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Mediterranean Journal of Chemistry **2018**, 7(1), 39-55

A new process for $Na_2Ca(HPO_4)_2$ synthesis and its application as a heterogeneous catalyst in Knoevenagel condensation

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Abstract: The novelty of this work is to propose a new process consisting to the modification of triple superphosphate (TSP) by sodium nitrate ($NaNO_3$) for the preparation of a heterogeneous catalytic support $Na_2Ca(HPO_4)_2$ (calcium hydrogen disodium phosphate). This product has been characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and infrared spectroscopy (IR). The catalytic activity of $Na_2Ca(HPO_4)_2$ was examined in Knoevenagel condensation between 4-chlorobenzaldehyde and malononit rile as a model reaction. The optimization of the reaction operating conditions was carried out based on a study of the effect of various parameters, namely reaction time, the catalyst charge, the nature, and volume of solvent on the reaction yield. From these considerations, this catalyst proves its efficiency since it allows to obtain the product with excellent yields in a short reaction time. Moreover, it has been reused several times without any significant loss of its activity. The process developed herein can be considered as an ecological and economical method because the catalyst used is non-toxic, cost-effective and easy to prepare.

Keywords: Heterogeneous catalytic support; phosphate fertilizer; TSP; $Na_2Ca(HPO_4)_2$; Knoevenagel condensation.

Introduction:

Knoevenagel condensation is a fundamental reaction widely used for the formation of unsaturated carbonyl compounds [1-2] which are used as an intermediate for the synthesis of several chemical molecules [3-5], drugs [6-8], and functional polymers [9]. This type of reaction is generally carried out by condensation of active methylene and carbonyl either aldehyde [10-13] or ketone [14-16]. Several methods have been reported in the literature concerning the Knoevenagel reaction, using organic bases, or their salts as catalysts, such as dimethylamino pyridine [17] and guanidine [18], as well as in the presence of Lewis acids including $ZnCl_2$ [19], $CuCl_2$ [20], $LaCl_3$ [21], $Mg(ClO_4)_2$ [22]. The simplicity of the synthesis of functionalized alkenes through Knoevenagel condensation, allowed it to be used as a model reaction to evaluate the catalytic performances of several heterogeneous catalysts, such as zeolites [23-24], zirconia promoted by sulfate ions [25], clay [26], and layered double hydroxides (LDH) [27]. Recently we find the use of magnetic catalysts [28-29], the organic metal frameworks MOF [30], KF-Clinoptilolite [31], amine grafted onto graphene oxide [32], sevelamer [33], hydrotalcite [34], silica-based [35], and phosphate-based catalysts, among which are natural phosphate [36], hydroxyapatites [37-39], fluoroapatites [40]. Furthermore, many phosphate-containing catalysts, such as KF/NP and $NaNO_3$/NP [41] and $Na_2CaP_2O_7$ [42], $CaHPO_4.2H_2O$ [43] were applied in Knoevenagel synthesis. Moreover, the development of new heterogeneous, green, available, inexpensive and reusable catalysts for the synthesis of chemical compounds has now become the ideal route for organic synthesis. In this context, and for the valorization of Moroccan natural resources in phosphate, our laboratory's interest was oriented towards the direct application of phosphate fertilizers MAP, DAP and TSP as heterogeneous catalysts in organic synthesis, the catalytic efficiency of these has been demonstrated in different synthesis performed by our team of research [44-48]. The efficiency, durability, and the ease of handling of these catalysts prompt us to direct our work towards their modification in order to extend their field of application by synthesizing others catalytic supports, based on simple

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DOI: http://dx.doi.org/10.13171/mjc71/01804111125-souizi

Received March 13, 2018
Accepted, March 21, 2018
Published April 11, 2018

and fast preparation processes. We, therefore, have prepared TSP modified with $NaNO_3$ which a new process was to obtain $Na_2Ca(HPO_4)_2$. A literature survey has shown that this catalyst was only prepared by a hydrothermal synthesis from $CaCl_2{\bullet}xH_2O$, NaCl, H_3PO_4 and $C_6H_{15}N$ [49]; moreover, it has never been applied as a catalyst in organic chemistry. To test the catalytic performance of this new heterogeneous support, it was used in the Knoevenagel reaction. Thus, the study of different parameters was carried out to determine the optimal conditions of the reaction which made it possible to lead to the desired products with excellent yields, in short reaction times. This catalyst has advantages such as low cost and ecological profile.

Experimental section

Materials and methods

The reagents used were purchased from Sigma-Aldrich. The progress of the reaction was monitored by thin layer chromatography (TLC) with SILG/UV 254 silica gel plates, using n-hexane-EtOAc (5:1, v/v) as eluent. The melting points were determined by a Kofler apparatus and showed a good agreement with those reported in the literature. The X-ray diffraction was performed under ambient pressure and temperature conditions, performed on a PANalytical X'Pert 3 Powder diffractometer using the Cu Kα radiation source ($\lambda = 1.54178$ Å) generated at 45 KV and 40 mA. Infrared spectra were made on a VERTEX 70 spectrometer using KBr pellets. The morphology of the surface was performed using a scanning electron microscope. The ^1H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra have been recorded in Brucker spectrometer in the presence of DMSO-d_6 using TMS as an internal reference (chemical shift in δ ppm). Mass spectra were recorded on a Thermo DSQII-Focus mass spectrometer.

Preparation of Catalyst $Na_2Ca(HPO_4)_2$

The $Na_2Ca(HPO_4)_2$ catalyst was formed by a simple operating method based on the addition of a solution of sodium nitrate ($NaNO_3$) on a mass of triple superphosphate (TSP) with a Na/TSP ratio = 1/2, the mixture was stirred for 30 min at room temperature and then evaporated. The resulting solid was dried at 150 °C overnight and calcined at 500 °C for 2 h. In the last step, the solid was crushed, sieved and stored in the oven at 150 °C. The sample is stored in a closed bottle until analysis. The catalyst obtained was analyzed by the XRD, IR and SEM methods and then applied in the Knoevenagel reaction. Figure 1 shows a summary of the Na/TSP preparation.

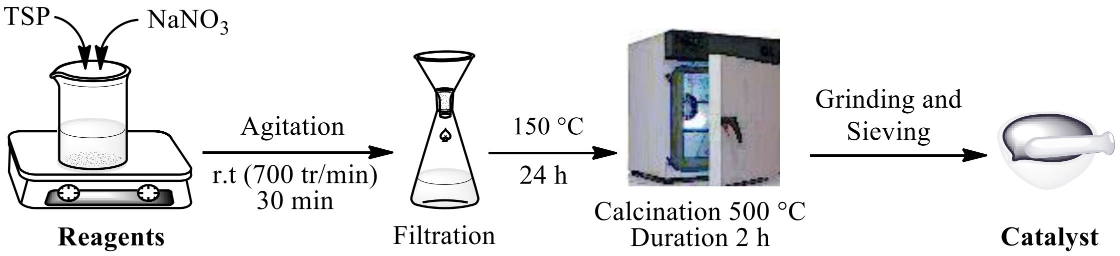


Figure 1. Different steps of $Na_2Ca(HPO_4)_2$ preparation.

General Procedure for Knoevenagel Condensation

The aromatic aldehyde (2 mmol) and malononitrile (3 mmol) were mixed in ethanol in the presence of $Na_2Ca(HPO_4)_2$ catalyst. The reaction mixture was undergone a constant stirring with a rate of 700 rpm at room temperature (25 °C), then, the reaction was monitored by TLC. When the reaction was completed, the product obtained was washed with ethanol and dissolved in THF. The catalyst was removed by filtration and washed with ethanol. The solid product was obtained after removal of the ethanol under vacuum. The product was purified by recrystallization from ethanol. The identity of the products was confirmed by ^1H, ^{13}C NMR, IR, and mass spectroscopy data. Melting point was determined for each product and compared with previous works, a good agreement was shown that consequently confirm the products chemical structures.

2-(4-Chlorophenylmethylene) malononitrile (3a)

Colorless solid, mp 161-162 °C (161-162 °C [50]); IR (KBr) ν: 2222, 1585. ^1H NMR (300 MHz, DMSO-d_6) δ: 7.67 (d, 2H, J = 8.7 Hz, ArH), 7.92 (d, 2H, J = 8.7 Hz, ArH), 8.49 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 160.5, 139.5, 132.5, 131.6, 130.1, 114.4, 113.4, 82.7. MS: m/z 188 $[M]^+$.

2-(Phenylmethylene) malononitrile (3b)

Colorless solid, mp 82-83 °C (82-83 °C [50]); IR (KBr) ν: 2225, 1560. ^1H NMR (300 MHz, DMSO-d_6) δ: 7.57-7.70 (m, 3H, ArH), 7.59 (d, 2H, J = 7.2 Hz, ArH), 8.50 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 155.7, 134.8, 131.7, 131.6, 130.9, 129.9, 114.6, 113.5, 82.0.

2-(4-Nitrophenylmethylene) malononitrile (3c)

Yellow solid, mp 159-160 °C (159-160 °C [50]); IR (KBr) ν: 2225, 1600. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 8.11 (d, J = 8.7 Hz, 2H), 8.29 (d, J = 8.7 Hz, 2H), 8.67 (s, 1H, C=CH).^{13}C NMR (300 MHz, DMSO-d_6) δ: 159.7, 150.1, 137.1, 131.9, 124.8, 114.0, 112.9, 82.4.

2-(p-Tolylmethylene) malononitrile (3d)

White solid, mp 119-120 °C (118-119 °C [43]); IR (KBr) ν: 2222, 1593 .^{1}H NMR (300 MHz, DMSO-d_6) δ: 2.37 (s, 3H), 7.38 (d, J = 8.4 Hz, 2H), 7.82 (d, J = 8.4 Hz, 2H), 8.39 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 161.6, 146.1, 131.1, 130.5, 129.1, 114.8, 113.8, 80.3, 21.5. MS: m/z 168 [M]$^+$.

Ethyl 3-(4-chlorophenyl)-2-cyanoacrylate (3e)

Colorless solid, mp 91-92 °C (91-92 °C [51]); IR (KBr) ν: 2230, 1725 .^{1}H NMR (300 MHz, DMSO-d6) δ: 1.28 (t, 3H, J = 7.2 Hz, CH$_3$), 4.29 (q, 2H, J = 7.2 Hz, CH$_2$), 7.61 (d, 2H, J = 8.7 Hz, ArH), 8.00 (d, 2H, J = 8.7 Hz, ArH), 8.33 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSOd6) δ: 162.0, 154.0, 138.5, 132.8, 130.5, 129.8, 115.7, 103.5, 62.9, 14.3. MS: m/z 235 [M]$^+$.

Ethyl 2-cyano-3-phenylacrylate (3f)

Colorless solid, mp 45-46 °C (45-46 °C [43]); IR (KBr) ν: 2235, 1720. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 1.38 (t, 3H, J = 7.2 Hz, CH$_3$), 4.29 (q, 2H, J = 7.2 Hz, CH$_2$), 7.56-7.69 (m, 3H, ArH), 7.92 (d, 2H, J = 7.2 Hz, ArH), 8.50 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 162.0, 154.0, 134.8, 131.7, 130.9, 129.9, 115.7, 103.5, 62.9, 14.3.

Ethyl 2-cyano-3-(4-nitrophenyl) acrylate (3g)

Yellow solid, mp 168-169 °C (167-169 °C [50]); IR (KBr) ν: 2230, 1720. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 1.28 (t, 3H, J = 7.2 Hz, CH$_3$), 4.29 (q, 2H, J = 7.2 Hz, CH$_2$), 7.62 (d, 2H, J = 8.4 Hz, ArH), 8.02 (d, 2H, J = 8.4 Hz, ArH), 8.30 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 162.0, 154.0, 138.4, 132.8, 130.6, 129.9, 115.8, 103.6, 62.9, 14.4.

Methyl 3-(4-chlorophenyl)-2-cyanoacrylate (3h)

White solid, mp 121-122 °C (122 °C [51]); IR (KBr) ν: 2230, 1720. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 3.84 (t, 3H, OCH$_3$), 7.65 (d, 2H, J = 8.4 Hz, ArH), 8.04 (d, 2H, J = 8.4 Hz, ArH), 8.38 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 162.5, 154.2, 138.5, 132.5, 130.6, 129.9, 115.8, 103.4, 53.8.

Methyl 2-cyano-3-phenylacrylate (3i)

White solid, mp 84-85 °C (84-85 °C [43]); IR (KBr) ν: 2235, 1725.^{1}H NMR (300 MHz, DMSO-d_6) δ: 3.84 (t, 3H, CH3), 7.54-7.65 (m, 3H, ArH), 8.03 (d, 2H, J = 8.4 Hz, ArH), 8.38 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 162.8, 155.6, 133.9, 131.7, 131.6, 129.8, 115.0, 102.8, 53.8.

Methyl 2-cyano-3-(4-nitrophenyl) acrylate (3j)

Yellow solid, mp 178-179 °C (178 °C [51]); IR (KBr) ν: 2232, 1722. ^{1}H NMR (300 MHz, DMSO-d_6) δ: 3.88 (s, 3H, CH$_3$), 8.19 (d, 2H, J = 7.1 Hz, ArH), 8.34 (d, 2H, J = 7.1 Hz, ArH), 8.48 (s, 1H, C=CH). ^{13}C NMR (300 MHz, DMSO-d_6) δ: 162.1, 153.1, 149.8, 137.6, 132.1, 131.0, 124.4, 115.1, 107.0, 53.9.

Results and discussion:

Characterization of $Na_2Ca(HPO_4)_2$

The microscopic and spectroscopic technics were carried out, namely XRD, SEM, and IR to characterize the structure of the modified catalyst.

The X-ray diffraction diagram of the catalyst (Fig. 2), present the characteristic peaks of $Na_2Ca(HPO_4)_2$, its structure has been shown to be monoclinic in the p21 space group with parameters network of a = 9.06 Å, b = 7.14 c = 5.47 Å, which are equal to those described in the literature [49].

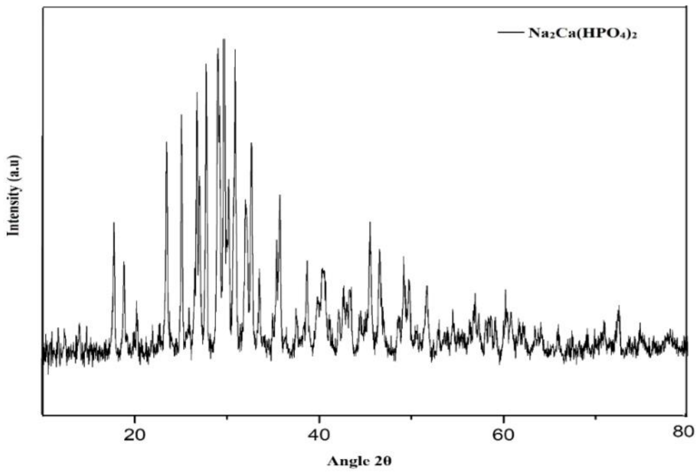


Figure 2. XRD Analysis Spectrum of $Na_2Ca(HPO_4)_2$.

Scanning electron microscopy of the catalyst surface shows that $Na_2Ca(HPO_4)_2$ is characterized by a set of phosphate crystals as well as some surface heterogeneity and a high porosity (Fig. 3).

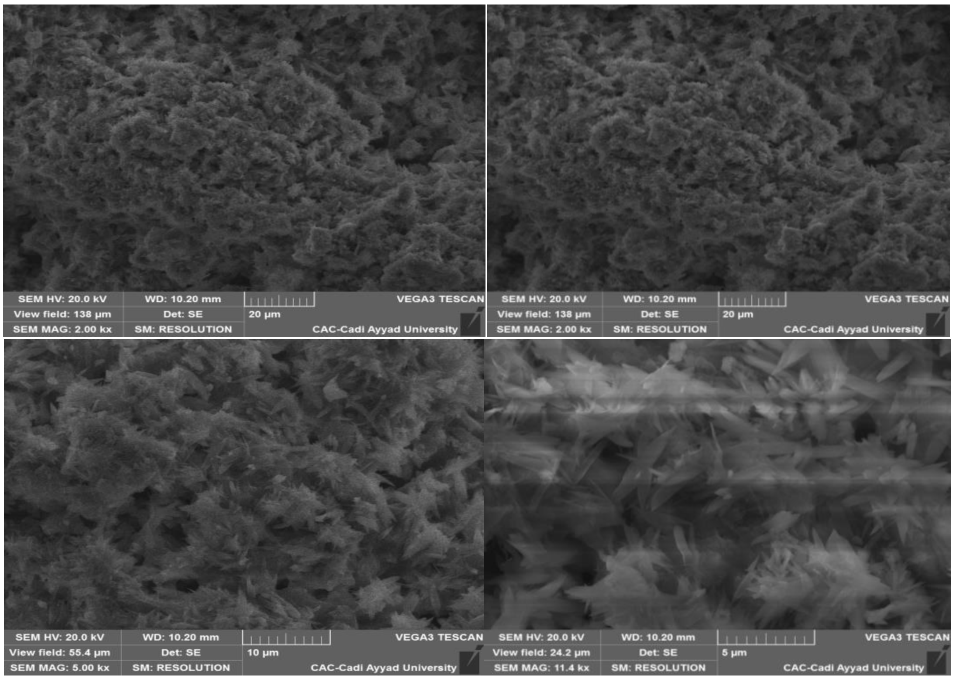


Figure 3. Images of $Na_2Ca(HPO_4)_2$ taken by SEM.

In order to determine the chemical composition of the catalyst Na_2Ca $(HPO_4)_2$, we performed an infrared spectroscopy analysis, which allows the identification of the chemical species presented on the surface of the solid (Fig. 4).

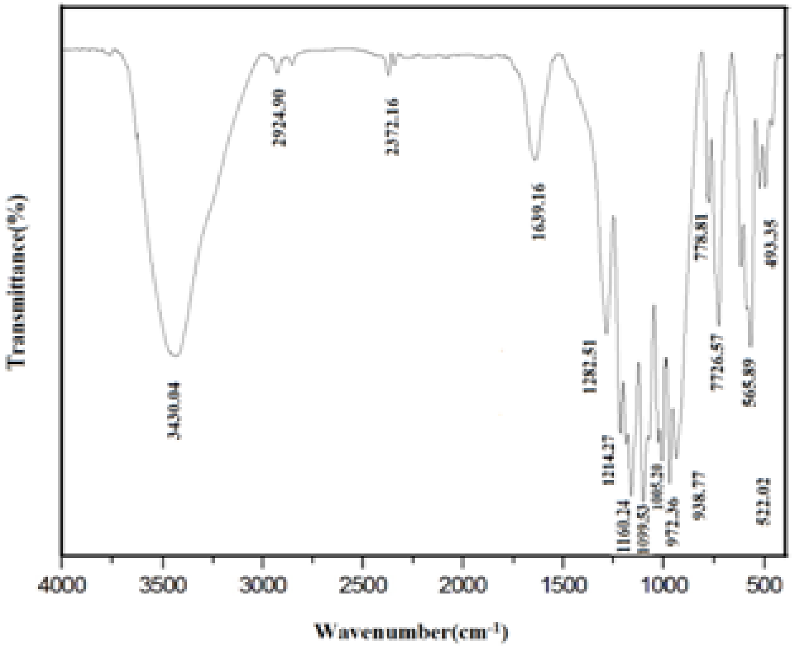


Figure 4. Infrared Spectra of $Na_2Ca(HPO_4)_2$.

The infrared spectrum of $Na_2Ca(HPO_4)_2$ (Fig. 3), shows a great similarity of the absorption bands, characteristic of TSP reported in previous work [52-53]. the appearance of peaks at 3430.04 cm^{-1} and 1639.16 cm^{-1}, characteristic of OH vibrations due to the presence of the molecule of water adsorbed on the surface of $Na_2Ca(HPO_4)_2$, two bands located in the high frequency region around 2924.90 cm^{-1} and 2372.16 cm^{-1} O-H vibration characteristics of the ion (HPO_4^{2-}), an intense band around 1282.51 cm^{-1} is due to the bending vibration in the P-OH planes and a band around 938.77 cm^{-1} of vibration characteristics P-OH out of plane bending, a strong band at 1160.24 cm^{-1} characteristics of asymmetric PO_2 vibrations and a symmetrical vibration towards 1099.53 cm^{-1} also corresponds to PO_2, two bands at 972.36 cm^{-1} and 778.89 cm^{-1} respectively correspond to the asymmetrical and symmetrical vibrations of P (OH), 565.89 cm^{-1} is corresponding to PO_2 bending modes, and two bands appeared at 522.07 cm^{-1} and 493.35 cm^{-1} which are attributed to PO_2 rocking modes [54-55]. Indeed, this confirmed that the presence of sodium does not alter the molecular vibrations existing groupings in the TSP network.

To determine the nature of the elements present in the sample of Na_2Ca $(HPO_4)_2$, the analysis of the composition of the surface by the energy dispersion spectrum (EDAX) was carried out as indicated in Figure 5.

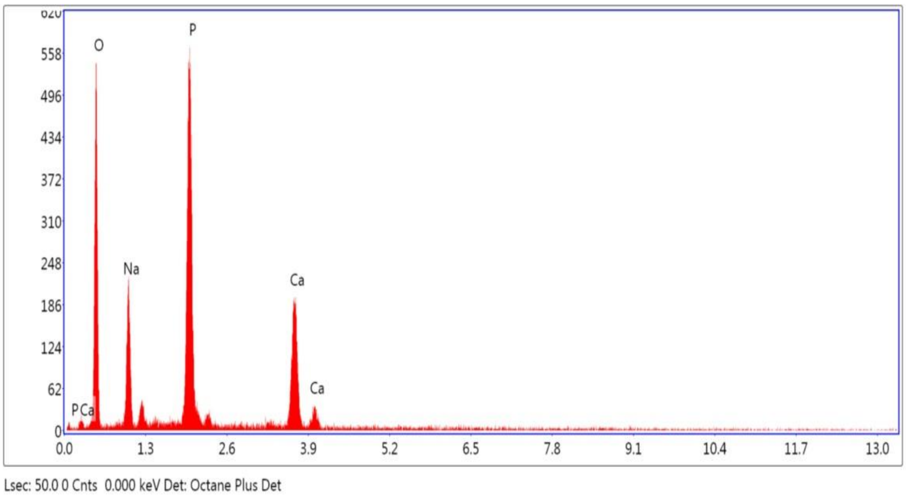


Figure 5. EDAX analysis of the chemical constituents of $Na_2Ca(HPO_4)_2$.

EDAX shows the presence of sodium in addition to the other main elements that make up TSP such as phosphorus, calcium, and oxygen [44]. Indeed, this analysis demonstrated the presence of sodium on the surface of the TSP.

In order to focus on the structure of $Na_2Ca(HPO_4)_2$, prepared from the modification of $Ca(H_2PO_4)_2$ by $NaNO_3$, the following mechanism is proposed which illustrates the grafted form of sodium with H_2PO_4 groups (Figure 6).

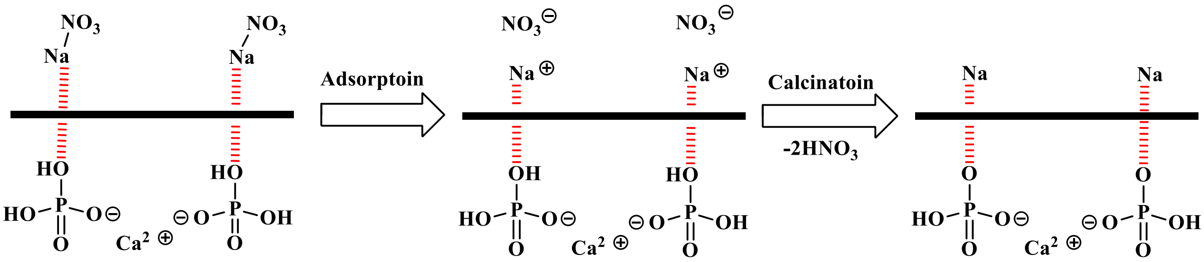
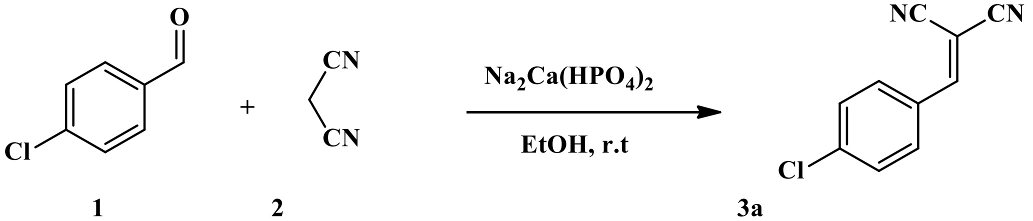


Figure 6. Proposed mechanism for the Na form presented in the TSP.

Catalytic application of $Na_2Ca(HPO_4)_2$ in the Knoevenagel reaction

The catalytic activity of $Na_2Ca(HPO_4)_2$ was tested on the Knoevenagel reaction. First, the condensation of 4-chlorobenzaldehyde and malononitrile (Scheme 1) was chosen as a pilot reaction in order to optimize the operating conditions.



Scheme 1. The Knoevenagel condensation of 4-chlorobenzaldehyde and malononitrile.

Each catalytic chemical reaction is controlled by several parameters, namely the reaction time, the mass of the catalyst used and even the nature and the volume of the solvent. Indeed, the study of the $Na_2Ca(HPO_4)_2$ catalytic performances, through the optimization of the operating parameters of the pilot reaction, was the objective of the work presented herein.

The determination of the optimal reaction time was the first study conducted on pilot reaction, this optimal time corresponds to the best yield taking in consideration that the reaction was carried out in the presence of ethanol and 0.01g of the catalyst. The results obtained are shown in Figure 7.

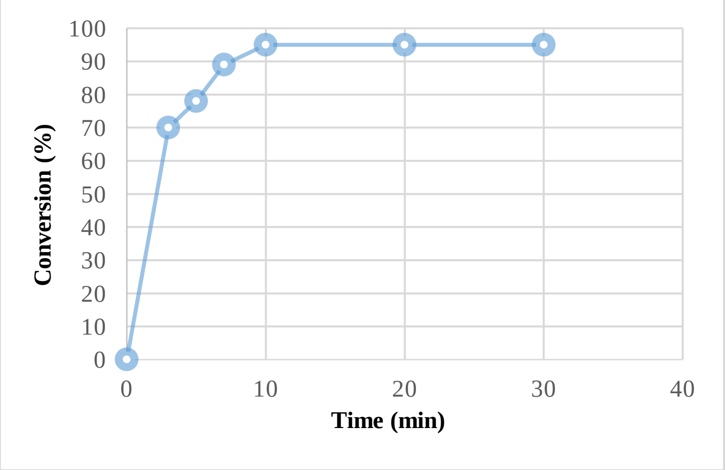


Figure 7. Time optimization for the Knoevenagel reaction.

The kinetic study of the reaction clearly showed that the conversion to **3a** increases gradually with increasing reaction time up to 10 min, reaching 95% yield.

In the next step, the mass effect has been carried out because it is well known that the mass of the catalyst plays a crucial role in the reaction yield. The reaction was tested in absence of the catalyst and then in presence of various catalyst mass. Table 1 summarizes the obtained results of each experiment performed.

Table 1. The catalysts amount effect on the Knoevenagel reaction[a]

Entry	Amount of catalyst (g/mol %)	Time (min)	Yield[b] (%)	TON[c]	TOF[d] (h^{-1})
1	neat	30	46	-	-
2	0.002/0.36	10	88	243.40	1466.26
3	0.004/0.72	10	92	125.00	753.01
4	0.006/1.08	10	97	88.42	532. 65
5	0.008/1.43	10	95	64.80	390.36
6	0.010/1.80	10	95	51.81	312.10
7	0.020/3.60	10	87	24.10	145.18
8	0.030/5.35	10	83	15.42	92.89
9	0.040/7.20	10	80	11.04	66.50

[a] Reaction conditions: malononitrile (3 mmol), 4-chlorobenzaldéhyde (2 mmol), EtOH (3 mL), x g of catalyst, r.t.
[b] Isolated yields.
[c] TON (turnover number) = moles of desired product formed/moles of catalyst.
[d] TOF (turnover frequency) = turnover number (TON)/hours.

From the obtained results, it is noted that the reaction in absence of the catalyst, is kinetically slow, after 30 min the reaction gave only 46% product **3a**, while in the presence of the catalyst, the product **3a** was obtained with a yield about 97% after only 10 minutes of reaction, the yield varies by variation of the mass of the catalyst. In fact, the best yield reaches 97% with only 0.006 g of catalyst, beyond this mass the yield begins to decrease, which can be explained by the catalyst dispersion on the surface of the reagents, it can be concluded that $Na_2Ca(HPO_4)_2$ has good catalytic activity towards the Knoevenagel reaction, even with very small amounts. The high values of TON and TOF are found for 0.002 g of $Na_2Ca(HPO_4)_2$ catalyst, it is clear that The TON and TOF increase when the mass of catalyst decrease. The best yield (97%) is obtained for 0.006g of catalyst, which corresponds to the value of the TON and TOF which are respectively 88.42 and 532.65 h^{-1}.

The time and the mass of the catalyst are not the determinant conditions that govern the reactional process, the nature of the solvent is also one of the important parameters that controlling the reaction progress. Thus, different solvents (Table 2) were used to decide on the best one appropriate for this synthesis.

Table 2. Solvent effect on the Knoevenagel reaction[a]

Entry	Solvent	Dielectric constant (ε)	Time (min)	Yield[b] (%)
1	EtOH	24.50	10	97
2	MeOH	32.70	10	95
3	Toluene	02.38	10	82
4	Dioxane	02.25	10	83
5	CH_3CN	37.50	10	89
6	THF	07.58	10	87
7	H_2O	80.10	10	66

[a] Reaction conditions: malononitrile (3 mmol), 4-chlorobenzaldéhyde (2 mmol), solvent (3 mL), 0.006 g of catalyst, r.t.
[b] Isolated yields.

From the results regrouped in Table 2, the reaction in ethanol which is a protic polar solvent lead to the best yield of desired products **3a** (97%) and is the suitable solvent for the Knoevenagel reaction. Interestingly, when the more protic polar solvent (H_2O, ε = 80.10) was used, the reaction is effective but resulted in the yield erosion (Entry 7, 66%).

The solvent volume effect was examined in the model reaction, by varying the volume of ethanol from 1 to 7 mL, under the same conditions described above. The obtained results are presented in Table 3.

Table 3. Ethanol volume effect on the Knoevenagel reaction yields[a]

Entry	Volume (mL)	Time (min)	Yield[b] (%)
1	1	10	90
2	3	10	97
3	5	10	92
4	7	10	82

[a] Reaction conditions: malononitrile (3 mmol), 4-chlorobenzaldehyde (2 mmol), EtOH, 0.006 g of catalyst, r.t.
[b] Isolated yields.

From the comparison of the yields obtained for the model reaction, it is clearly shown that the volume of 3 mL of ethanol is sufficient to generate the expected product **3a**, with a good yield (97%).

However, during the increase in volume, a decrease in the reaction yield is observed, due probably to the deactivation of the interaction between the reagents and the catalyst by the formation of a layer of solvent's molecules on the surface of the catalyst.

The catalytic activity is an important criterion to confirm the efficiency of the catalyst, nevertheless, its capacity to be reused for many times is also a basic factor especially for developing green chemistry. In order to examine the long durability of the used catalyst in the present work, the reaction was performed, the catalyst was recovered, washed with EtOH, stirred for 10 min, and then dried at 80 °C for the reuse. The results are represented in Figure 8.

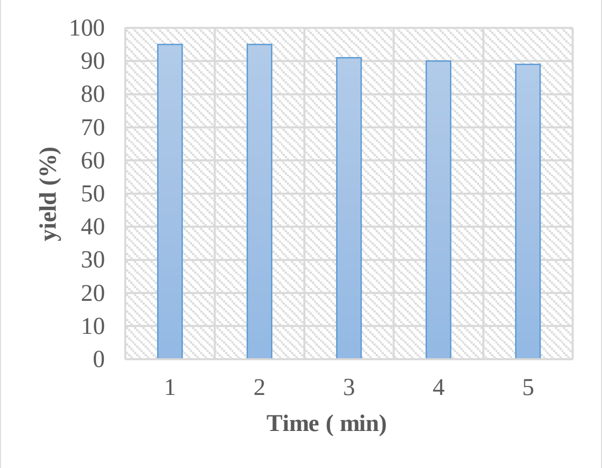
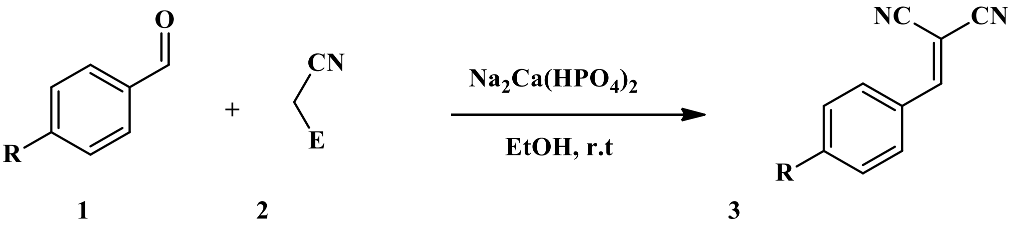


Figure 8. Recyclability of $Na_2Ca(HPO_4)_2$ catalyst.

Figure 8 shows that the yield remains almost unchanged, that let's conclude that $Na_2Ca(HPO_4)_2$ does not easily lose its catalytic activity even after 5 cycles of use.

Finally, we proceeded to the application of the optimized operating conditions in the Knoevenagel reaction (Scheme 2) in general framework. The yield obtained for each product prepared is given in Table 4.



R = Cl, H, NO_2, CH_3 ; E = CN, CO_2R

Scheme 2. Knoevenagel condensation between aromatic aldehyde and malononitrile or ethyl or methyl acetate.

Tableau 4. Generalization of the Knoevenagel reaction[a]

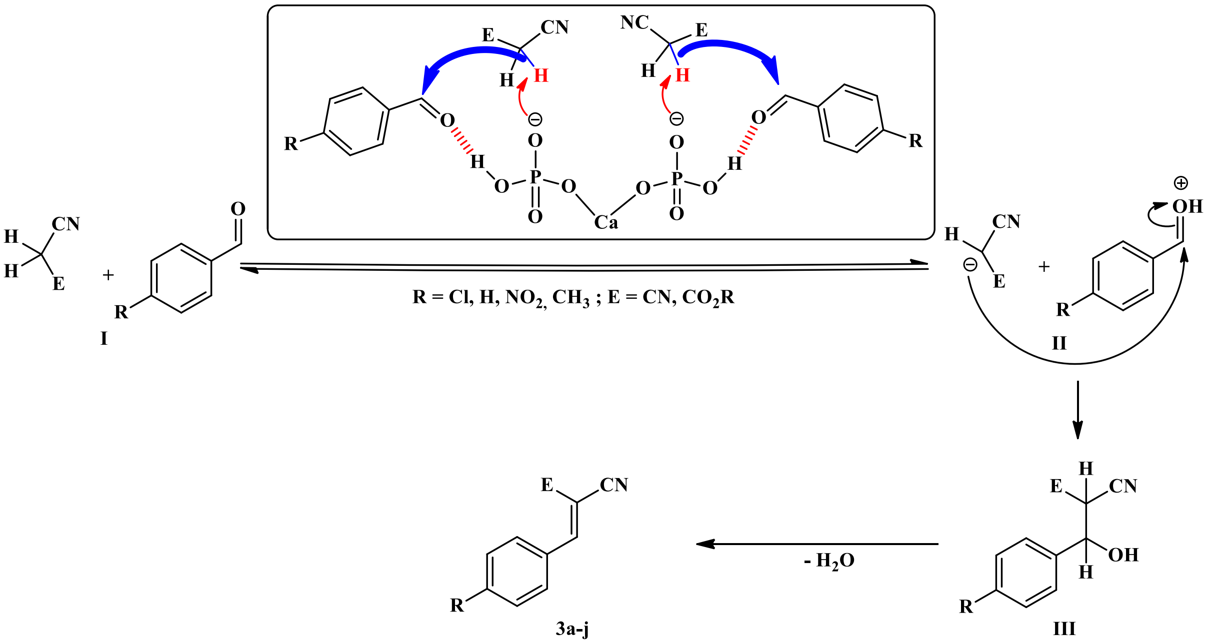
Entry	Product	R	E	Temps (min)	Yield[b] (%)	TON	TOF (h^{-1})
1	**3a**	Cl	CN	10	97	88.42	532.65
2	**3b**	H	CN	10	93	87.04	524.34
3	**3c**	NO_2	CN	10	87	81.02	488.07

4	**3d**	CH_3	CN	10	87	80.09	482.47
5	**3e**	Cl	CO_2Et	45	93	86.57	115.43
6	**3f**	H	CO_2Et	65	84	77.78	71.80
7	**3g**	NO_2	CO_2Et	40	82	76.00	114
8	**3h**	Cl	CO_2Me	30	99	91.66	183.32
9	**3i**	H	CO_2Me	60	82	76.00	76
10	**3j**	NO_2	CO_2Me	35	89	82.40	141.26

[a] Reaction conditions: malononitrile (3 mmol), aldehyde aromatic (2 mmol), EtOH (3 mL), 0.006 g of catalyst, r.t.
[b] Isolated yields.

From Table 4, one can notice that high yields are observed varying between 82-99% in short reaction time 10-65 min this result is valid regardless of the group nature "attractor or electron donor" of the aromatic aldehyde used. Concerning the values of the calculated TON and TOF, it is noted that the best results are obtained for the model reaction (condensation between chlobenzaldehyde and malononitrile), which are 88.42 and 535.65 h^{-1} respectively.

The proposed mechanism for the Knoevenagel reaction in the presence of $Na_2Ca(HPO_4)_2$, is presented in Scheme 3.



Scheme 3. Plausible catalytic mechanism for $Na_2Ca(HPO_4)_2$ of the Knoevenagel condensation

Firstly, deprotonation of the malononitrile group by $Na_2Ca(HPO_4)_2$ takes place, then the benzaldehyde carbonyl group forms a hydrogen bond with the catalyst to facilitate a nucleophilic attack on carbonyl compound **II** to obtain the intermediate **III**, followed by removal of a molecule of water for the formation of the desired products **3a-3j**. At this stage, a concerted mechanism via an interesting bi-catalytic action of $Na_2Ca(HPO_4)_2$ (see the complex intermediate in Scheme 3) cannot be reasonably excluded. In this context, the intermediate **III**, not isolated in the reaction media, can be obtained directly without the formation of ion pair **II**.

To confirm the effectiveness of this catalyst and to validate the catalytic process proposed for the Knoevenagel reaction, the comparison between the efficiency of $Na_2Ca(HPO_4)_2$ with other catalysts described in the literature is presented in Table 5.

Table 5. Comparison of the catalytic activity of $Na_2Ca(HPO_4)_2$ catalyst with other catalytic supports reported in the literature.

Entry	**Catalyst**	**Reaction condition**	**Time**	**Yield (%)**	**Ref**

1	$Na_2Ca(HPO_4)_2$	EtOH/r.t	10 min	97	This work
2	TSP	EtOH/r.t	60 min	97	[44]
3	Fe_3O_4@SiO_2	Toluene/ 75 °C	20 min	90	[56]
4	Fe_3O_4@DETA@GO	THF/ 50 °C	60 min	92	[57]
5	chitosan	EtOH/40 °C	6 h	85	[58]
6	MNP@PIL/W	H_2O/ r.t	3 h	81	[59]
7	Graphene oxide	solvent-free/r.t	3 h	96	[60]
8	Microporous graphitic carbon nitride	CH_3CN/90 °C	4 h	92.4	[61]

The method developed in this article is effective for the knoevenagel reaction in terms of yield, reaction time, temperature, solvent and non-toxic catalyst used compared with the other heterogeneous catalysts presented in the Table 5, leading to the desired product with long reaction times using.

Conclusion

The $Na_2Ca(HPO_4)_2$ catalyst was prepared by a modification of TSP by $NaNO_3$ and identified using microscopic and spectroscopic technics. Its application in the Knoevenagel reaction has demonstrated a remarkable catalytic activity under the optimal conditions (reaction time, catalyst amount, nature of the solvent and its volume used). The results show that excellent yields in short reaction times were observed for the formation of the products. The method reported in this article is characterized by simplicity of handling, ecological profile, good yields, short reaction times, as well as the use of a non-toxic, not expensive, and reusable catalyst.

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