollo
Revista de la Facultad de Ciencias
Vicerrectoría en Investigación y Extensión - VIE
Centro de Investigaciones y Extensión de la Facultad de Ciencias - CIEC

https://doi.org/10.19053/01217488.v13.n1.2022.14165

A Hybrid System Base on Silica-Alumina and Keggin Heteropolyacid as Catalyst in the Suitable 2-(2-Furyl)-Chromones and Chromanones Synthesis

Un sistema híbrido basado en sílice-alúmina y heteropoliácido de Keggin como catalizador en la síntesis adecuada de 2-(2-furil)-cromonas y cromanonas

V. Palermo[1], D. Ruiz[2], A. Sathicq[1], P. Vázquez[1] and G. Romanelli[1,2]

Abstract

Molybdophosphoric acid/silica-alumina composites were synthesized through a process, in which the heteropolyacid was impregnated on different silica-aluminas, obtained by sol-gel. Three different techniques were used to prepare the samples. The catalysts were prepared by incipient wetness impregnation and different thermal treatments were applied. The hybrid systems were characterized by S_{BET}, XRD, and acidity measurements.

The catalytic activity of these materials was tested in the solvent-free cyclization of 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanedione to 2-(2-furyl)-chromones. The transformation gives very good yields of product, free of secondary products. Environmental benign procedure, and easy catalyst separation, is relevant features of this methodology. In this way, the catalyst can be used and reused six cycles without loss of catalytic activity. The most active catalyst was also used in the solvent-free cyclization of 1-(2-hydroxyphenyl)-3-(2-furyl)-2-propen-1-one and the methodology can be extended to the synthesis of other 2-(2-(furyl)-chromones and chromanones. The green context for this new procedure was confirmed by greenmetrics parameters.

***Keywords*:** Keggin heteropolyacids, Silica-alumina, Sol–gel synthesis, 2-(2-Furyl)-chromones, 2-(2-Furyl)-chromanones.

Resumen

Materiales compuestos por ácido fosfomolíbdico, sílice y alúmina fueron preparados por medio de un proceso en el cual el heteropoliácido fue impregnado sobre diferentes soportes de sílice y alúmina, obtenidas por sol-gel. Tres técnicas diferentes fueron usadas para preparar las muestras. Los catalizadores fueron preparados por impregnación a humedad incipiente y se sometieron a diferentes tratamientos térmicos. Los sistemas híbridos se caracterizaron mediante SBET, XRD y medidas de acidez. La actividad catalítica de estos materiales fue evaluada en la ciclación en ausencia de solvente de 1-(2-hidroxifenil)-3-(2-furil)-1,3-propanodiona a 2-(2-furil)-cromonas. Se obtuvieron buenos rendimientos del producto deseado, sin la formación de productos secundarios. Este procedimiento se destaca por ser un proceso ecocompatible, y la facilidad de separación del catalizador. En este sentido, el catalizador puede ser utilizado hasta seis ciclos sin pérdida de la actividad catalítica. El catalizador más activo también fue usado en la ciclación de 1-(2-hidroxifenil)-3-(2-furil) 2-propen-1-ona y esta metodología puede ser extendida para la síntesis de otras 2-(2-furil)-cromonas y cromanonas. El grado de sustentabilidad de este nuevo procedimiento es confirmado por los parámetros conocidos como “greenmetrics”.

***Palabras clave*:** Heteropoliácidos Keggin, Sílice-alúmina, Síntesis Sol-Gel, 2-(2-furil)-cromonas, 2-(2-furil)-cromanonas.

Recepción: 10-Jul-2021
Aceptación: 15-Dic-2021

---

[1] Centro de Investigación y Desarrollo en Ciencias Aplicadas “Dr. Jorge J. Ronco” (CINDECA-CCT La Plata-CONICET), Universidad Nacional de La Plata, La Plata, Argentina.

[2] Centro de Investigación en Sanidad Vegetal (CISaV) / Cátedra de Química Orgánica, Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata, La Plata, Argentina. e-mail: gpr@quimica.unlp.edu.ar

1 Introduction

The transformation of molecules derived from biomass (starting materials or building blocks to produce chemicals) has been recognized in recent decades as the key to converting biomass into fuels and chemical products. Within the chemical processes, a very important approach for the conversion of biomass is through the transformation of platform molecules. These building blocks were selected by researchers and comprise a series of compounds that can be easily transformed into other products with high added value. The derivatization of compounds from biomass, is a key step in the valorization of the chemical products [1-2].

One of these building blocks is furfural, an important non petroleum based and chemical feedstock. Several procedures were redefined to obtain valuable products through clean processes and recyclable solid catalysts from furfural, that include the reduction of furfural to furfuryl alcohol and tetrahydrofurfuryl alcohol, the preparation of furoic acid from furfural via oxidation reaction and the furan synthesis via decarbonylation of furfural using a Palladium catalyst [3].

Although, there are numerous heterocyclic compounds containing furfural as substructure, processes for their synthesis, have in general a high E factor, the reaction conditions are rigorous and the yields and selectivity of the reactions are very low. Likewise, the synthesis of these compounds requires the use of toxic reagents and large quantities of reaction solvents [4].

For this reason, our research group has been dedicated during several years to the study to the synthesis of heterocycles through more environmentally friendly processes that include: reactions in the absence of solvent and the use of recyclable hybrid materials based in heteropolyacid (Keggin, Wells-Dawson and Preyssler type) [5].

The main objectives of our research group are to design new materials for sustainable organic synthesis and generate heterocycles with proven or potential biological activity, containing in their skeleton substructures obtained from the building blocks present in biomass (furfural, 5-hydroxymethylfurfural, levulinic acid, cinnamic acid, etc) [6].

Some of our recent works in the design of new materials include: vanadium substituted Keggin polyoxometalate incorporated in poly (acrylic acid-co-acrylamide) polymer [7], bifunctional mesoporous catalysts based on Preyssler heteropolyacids [8], Preyssler heteropolyacids immobilized on magnetic composites [9] and nanoparticulate silica with organized multimodal porous structure impregnated with 12-phosphotungstic acid [10]. In general, the new materials are used in the suitable synthesis of heterocycles for example dihydropyrimidinones [11], pyrroles [8], 4H-pyrans [12], flavones and chromones [13].

The chromone ring system, 1-benzopyran-4-one, is the core fragment in several natural product as flavonols, flavones, and isoflavones [14]. The chromone substructure has been defined as a privileged structure in drug discovery, due to its use in a wide variety of active compounds such as anti-inflamatory, anti-cancer, anti-HIV agents, cancer preventive and efficient agents in the treatment of cystic fibrosis. The most important chromone-based compound present in the nature are 2-arylsubstituted chromones (flavones), which are present in the different food source as tea, fruits, wine, and oil. The different substituent of the chromone ring determines their different biological activities [15].

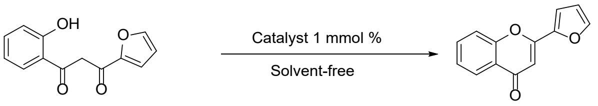
One of the most classic methods for the synthesis of 2-arylchromones is the cyclodehydration of 1-(2-hydroxyphenyl)-1,3-diketones. Particularly, the cyclodehydration of 1-(2-hydroxyphenyl-3-(2-furyl)-1,3-propanodione to obtained 2-(2-furylchromone) were usually catalyzed and it has been performed in different reaction media. Catalyst and reaction medium include: acetic acid [16], hydrogenchloride in acetic acid [17-19], sulfuric acid in acetic acid [20], and heteropolyacid in acetonitrile [21].

For its part, the chromanone substructure are present in flavanone compounds (2-phenylchromanones). They also exhibit ample range of bioactivities that include hypotensive, anti-fungal, anti-bacterial, and antitumoral [22].

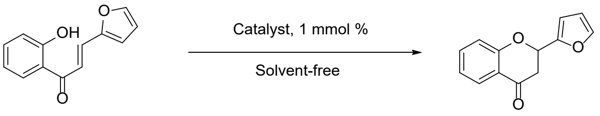
The classical method for the synthesis of flavanones consists of an intramolecular conjugated addition of o-hydroxychalcones to the corresponding cyclic carbonylic system [22]. Several catalysts were used to performed the 1-(2-hydroxyphenyl)-3-(2-furyl)-2-propen-1-one to the corresponding 2-(2-furyl)-chromanone that including: aq. buffer, T= 20 °C, pH= 12 [23], phosphorus pentoxide in ethanol [24], ytterbium (III) triflate [25], polyethylene glycol-400 [26], 1-butyl-3-methylimidazolium under microwave irradiation [27], sodium perborate in water/acetonitrile [28], sodium acetate in ethanol [29], and methane sulphonic acid [30].

In this article we present a systematic study about the use of a hybrid system bases on the combination of silica-alumina and Keggin heteropolyacid as catalyst in the selective cyclodehydration of 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanodione in solvent-free conditions (Scheme 1). Similarly, 1-(2-hydroxyphenyl)-3-(2-furyl)-2-propen-1-one was cyclized to 2-(2-furyl)-2-chromanone (Scheme 2). The optimal conditions, using the most active material ($SUIPMoT_{250}$) was used in the synthesis various of 2-(2-furylchromones) and 2-(2-furylchromanones).

Scheme 1. 2-(2-furyl) chromone synthesis



Scheme 2. 2-(2-furyl) chromanone synthesis



2 Experimental

2.1 General

All organic and inorganic chemical were purchased from Aldrich or Fluka and used without purification. The 1-(2-hydroxyphenyl)-3-(2-furyl)-2-propen-1-ones and 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanediones were prepared using previously reported methods [20, 21]. The yields were calculated from pure products. All the products were characterized by comparison of melting point (mp), thin layer chromatography (TLC) and nuclear magnetic resonance (NMR) data with those reported. Samples were prepared in $CDCl_3$ with tetramethylsilane (TMS) as an internal standard. The chemical shifts and coupling constants (*J*) were expressed in d and Hz, respectively.

2.2 Support preparation

The supports were prepared using three different methodologies previously developed in our laboratory with some modifications [31]:

Methodology A: the mixed oxide was prepared from tetraethyl orthosilicate (TEOS) and aluminum tri-sec-butoxide (TSBA). The molar ratio TEOS: TSBA: absolute ethanol (EtOH) and water (H_2O) was 1:1:2:8. First TEOS was hydrolyzed for 3 h at 45 °C. Then, an ethanol solution of TSBA was added and the mixture was stir during 24 h. The formed solid were drying at 50 °C for 48 h and at 95 °C for 4 h. The support was named as $SUIPMo0T_{25}$.

Methodology B: a solution of TEOS in absolute ethanol was prepared. Then, alumina Aldrich, 10 μm particle size was added. The TEOS hydrolysis was performed by addition of distiller water at 40 °C. The molar ratio TEOS:EtOH:H_2O was 1:1:4. After 24 h, the solid was filtered, dried at 50 °C for 48 h, and at 95 °C for 4 h. The materials was named $SUIIPMo0T_{25}$.

Methodology C: a solution of TEOS, TSBA, EtOH and H_2O (1:1:2:8) was prepared and stirring at 45 °C 3 h. The formed solid were drying at 50 °C for 48 h for 95 °C for 4 h. The material was named $SUIIIPMo0T_{25}$.

2.3 Catalysts synthesis

The supports (SUI, SUII, SUIII) were impregnated using the incipient wetness method with ethanol-water solutions (50% v/v) of PMo Aldrich ($H_3PMo_{12}O_{40}.nH_2O$). Six catalysts with two amounts of the PMo (10 % w/w and 20 % w/w) were prepared. The materials were named $SUIPMo10T_{25}$, $SUIPMo20T_{25}$, $SUIIPMo10T_{25}$, $SUIIPMo20T_{25}$, $SUIIIPMo10T_{25}$, and $SUIIIPMo20T_{25}$ respectively.

2.4 Catalysis calcination

Particularly, SUIPMo20T$_{25}$ was calcinated different temperatures (150, 250, and 400 °C) to obtaine the corresponding materials: SUIPMo20T$_{150}$, SUIPMo20T$_{250}$, and SUIPMo20T$_{400}$.

2.5 Catalysts characterization

The complete characterization of these materials was reported by our research group in previous works. Only some characterizations were made to verify the identity of the material. In the supplementary materials we added de characterization of the most active catalyst (SUIPMo20T$_{250}$).

2.6 Catalytic test for the 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanedione cyclization

Initially, catalytic tests in order to analyze the effect of catalyst type, material calcination temperature, % active phase, catalyst amount, time, and temperature on reaction yields were made. The general procedure was performed in a test tube reaction and immersed in an oil bath.

A mixture of 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanedione and catalytic amount of the catalyst in solvent-free condition was subjected to the temperature and time of the experiment. Reactions were monitored by gas chromatography (GC), with Shimadzu GC-2014 equipment according to the following conditions; detector temperature, 320 °C; injector temperature, 200 °C; split ratio, 1:10; pressure, 60 kPa; purge flow, 3.0 mL min^{-1}; and using a flame ionization detector (FID). The reaction yields were defined as the molar ratio of the product 2-(2-furyl)-chromone to the initial concentration of reactant.

2.7 General procedure for the synthesis of 2-(2-furyl)-chromone

A mixture of the corresponding 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanediones (0.5 mmol), catalytic amount of catalyst (SUIPMo20T$_{250}$, 1 mmol %) in solvent-free condition was subjected to 110 °C for 1 h. When the reaction time was over, the catalyst was washed (toluene, 2 x 1 mL) and filtered off, and the product was recrystalized using ethanol as solvent. Stability tests of the catalyst were carried out running six consecutive experiments under the same reaction conditions. After each test, the catalyst was separated from the reaction mixture by filtration, washed with toluene (2 x 1 mL), and then it was dried under vacuum and reused.

2.8 General procedure for the synthesis of 2-(2-furyl)-chromanone

A mixture of 0.5 mmol 1-(2-hydroxyphenyl)-3-(2-furyl)-2-propen-1-one and the catalytic amount of catalyst (SUIPMo20T$_{250}$, 1 mmol %) in solvent-free condition was heated in a sealed tube with stirring for 4 h at 140 °C. When the reaction time was over, 2 mL of toluene was added in portions (2 x 1 mL), and the catalyst was filtered. The extracts were combined and the organic solution was concentrated the vacuum, giving the pure product. The solid products were recrystallized from methanol. Similarly, to the 2-(2-furyl)-chromone synthesis the stability tests of the catalysts were carried out running six consecutive experiments.

2.9 Mp, ^{1}H and ^{13}C NMR data for synthetized compounds

All compounds are known. Melting point and NMR spectra were determined and compared with the literature. (See description in supplementary materials).

3 Results and discussion

The materials were prepared and characterized following a procedure described in the literature by our research group [31]. Table 1 presents the results of the surface area and the acid strength of some synthetized materials

Optimum reaction conditions were examined for 2-(2-furyl) chromone synthesis using 1-(2-hydroxyphenyl)-3-(2-fury)-1,3-propanodione as test reaction substrates in absence of solvent (solvent-free condition) at 110 °C for 1 h.

In the test experiment without the presence of catalyst, traces of 2-(2-furyl)-chromone was obtained (2 %) (blank experiment, Entry 1 in Table 2).

Table 1. S_{BET} and acid strength of representative hybrid materials.

Entry	Catalyst	S$_{BET}$ (m^2)	Acid Strength (mV)
1	SUIPMo0T$_{25}$	5	100
2	SUIPMo10T$_{25}$	3	667
3	SUIPMo20T$_{25}$	2.4	1060
4	SUIIPMo20T$_{25}$	220.2	838
5	SUIIIPMo20T$_{25}$	185.3	840
6	SUIPMo20T$_{150}$	3	1100
7	SUIPMo20T$_{250}$	2.8	1150
8	SUIPMo20T$_{400}$	2.4	200

Table 2. Effect of different synthetized materials on 2-(2-furyl)-chromone yields.

Entry	Catalyst	Yields (%)
1	None	2
2	PMo ($H_3PMo_{12}O_{40}$)	53
3	SUIPMo0T$_{25}$	15
4	SUIIPMo0T$_{25}$	14
5	SUIIIPMo0T$_{25}$	14
6	SUIPMo10T$_{25}$	62
7	SUIIPMo10T$_{25}$	48
8	SUIIIMo10T$_{25}$	44
9	SUIPMo20T$_{25}$	69
10	SUIIPMo20T$_{25}$	55
11	SUIIIPMo20T$_{25}$	53
12	SUIPMo20T$_{150}$	82
13	SUIPMo20T$_{250}$	**90**
14	SUIPMo20T$_{400}$	39

Nota: Reaction conditions: substrate (0.5 mmol), catalyst (1 mmol %), temperature (110 °C), solvent-free, time (1 h), stirring.

In a second test, when the support (SUIPMo0T$_{25}$) was utilized and the same reaction condition a very poor yield of only 15 % was obtained (Entry 3 in Table 2). Similar results were obtained with the support SUIIPMo0T$_{25}$ and SUIIIPMo0T$_{25}$ (Entries 4 and 5 in Table 2).

In the next experiment, bulk Keggin heteropolyacid (PMo) were checked in the same reaction condition. In this case, the reaction yields improve to 53 % (Entry 2 in Table 2).

In previous works we found that the preparation of hybrid material based in a support and a HPAs increases notably the yields of the reaction. Likewise, the supported/HPAs material allow a better separation of the reaction medium and its subsequent reuse. For example, similar materials were employed in the selective pyranylation/depyranilation of phenols with excellent reaction yields [31].

For this raison, the next experiments were performed using the prepared hybrid materials. Six experiment using the system SUI, SUII and SUIII with two content of active phase of the catalyst (10 and 20 %) were tested.

The catalysts with high content of PMo (20%) showed elevated reaction yields unlike the others with low PMo content (10%) (see Table 2: SUIPMo10T$_{25}$ 62 % vs SUIPMo20T$_{25}$ 69 %; SUIIPMo10T$_{25}$ 48 % vs SUIIPMo20T$_{25}$ 55 %; and SUIIIPMo10T$_{25}$ 44 % vs SUIIIPMo10T$_{25}$ 53 % respectively).

Then, we studied the hybrid materials that contain the PMo, which was supported in the different prepared materials (varying the synthesis method) (SUI, SUII, and SUIII).

With both catalysts (high, 20% and low,10% content) a decrease in the yields of 2-(2-furyl) chromone was observed when passing the material prepared with support I (SUI) to support III (SUIII). The observed order for the catalysts with higher content of PMo was: SUIPMo20T$_{25}$ > SUIIPMo20T$_{25}$ > SUIIIPMo20T$_{25}$ (Entries 9,10 and 11).

The best chromone yield was observed when the catalysts with the highest acidity were used (entries 3-5 in Table 1), independent of the material surface area, (SUIPMo20T$_{25}$ 69 % entry 9 in Table 2). The higher acidity associated with the smaller surface area is related to a lower interaction between the support and the PMo. The supports SUII and SUIII have higher surface area and then a higher number of surface groups compared to SUI carrier, increasing the PMo-carrier interaction and leading to well-dispersed PMo-phase. This increase leads to a decrease of the acidic strength in SAII and SAIII-supported catalysts [31].

The low interaction between the SUI and the PMo due to its low surface area could cause loss of catalytic activity in the different reuses of the catalyst, due to a greater leaching during the isolation and recovery phase of the catalyst (this operation is carried out using free toluene). For this reason, it is necessary to perform a leaching test. The fresh catalyst (SUIPMo20T$_{250}$, 0.5 mmol) was put in contact with dry toluene (5 mL) in order to evaluate the possible catalyst solubilization. The catalyst was refluxed (110 °C) in toluene for 5 h, separated by filtration and dried in vacuum to constant weight. The observed mass loss was less than 0.2 %.

The reaction was also evaluated in order to study the effect of the catalyst dehydration temperature. The tests were performed using the materials SUIPMo20 without dehydration and dehydration at different temperatures: 150, 250, and 400 °C (SUIPMo20T$_{150}$, SUIPMo20T$_{250}$, and SUIPMo20T$_{400}$ respectively. The highest yield was attained using SUIPMoT$_{250}$ (90 % Entry 13 in Table 2).

In general, the yields employing dehydrated HPAs are higher than those using HPAs without dehydration. When HPAs are dehydrated, the number of water molecules in the secondary structure is lower, so that the acid strength and, consequently, the catalytic activity increases [21].The reaction is reversible, the secondary product is water, therefore, the presence of water discourages the displacement of the reaction equilibrium (chromone formation is best performed using anhydrous aprotic solvent or solvent free conditions). Finally, the catalytic system calcined at 400 °C (SUIPMoT$_{400}$) gave very poor yields 39 % (see entry 14 in Table 2). In this case the low reaction yields are due to their low acidity as consequence of HPAs Keggin unit degradation [31].

Afterwards, the best catalyst, SUIPMo20T$_{250}$ was studied in the next experiment and excellent result were obtained. The influence of temperature reaction on 1-(2-hydroxyphenyl)-3-(2-furyl)-1,3-propanodione cyclization were analyzed using 1 mmol % of, SUIPMo20T$_{250}$. Six temperature were studied (25, 80, 90, 100, 110 and 120 °C. No reaction was observed at 25 °C (entry 1 in Table 3), and the yields was very low at 80 °C (23 %, entry 2 in Table 3).

When the reaction temperature increases to 90 and 100 °C (49 and 68 %, entries 3 and 4 in Table 3) a moderate yield of 2-(2-furyl)-chromone was obtained. A further temperature increase, to 110 °C leads notable increase of the yield (90 %, entry 5 in Table 3). This temperature favors the displacement of the equilibrium of the reaction by loss of water.

Table 3. Effect of different reaction conditions on 2-(2-furyl)-chromone yields (%).

Entry	Temp (°C)	Time (h)	Amount of catalyst (mmol %)	Yields (%)
1	25	1	1	-
2	80	1	1	23
3	90	1	1	45
4	100	1	1	68
5	110	1	1	**90**
6	120	1	1	**85**
7	110	2	1	89
8	110	0.5	1	71
9	110	0.25	1	55
10	110	1	0.25	68
11	110	1	0.50	85
12	110	1	2	89

Nota: Reaction conditions: substrate (0.5 mmol), catalyst: SUIPMo20T$_{250}$ (1 mmol %), solvent-free, stirring.

Finally, at 120 °C, the reaction yield is a little (85 % entry 6 in Table 3). In this case secondary products begin to be detected by CG analysis. For this reason, a temperature of 110 °C was employed in the next experiment.

The test performed using different reaction time under the same reaction conditions (substrate: 0.5 mmol, catalyst: SUIPMo20T$_{250}$, 1 mmol %, temperature: 110 °C, and solvent-free conditions) shows that the yields of 2-(2-furyl)-chromone increased when the reaction time increased to 1 h (entries 5 and 9 in Table 3)

The catalyst amount was also studied in the same reaction condition using a variable mmol % of the SUIPMo20T$_{250}$ (0.25, 0.5, 1.5 and 2 mmol %). The yield of 2-(2-furyl)-chromone increased from 68 % (entry 10 in Table 3) to 90 % (entry 5 in Table 3) and no appreciable changes of the yields were obtained with an increase of 2 mmol % in the catalyst amount (89 % entry 12 in Table 3).

The reuse of the catalyst of SUIPMoT$_{250}$ was analyzed by the synthesis of 2-(2-furyl)-2-chromone in solvent-free condition at 110 °C using an amount of 1 mmol % (Table 4).

Table 4. Catalyst reuse. Effect on 2-(2-furyl)-chromone yields (%).

Entry	**Catalyst cycle**	**Yields (%)**
1	1	90
2	2	89
3	3	89
4	4	87
5	5	86
6	6	86

Nota: Reaction conditions: substrate (0.5 mmol), catalyst (SUIPMo20T$_{250}$, 1 mmol %), solvent-free, temperature (110 °C), time (1 h), stirring.

The catalyst was recovered and reused five times and it can be observed that the materials maintains the catalytic activity. Only a loss of 5% the catalyst mass was lost and by FT-IR, it was noticed that the SUIPMo20T$_{250}$ preserved the Keggin structure after all catalytic cycles. The results showed that the reutilization in six consecutives test were: 90, 89, 89, 87, 86, and 86 % respectively (Entries 1-6 in Table 4).

The auspicious results obtained in the synthesis of 2-(2-furyl)-chromones motivated us to use the SUIPMo20T$_{250}$ catalyst in the synthesis of 2- (2-furyl) -chromanones. The reaction carried out by cyclodehydration of 2-hydroxyphenyl-3-(2-furyl)-2-prpopen-1-one as can be seen in Figure 2.

Similarly, to the synthesis of 2-(2-furyl)-chromone different reaction conditions including temperature, reaction time and amount of catalyst were studied in solvent-free conditions. However, when the reaction was studied at 110 °C quantitative amount of substrate was recovered, and no reaction product was detected. Next, the reaction temperature was raised to 140 °C (sealed tube). In this condition good yield of 2-(2-furyl)-chromone were obtained within secondary product formation.

The experimental conditions were: substrate (0.5 mmol), catalyst (1 % mmol), temperature (140 °C), reaction time (4 h), in a sealed tube with stirring. In this condition, the yield of 2-(2-furyl)-chromanone was 72 %. The reuse of the catalyst of SUIPMo20T$_{250}$ was analyzed and the results showed that the reutilization in six consecutives test were: 72, 70, 68, 66, and 66 % respectively (entry 4 in Table 5).

Finally, under the optimized reaction condition, three 2-(2-furyl)-chromones and three 2-(2-furyl)-chromanones were synthetized. The results are given in the Table 5. In all the examples the expected products were obtained with very good yields and excellent selectivity without appreciable amounts of secondary products. It can be observed in Table 5 that the proposed methodologies give very good yields of 2-furyl-2-(chromones) (71-90 %) and (2-(2-furyl)-chromanones (65-72 %) respectively.

In order to quantify how much ‘greener’ the methodology is, the Atom Economy (AE), Atomic efficiency factor (E), Process Mass Intensity (PMI), Reaction Mass Efficiency (RME), Material Recovery Parameter (MRP) and EcoScale were calculated for each reaction product. The results are given in the Table 6.

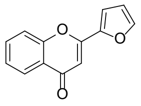
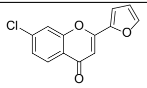
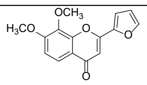
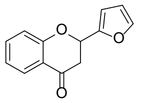
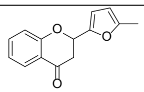
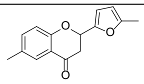
Results show high efficiencies, very low recovery parameters, and acceptable to excellent green reaction conditions, incontrast with classic synthesis methods [22].

4 Conclusions

The preparation and characterization of materials based on a Keggin Heteropolyacid supported on silica-alumina was reported with the object of recycling the catalyst efficiently after the reaction, and to carry out reaction for the 2-(2-furyl)-chromones and chromanones synthesis (containing the furyl group, building block obtainable from biomass). The supports were prepared by sol-gel methods and the supported catalysts by impregnation techniques in a mixture of ethanol-water (1:1) was satisfactory. The material maintained their structure after the synthesis and were characterized by routine techniques and the acidity was determined by potentiometric titration.

Three 2-(2-furyl)-chromones and three 2-(2-furyl)-chromanones synthetized using the most suitable catalyst (SUIPMo20T$_{250}$) under solvent-free conditions. The catalytic methodology represents an environmentally friendly procedure in comprehensive, compared with other systems (soluble acids such as acetic, hydrochloric, and *p*-toluensulfonic acids or high cost catalyst as ytterbium (III) triflate).

Table 5. 2-(2-Furyl)-chromones and chromanones synthesis using SUIPMo20T$_{250}$ as catalyst.

Entry	**Product**	**Time (h)** **Temp. (°C)**	**Yields (%)**	**Mp. (°C)**	**Mp$_{Lit}$ (°C)**
1		1 110	90 89^a 89^a 87^a 86 86	134-136	135
2		1.5 110	85	208-209	208
3		1 110	71	177-179	178-179
4		4 140	72 72 70 68 66 66	80-81	80
5		4.5 140	68	124-125	124-126
6		4.5 140	65	111-113	111-113

Nota: 1-Reaction conditions for 2-(2-furyl)-chromone synthesis (Entry 1-4): substrate (0.5 mmol), catalyst (SUIPMo20T$_{250}$, 1 mmol %), solvent-free, stirring.

2-Reaction conditions for 2-(2-furyl)-chromanone synthesis (Entry 5-7): substrate (0.5 mmol), catalyst (SUIPMo20T$_{250}$, 1 mmol %), sealed tube, stirring.

Table 6. Greenmetrics parameters for 2-(2-Furyl)-chromones and chromanones synthesis.

Product	**Yields (%)**	**AE (%)**	**E factor**	**PMI**	**RME**	**MRP**	**EcoScale**
1	90	92.1	31.76	35.29	0.031	0.037	82.0
3	85	93.1	30.21	33.57	0.032	0.040	79.5
4	71	94.0	28.94	32.16	0.033	0.050	72.5
5	72	100	43.74	48.55	0.022	0.031	68.0
6	68	100	46.65	54.00	0.021	0.031	66.0
7	65	100	47.84	53.18	0.020	0.031	64.5

The of the hybrid materials based in silica/alumina/HPAs give very good yields (65 to 90 %), and easy separation and recovery of catalyst. The catalytic activity was practically constant in consecutive runs, and the high recovery of the materials allows low cost and environmental impact.

The utilization of these material in the suitable synthesis of the other heterocycles containing building block present in biomass are in progress in our laboratory.

Acknowledgments

We thank Universidad Nacional de La Plata, CONICET, and ERANET-1, for financial support. VP, AGS, PGV, and GPR are member of CONICET.

References

[1] M. J. Climent, A. Corma, S. Iborra. Converting carbohydrates to bulk chemicals and fine chemicals over heterogeneous catalysts. *Green Chem.*, vol. 13, no. 3, 520-540, 2011.

[2] J. J. Bozell, G. R. Petersen. Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "Top 10" revisited. *Green Chem.*, vol. 12, no. 4, 539-554, 2010.

[3] A. Escobar, A. Sathicq, L. Pizzio, M. Blanco, G. Romanelli. Biomass valorization derivatives: Clean esterification of 2-furoic acid using tungstophosphoric acid/zirconia composites as recyclable catalyst. *Process Safety and Environmental Protection*, vol. 98, 176-186, 2015.

[4] R. Sheldon, E. Factors. Green Chemistry and Catalysis: An Odyssey. *Chemical Communications*, vol. 39, no. 29, 3352-3365, 2008.

[5] G. Romanelli, J. Autino. Recent applications of heteropolyacids and related compounds in heterocycles synthesis. *Minireview in Organic Chemistry*, vol. 6, 359-366, 2009.

[6] J. Lewkowski. Synthesis, chemistry and applications of 5-hydroxymethylfurfural and its derivatives, *ARKIVOC*, vol. 1, 17-54, 2001.

[7] R. Frenzel, G. Romanelli, L. Pizzio. Novel catalyst based on mono- and di-vanadium substituted Keggin polyoxometalate incorporated in poly (acrylic acid-co-acrylamide) polymer for the oxidation of sulfides. *Molecular Catalysis*, vol. 457, 8-16, 2018.

[8] O. Portilla-Zúñiga, Á. Sathicq, J. Martínez, H. Rojas, E. De Geronimo, R.l Luque, G. P. Romanelli. Novel bifunctional mesoporous catalysts based on Preyssler heteropolyacids for green pyrrole derivative synthesis. *Catalysts*, vol. 8, 419-439, 2018.

[9] O. Cuervo, H. Rojas, H. Santos, T. Ramalho, G. Romanelli, J. Martínez. Etherification of hydroxymethylfurfural with Preyssler heteropolyacids immobilized on magnetic composites. *ChemistrySelect*, vol. 3, 5526-5533, 2018.

[10] D. M. Morales, R. A. Frenzel, G.P. Romanelli, L.R. Pizzio, L.R. Synthesis and characterization of nanoparticulate silica with organized multimodal porous structure impregnated with 12-phosphotungstic acid for its use in heterogeneous catalysis. *Molecular Catalysis*. In press. 2018. https://doi.org/10.1016/j.mcat.2018.10.005

[11] O. Portilla, A. Sathicq, J. Martínez, S. Fernandes, T. Rezende, G. Romanelli. Synthesis of Biginelli adducts using a Preyssler heteropolyacid in silica matrix from biomass building block. *Sustainable Chemistry and Pharmacy*, vol. 10, 50-55, 2018.

[12] L. Gutierrez, E. Nope, H. Rojas, A. Sathicq, G. Romanelli, J. Martínez. New application of decaniobate salt as basic solid in the synthesis of 4H-pyrans by microwave assisted multicomponent reactions. *Research on Chemical Intermediates*, vol. 44, 5559-5568, 2018.

[13] M. E. Perez, D. Ruiz, J. Autino, M. Blanco, L. Pizzio, G. Romanelli. Mesoporous titania/tungstophosphoric acid composites: suitable synthesis of flavones. *Journal of Porous Materials*, vol. 20, 1433-1440, 2013.

[14] L. Rackova, S. Firakova, D. Kostalova, M. Stefek, E. Sturdik, M. Majekova. Oxidation of liposomal membrane suppressed by flavonoids: Quantitative structure-activity relationship. *Bioorg Med. Chem.*, vol. 13, 6477-6484, 2005.

[15] H. A. Tawfik, E. F. Ewies, W. S. El-Hamouly. Synthesis of Chromones and their Applications during the Last Ten Years, in Ewies F Ewies et al. *IJRPC*, vol. 4, no. 4, 1046-1085, 2014.

[16] J. C. L. Menezes, L. B. A. Vaz, P. M. De Abreu Vieira, K. Da Silva Fonseca, C. Martins Carneiro, J. G. Taylor Synthesis and Anti-Trypanosoma cruzi Activity of Diaryldiazepines. *Molecules*, vol. 20, 43-51, 2015.

[17] W. D. Ollis, D. Weight. The synthesis of 3-substituted chromones by rearrangement of o-acyloxyacetophenones. *Journal of the Chemical Society*, 3826-3830, 1952.

[18] S. B. Nair, K. N. Wadodkar. *Indian Journal of Chemistry, Section B: Organic Chemistry Including Medicinal Chemistry*, vol. 21, no. 6, 573-574, 1982.

[19] I. Hirao, M. Yamaguchi, M. Hamada. A Convenient Synthesis of 2- and 2,3-Substituted 4H-Chromen-4-ones. *Synthesis*, vol. 12, 1076-1078, 1984.

[20] D. Ravishankar , K. A. Watson, F. Greco, H. M. I. Osborn. Novel synthesised flavone derivatives provide significant insight into the structural features required for enhanced anti-proliferative activity. *RCS Advances*, vol. 6, 64544-64556, 2016.

[21] D. O. Bennardi, G. P. Romanelli, J. L. Jios, P.G. Vazquez, C. V. Caceres, J. C. Autino. Synthesis of substituted flavones and arylchromones using P and Si Keggin heteropolyacids as catalysts. *Heterocyclic Communications*, vol. 13, 77-81, 2007.

[22] G. J. Sagreraa, G. A. Seoane. Microwave Accelerated Solvent-Free Synthesis of Flavanones. *J. Braz. Chem. Soc.*, vol. 16, 851-856, 2005.

[23] B. M. Muller, T. J. Litberg, R. A. Yocum, C. A. Pniewski, M. J. Adler. Extended Aromatic and Heteroaromatic Ring Systems in the Chalcone-Flavanone Molecular Switch Scaffold. *Journal of Organic Chemistry*, vol. 81, 5775-5781, 2016.

[24] Y. Otsuka. Synthesis of 2-α-Furyl-chromanone and Its Derivatives. *Nippon Kagaku Kaishi*, vol. 65, 539-541, 1944.

[25] V. K. Rao, M. S. Rao, A. Kumar, Anil, Ytterbium(III) triflate: An efficient and simple catalyst for isomerization of 2'-hydroxychalcone and 2'-aminochalcones in ionic liquid, *Journal of Heterocyclic Chemistry*, vol. 48, 1356-1360, 2011.

[26] D. Kumar, G. Patel, B. G. Mishra, R.S. Varma. Eco-friendly polyethylene glycol promoted Michael addition reactions of α,β-unsaturated carbonyl compounds. *Tetrahedron Letters*, vol. 49, 6974-6976, 2008.

[27] D. Kumar, G. Patel, A. Kumar, R.K. Roy. Ionic liquid catalyzed expeditious synthesis of 2-aryl-2,3-dihydroquinolin-4(1H)-ones and 2-aryl-2,3-dihydro-4H-chromen-4-ones under microwave irradiation. *Journal of Heterocyclic Chemistry*, vol. 46, 791-795, 2009.

[28] N. C. Ganguly, S. Chandra, S. K. Barik. Sodium Perborate Tetrahydrate-Mediated Transformations of 2'-Hydroxychalcones to Flavanones, Flavones, and 3', 5'-Diiodoflavone Under Mild, Environmentally Friendly Conditions. *Synthetic Communications*, vol. 43, 1351-1361, 2013.

[29] G. Yang, X. Jiang, H. Yang. Development of novel pesticides based on phytoalexins: Part 2. Quantitative structure-activity relationships of 2-heteroaryl-4-chromanone derivatives. *Pest Management Science*, vol. 58, 1063-1067, 2002.

[30] P. Kulkarni, P. Wagh, P. Zubaidha. An Improved and Eco-Friendly Method for the Synthesis of Flavanone by the Cyclization of 2'-Hydroxy Chalcone using Methane Sulphonic Acid as Catalyst. *Chemistry Journal*, vol. 2, 106-110, 2012.

[31] G. Romanelli, P. Vázquez, L. Pizzio, N. Quaranta, J. Autino, M. Blanco, C. Cáceres. Phenol tetrahydropyranylation catalyzed by silica-alumina supported heteropolyacids with Keggin structure. *Applied Catalysis A: General*, 261, 163-170, 2004.