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Article

Efficient and Selective Acetylation of Biomolecules with 1-Acetylimidazole Catalyzed by $Er(OTf)_3$.

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Abstract: It is of great significance to develop sustainable processes of catalytic reaction. We report an efficient and selective procedure for the synthesis of acetylated bioactive compounds in water. The use of 1-acetylimidazole combined with $Er(OTf)_3$ as Lewis acid catalyst gives high regioselectivity and good to excellent yields for the acetylation of primary hydroxyl groups as well as amino groups. The protection is achieved in short reaction times under microwave irradiation and is successful even in the case of base-sensitive substrates.

Keywords: Catalysis; Acetylation; Biomolecules.

1. Introduction

Protecting strategies are of critical importance in synthetic chemistry and represent important tools for industrial biotechnology. One of the most commonly used techniques for the protection of hydroxyl groups is acetylation. Regioselective acetylation is one of the strategies that chemists have tentatively developed, over the time, in order to maximize the different reactivity of the primary hydroxyl groups in polyols and carbohydrates to be used as constituents of many biologically active compounds [1]. Nevertheless, many of the proposed methods involve the use of non-environmentally friendly or expensive reagents, anhydrous environment and require the iterative blocking and de-blocking of all other potentially reactive OH groups functionalities in the molecule [2].

Earlier, carbonylimidazole derivatives have proven to be excellent acylating agents [3]. Imidazole carbamates and ureas have been successfully applied in the conversion of aliphatic and aromatic carboxylic acids into esters and amides in 70-93% yields [4]. In this endeavor, Sarpong et al. have reported the selective acylation of indoles and oxazolidinones by using several reactive *N*-acyl imidazoles and/or carbamates: the reaction shows a high selectivity at the nitrogen atom of the non-nucleophilic azacycles, even in the presence of other strong nucleophiles, such as amines or hydroxyl groups [5]. The reaction, conducted at room temperature in acetonitrile for about 24 hours, is catalyzed by 1,8-diazabicyclo [5.4.0] undec-5-ene (DBU) (20-50 mol%) [5]. Pei et al. reported a regioselective benzoylation of diols and carbohydrates using 1-benzoylimidazole and catalytic amounts of DBU in acetonitrile [6]. Nonetheless, most of these reactions were performed in conventional organic solvents because of poor water solubility of carbonylimidazole derivatives.

The use of toxic and hazardous solvents in laboratories and in the chemical industry is considered a major risk for the environment, human health and safety of workers. Green chemistry

is a chemical philosophy encouraging the use of products and processes that reduce or eliminate the use and generation of harmful substances of safer solvents. Various methods where organic synthesis can be performed without solvents, under mild conditions, and with low energy consumption have been developed. Conferences and symposia have promoted the use of alternative methods or "green" solvents, [7,8] and water is undoubtedly the best choice to conduct chemical processes in "safe solvents".

Only a few years ago, the use of water as solvent was considered a difficult journey because of the poor solubility of many organic compounds in aqueous solution. Nevertheless, in the last decade, the possible use of aqueous environments for the chemical synthesis has directed the studies towards the development of catalysts resistant to moisture. Moreover in recent times, microwave (MW) irradiation as an alternative source of heating has been proposed in many reactions performed in water such as Mannich reactions,]9,10] substitution reactions,[11,12] epoxides opening,[13,14] Diels-Alder cycloadditions,[15,16] heterocycle synthesis,[17,18] carbonylation reactions,[19-21] and carbon-carbon coupling reactions [22-24]. Microwave-assisted organic reaction offers several advantages over conventional heating including homogeneous and rapid heating, remarkable accelerations in reactions as a result of the heating rate producing high yields and lower quantities of side-products.

Recently, Pey et al. [25] reported the first example of acetylation of carbohydrates and diols in water using the water-soluble 1-acetylimidazole as an acetylating reagent. However, the acetylated products are afforded after 16 hours in moderate yields and in the presence of a strong base such as tetramethylammonium hydroxide.

Over the years, the use of mild Lewis acid catalysis has increased very quickly and $Er(OTf)_3$ has been proposed as excellent catalysts in many organic transformations. $Er(OTf)_3$ is easy to handle, recyclable and is one of the cheapest commercially available lanthanoid triflate derivatives.

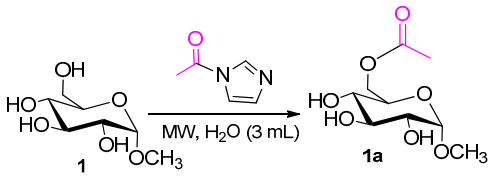
Considering the stability and catalytic activity of Erbium (III) in water that can be ascribed to their large ionic radii and an equilibrium between the Lewis acids and water [26] and taking into account our experience in developing eco-friendly reactions [27] and selective procedures for the protection of natural compounds, [28-34] we decided to test the reactivity of 1-acetylimidazole and the catalytic activity of $Er(OTf)_3$ in water for the selective acetylation of bioactive compounds.

We propose here a catalytic procedure based upon the use of $Er(OTf)_3$ that promotes a clean synthesis avoiding the formation of byproducts and making the process appropriate even in the case of base-sensitive substrates.

2. Results

According to our ability in Er(III) catalysis in mild, non-dry reaction conditions, both in homogeneous and in heterogeneous phase,[27] as well as our gained familiarity in MW/H_2O synthesis [35] and "on water" reactions,[36] we decided to test the potential use of MW in the regioselective acetylation reaction of alcohols and amino groups using 1-acetylimidazole as acetylating agent, and replacing the basic catalyst proposed by Pey et al [25] with an eco-friendly Lewis acid catalyst like $Er(OTf)_3$. Thus, preliminary experiments were carried out on the model reaction between methyl α-D-glucopyranoside (1 mmol) and 1-acetylimidazole (1.2 mmol) using water as the reaction solvent. Table 1 summarizes our preliminary results.

Table 1. Optimization of regioselective acetylation reaction of the model substrate of methyl α-D-glucopyranoside.



Entry	1-acetylimidazole	Er(OTf)$_3$ mol %	Time min	Yield%[b]
1	1.2	10	10	trace
2	1.2	10	20	5
3	1.2	10	30	26
4[c]	1.2	10	30	14
5	2.0	10	10	15
6	2.0	10	30	28
7	3.0	10	15	52
8	3.0	10	30	67
9	3.0	10	60	40
10	3.0	0	40	-
11	3.0	20	30	68
12	3.0	5	30	26
13	3.0	20	60	66

[a] General reaction conditions: 1 (0.8 g.), 1-acetylimidazole (3.0 equiv.) and Er(OTf)$_3$ (10 mol %) were dissolved in water (3 mL) and heated under MW-irradiation (60°C); [b] Isolated yield; [c] Conventional heating method with an oil bath using an internal temperature measurement (100 °C).

In the first instance, the reaction was performed using Er(OTf)$_3$ as catalysts and MW irradiation. The use of 1.2 mmol of 1-acetylimidazole in the presence of 10% mmol of Er(OTf)$_3$, provided the corresponding products in low yields even by increasing the reaction times (Table 1, entries 1-3). Most likely, the catalytic activity of Er(III) is enhanced by the MW effect in the aqueous system. The same reaction, in fact, conducted under conventional heating, led to the formation of the acetylated product in only 14 % yield (Table 1, entry 4).

Repetition of the reaction using a threefold molar excess of the acetylating agent and extending the time of the reaction, resulted in an increase in the yield (Table 1, entries 7-8). Prolonged reaction times (60 min.) caused lower isolated yield (Table1, entry 9) probably for a decomposition of the starting material. No conversion of the starting substrate was obtained in the absence of catalyst also after a protracted reaction time (Table 1, entry 10). Noteworthy, the use of an excess of catalyst did not affect the yield of the reaction (Table 1, entry 11), while reducing the amount of Er(III) resulted in poor reaction yields (Table 1, entry 12). The prolonged reaction time did not change the yield significantly (Table 1, entry 13). In any case, no by-product formation has been observed.

Thus, the optimized catalytic system (Table 1, entry 8) was chosen for the selective monoacetylation of a wide range of multifunctional natural compounds (Table 2) such as methyl D-pyranosides (Table 2, entries 1-6), phenyl D-pyranosides (Table 2, entries 7-8), nucleosides (Table 2, entries 9-12), phenolic antioxidant compounds (Table 2, entries 13-15) and aliphatic alcohols (Table 2, entries 16-19).

Table 2. Selective acetylation of biomolecules using 1-acetylimidazole in the presence of Er(OTf)$_3$ under MW irradiation.[a]

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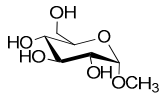
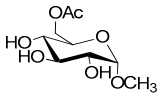
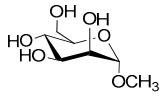
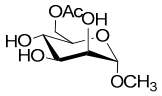
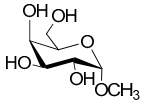
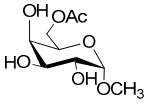
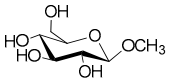
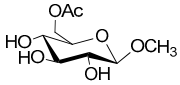
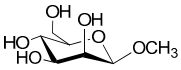
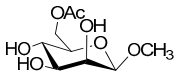
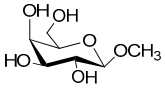
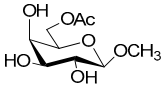
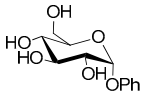
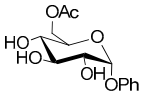
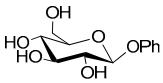
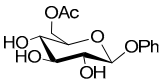
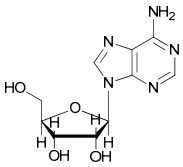
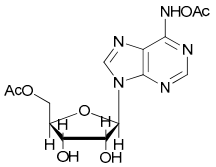
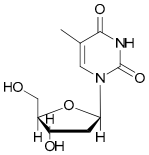
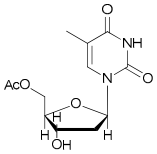
Entry	Substrate	Product	Yield(%)[b]
1	 **1**	 **1a**	67
2	 **2**	 **2a**	63
3	 **3**	 **3a**	64
4	 **4**	 **4a**	65
5	 **5**	 **5a**	62
6	 **6**	 **6a**	65
7	 **7**	 **7a**	60
8	 **8**	 **8a**	63
9	 **9**	 **9a**	67
10	 **10**	 **10a**	64

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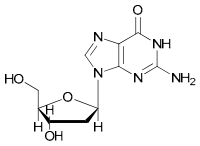
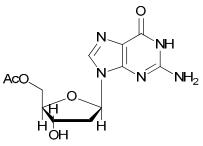
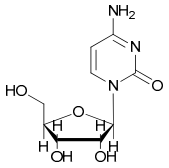
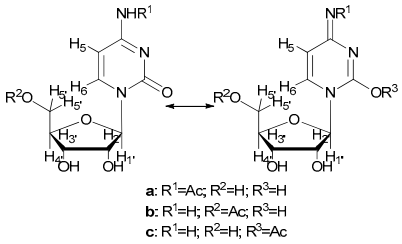
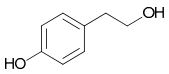
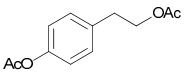
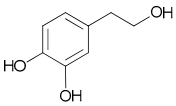
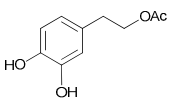
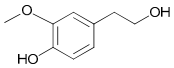
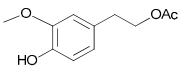
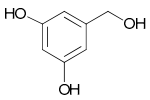
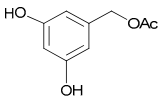
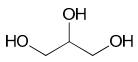
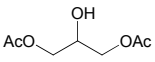
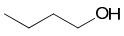
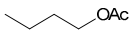
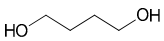
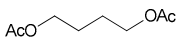
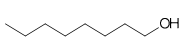
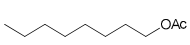
11	 **11**	 **11a**	50
12	 **12**	 **a**: R^1=Ac; R^2=H; R^3=H **b**: R^1=H; R^2=Ac; R^3=H **c**: R^1=H; R^2=H; R^3=Ac **(12a,b,c)**	60 a: 40 b: 15 c: 45
13	 **13**	 **13a**	59
14	 **14**	 **14a**	80
15	 **15**	 **15a**	80
16	 **16**	 **16a**	75
17d	 **17**	 **17a**	95
18	 **18**	 **18a**	65
19	 **19**	 **19a**	80
20[c]			95

	20	**20a**	
21			92
	21	**21a**	
22			93
	22	**22a**	

[a] General reaction conditions: 0.8 mmol of substrate, 2.3 mmol of *N*-acetylimidazole and 0.075 mmol of $Er(OTf)_3$ was dissolved in H_2O (3 mL). The reactions were conducted in a Syntos 3000 microwave oven (Anton-Paar) at 60°C for 30 min; [b] Isolated yield; [c] Reaction carried out 1 M NaCl; in the absence of NaCl no product formation is observed.

Increasing the steric hindrance of the substituents attached to the carbon atom 1, the reaction showed the same behavior as that of phenyl glucopyranoside (Table 2, entries 7 and 8). When the reagent system was used with substrates containing both primary and secondary hydroxyl groups as well as amino groups such as in the case of adenosine, the *N,O*-diacetylated derivative was obtained. (Table 2, entry 9). Instead, the acetylation reaction of deoxyguanosine **11** led to the formation of the 5′-*O*-acetyl derivative as the main product without any traces of the products acetylated on the secondary OH group and on the NH_2 function (Table 2, entry 11).

In the case of cytidine (12), the reaction deserves special attention; in fact, the presence of tautomerism in the molecule is responsible for the formation of the N-acetyl derivative as the main product (Table 2, entry 12). The ^{1}H NMR spectrum of the product resulting from the acetylation of cytidine showed the formation of three isomers indicated as *N*-acetylcytidine (A) in 40%, acetylcytidine (C) in 45% and 5'- *O*-acetylcytidine (B) in 15% yields respectively (Fig.1).

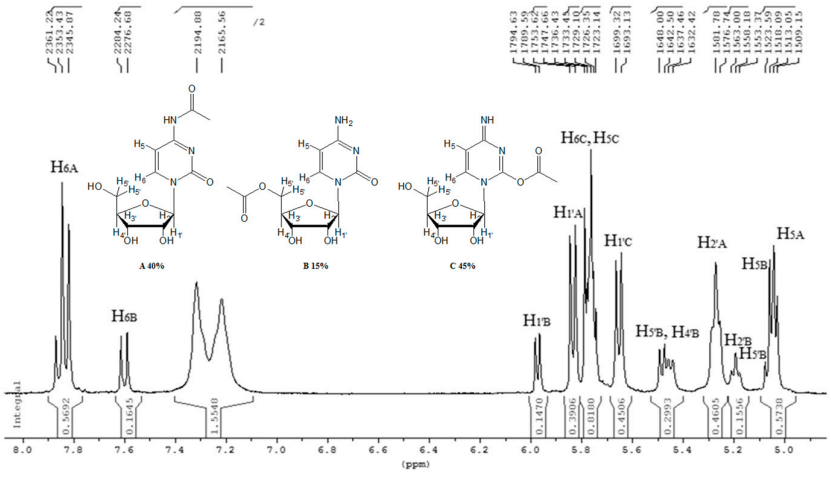


Figure 1. ^{1}H NMR spectrum of crude product obtained from cytidine acetylation.

It is well known that rare earth ions have high affinity for hard donor atoms like ligands containing oxygen or hybrid oxygen-nitrogen atoms; [37] various research reported the extraction of lanthanides with the amides and their coordination with carbonyl group for the synthesis of ternary 4f-element complexes. [38-40]

In addition, the formation of ligands obtained by bis-chelating mode of the pyrimidine carboxylate with lanthanides (III) is reported in crystallographic studies.[41] It can be supposed that the

coordination with the carbonyl group of the pyrimidine base, assisted by an iminol keto tautomerism of cytidine that shifts the equilibrium toward the iminol tautomer in acid condition and high temperature,[42] favours the formation of 2-O-acetyl-cytidine in 45% yield (Figure 2).

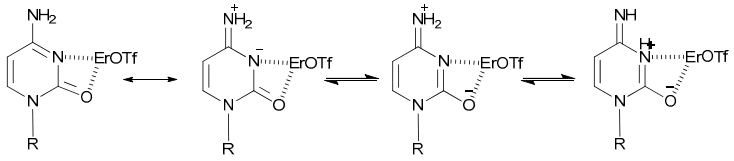


Figure 2. Diagram of tautomeric forms of cytosine-Er(III) coordinate.

Attempted acetylation reaction of phenolic compounds such as tyrosol and its derivatives was particularly interesting. The reaction carried out on tyrosol led to the formation of a diacetylated product (Table 2, entry 13). On the contrary, the acetylation reaction of ortho and meta hydroquinone derivatives occurred only on the aliphatic OH group, probably because the hydrogen-bonding to the adjacent groups hinders the acetylation reaction of the aromatic hydroxyl groups (Table 2, entries 14-16). When the method was extended to the protection of the primary hydroxyl group of glycerol, no formation of the primary acetylated product was observed. When the same reaction was carried out in 1 M aqueous NaCl, good regioselectivity and yield in the formation of glycerol 1,3- diacetate (**17a**) were obtained. Apparently, the presence of the salt prevents the formation of intramolecular H-bonds favouring the acetylation reaction.

Therefore, our study proposes a new regioselective method that offers good yields, shorter reaction times and a possible extension to various substrates. With this aim and to compare our procedure with Pei's method, [25] we applied our reaction conditions to base-sensitive substrates. The acetylation of amino groups is among the most widely used transformation in organic synthesis and frequently required during the peptide synthesis. We attempted the acetylation of a side-chain functionalized amino acid such as lysine protected on the α-amino group with the base labile [43] Fluorenylmethyloxycarbonyl (Fmoc) protecting group (Table 2, entry 22). We observed the formation of the corresponding side chain *N*-acetylated *N*-Fmoc lysine **22a** in high yields after only 10 minutes without affecting the Fmoc protecting group. The procedure works well also for the acetylation of the OH group in the side-chain of *N*-Fmoc serine (Table 2, entry 21). Performing the acetylation reaction on the same substrates using the Pei's method, the removal of the base labile *N*-Fmoc protecting group occurred along with the formation of traces of by-products. In fact, TLC analysis of the reaction mixture after 16 hours revealed the presence of dibenzofulvene and ninhydrin assay confirmed the formation of the free α–amino group.

3. Materials and Methods

3.1. General Methods

All chemicals and solvents were purchased from common commercial sources and were used as received without any further purification. All reactions were monitored by TLC on silica Merck 60 F_{254} pre-coated aluminum plates and were developed by spraying with sulfuric acid in ethanol solution when possible. The tautomeric forms of acetyl cytosine was purified by semipreparative RP-HPLC chromatography [Phenomenex Jupter C18, 250 × 10 mm, 10 μm, UV 272 nm, 4.0 mL/min, (H2O 100%). Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded on a Brüker spectrometer at 300 MHz. Chemical shifts are reported in δ units (ppm) with TMS as reference (δ 0.00). All coupling constants (J) are reported in Hertz. Multiplicity is indicated by one or more of the

following: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet). Carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded on a Brüker at 75 MHz. Chemical shifts are reported in δ units (ppm) relative to $CDCl_3$ (δ 77.0).

MW-assisted reactions were performed on a Synthos 3000 instrument from Anton Paar, equipped with a 4×24MG5 Rotor and an IR probe used for external temperature control.

3.2. General Experimental Procedure for Microwave-Assisted Acetylation.

The substrate (0.8 mmol) of was dissolved in 3 mL water in a glass vial. 1-Acetylimidazole (2.4 mmol) and $Er(OTf)_3$ (10 mol %) were then added to the solution. The mixture was reacted for 30 min in a Synthos 3000 microwave instrument, fixed on the temperature value of 60 °C (IR Limit). TLC analysis was used to monitor the progress of the reaction. After reaction completion, water was removed under reduced pressure and the resulting crude product was purified by flash chromatography (CH_2Cl_2/MeOH 9.5:0.5).

- *Methyl 6-O-acetyl α-D-glucopyranoside* (**1a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [45]
- *Methyl 6-O-acetyl α-D-mannopyranoside* (**2a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [46]
- *Methyl 6-O-acetyl α-D-galattopyranoside* (**3a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [47]
- *Methyl 6-O-acetyl α-D-glucopyranoside* (**4a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [47]
- *Methyl 6-O-acetyl α-D-mannopyranoside* (**5a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [46]
- *Methyl 6-O-acetyl α-D-galattopyranoside* (**6a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [48]
- *Phenyl 6-O-acetyl α-D-glucopyranoside* (**7a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [49]
- *Phenyl 6-O-acetyl α-D-glucopyranoside* (**8a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [49]
- *N-acetyl-5′-O-acetyl adenosine* (**9a**): ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.02 (s, 3H, CH_3COO), 2.18 (s, 3H, CH_3CON), 3.85 (d, 1H, H5′, J=13.15), 3.98 (d, 1H, H5′, J_{gem}=13.15 Hz), 4.37 (s, 1H, H3′), 5.69 (s, 1H, H2′), 6.01-6.03 (m, 4H, H4′, H1′ 2OH), 7.84 (s, 1H, H8), 8.34 (s, 1H, H2). ^{13}C NMR ($CDCl_3$, 75.5 MHz).
- *5′-O-acetyl thymidine* (**10a**): ^{1}H NMR (DMSO, 300 MHz): δ 1.93 (s, 3H, CH_3), 2.09 (s, 1H, H2′), 2.13 (s, 3H, CH_3COO), 2.18 (s, 1H, H2′), 2.46-2.44 (br, 1H, OH), 4.19 (t, 1H, H3′, *J*= 3.40 Hz), 4.27 (t, 1H, H4′, *J*= 3.29 Hz), 4.30 (dd, H5′, *J*=11.84 Hz, *J*=3.29 Hz), 4.36-4.40 (m, 1H, H5′), 3.98 (d, 1H, H5′, J_{gem}=13.15 Hz), 6.30 (t, 1H, H1′, J= 6.47 Hz), 7.32 (s, 1H, H6), 9.78 (s, 1H, NH). 13C NMR (DMSO, 75.5 MHz): 19.8, 21.5, 40.6, 63.9, 69.3, 82.6, 84.8, 109.7, 150.4, 163.8, 170.5.
- *5′-O-acetyl-2′-deoxyguanosine* (**11a**): ^{1}H NMR (DMSO, 300 MHz): δ 1.90 (s, 3H, CH_3CON), 2.19 (s, 3H, CH_3COO), 2.30 (m, 1H, H2′), 2.52 (m, 1H, H2′), 3.58-3.60 (m br, 2H, H3′ OH), 4.08 (dd, 1H, H5′, Jgem= 13.17 Hz, *J*=3.31 Hz), 4.33 (dd, 1H, H′, Jgem=13.17 Hz, *J*=3.31 Hz), 4.89 (t, 1H, H4′, *J*=3.31 Hz), 5.95 (t, 1H, H1′, *J*= 6.50 Hz), 7.96 (s, 1H, H8). ^{13}C NMR (DMSO, 75.5 MHz): 20.8, 40.2, 61.5, 75.0, 82.6, 84.9, 116.7, 135.1, 150.9, 153.9, 156.7, 169.9, 165.5.
- *2′-deoxy-3′,5′-di-O-acetylguanosine* (**11b**): ^{1}H NMR (DMSO, 300 MHz): δ 2.03 (s, 3H, CH_3COO), 2.08 (s, 3H, CH_3COO), 2.41 (1H, ddd, ^2J = 14.26 Hz, $^3J_1$ = 5.47 Hz, $^3J_2$ = 2.1 Hz, H-2b′) (m, 1H, H2′), 2.92 (1H, ddd, ^2J = 14.27 Hz, ^{3} J_1 = 8.7 Hz, $^3J_2$ = 6.4 Hz, H-2a′), 4.15-4.30 (m, 3H, H5′, H3′), 5.28 (d, 1H, H4′, *J*=6.83), 6.08-6.15 (m, 1H, H1′), 6.52 (2H, s, NH_2), 7.92 (1H, s, H8), 10.68 (1H, s, NH, ^{13}C NMR (DMSO, 75.5 MHz): 20.4, 20.7, 35.4, 63.6, 74.4, 81.4, 82.9, 116.7, 151.0, 153.7, 156.9, 169.9, 170.1.45
- *N-acetyl-cytidine* (**12a**), *5′-O-acetyl-cytidine* (**12b**), *6-O-acetyl-cytidine* (**12c**): ^{1}H NMR (DMSO, 300 MHz): δ 2.05 (s, 3H, CH_3A), 2.08 (s, 6H, CH_3B + CH_3C), 3.51-3.71 (m, 6H, H5′A, H5′C, H3′C, , H2′C), 3.82-4.01 (m, 3H, , H5′A, H5′C¸H4′A), 4.11-4.29 (m, 4H, H3′A, H4′A, H4′C, H3′B), 5.03-5.07 (m, 3H, H5A, H5B, H5′B), 5.19 (t, 1H, H2′B, *J*= 4.81 Hz), 5.27 (t, 1H, H2′A, *J*= 5.04 Hz), 5.45 (d, H4′B, *J*=5.04 Hz), 5.48 (d, 1H, H5′B), 5.65 (d, 1H, H1′C, *J* = 6.19 Hz), 5.76 (m, 2H, H6C,H5C), 5.83 (d, 1H, H1′A, *J* =5.96), 5.97 (d, 1H, H1′B), 7.60 (d, 1H, H6B, *J*=7.56 Hz), 7.83 (d, 1H, H6A, *J*=7.56

Hz). ^{13}C NMR (DMSO, 75.5 MHz): 60.5, 60.7, 68.1, 69.6, 71.8, 72.4, 73.2, 75.3, 79.1, 80.4, 81.9, 84.7, 86.7, 88.7, 90.0, 94.2, 94.3, 94.4, 141.3, 155.2, 155.4, 155.4, 165.5, 165.5, 169.6, 169.7, 178.3.

- *4-[2-(Acetyloxy)ethyl]phenyl acetate* (**13a**): ^{1}H NMR (DMSO, 300 MHz): δ 1.98 (s, 3H, CH_3), 2.25 (s, 3H, CH_3), 2.88 (t, 2H, CH_2, *J*= 7.50 Hz), 4.20 (t, 2H, CH_2, *J*= 7.11 Hz), 7.05 (d, 2H, Har, *J*= 8.49 Hz), 7.28 (d, 2H, Har, *J*= 8.46 Hz), ^{13}C NMR (DMSO, 75.5 MHz): Spectroscopic data compared to those reported in the literature.[50]
- *3,4-dihydroxyphenethyl acetate* (**14a**): ^{1}H NMR (DMSO, 300 MHz): δ 1.97 (s, 3H, CH_3), 2.68 (t, 2H, CH_2, *J*= 6.87 Hz), 4.10 (t, 2H, CH_2, *J*= 7.11 Hz), 6.45-6.48 (m, 1H, Har), 6.48-6.62 (m, 2H, Har). ^{13}C NMR (DMSO, 75.5 MHz): 19.9, 33.8, 64.8, 114.5, 116.6, 128.6, 133.9, 143.8, 145.2, 170.4.
- *4-hydroxy-3-methoxyphenethyl acetate* (**15a**): ^{1}H NMR (DMSO, 300 MHz): δ 1.99 (s, 3H, CH_3), 2.25 (s, 3H, CH_3), 2.85 (t, 2H, CH_2, *J* = 7.50 Hz), 3.73 (s, 3H, CH_3), 4.33 (t, 2H, CH_2, *J* = 7.11 Hz), 7.03 (d, 2H, Har, *J* = 8.43 Hz), 7.25 (d, 2H, Har, *J* = 8.43 Hz). ^{13}C NMR (DMSO, 75.5 MHz): 20.0, 35.1, 56.2, 64.9, 121.5, 121.1, 133.1, 142.9, 151.1, 170.0.
- *Acetyl-3,5-Dihydroxybenzyl alcohol* (**16a**): ^{1}H NMR (DMSO, 300 MHz): 2.05 (s, 3H, CH_3), 4.88 (s, 2H, CH_2), 6.14-6.18 (m, 3H, Har). ^{13}C NMR (DMSO, 75.5 MHz): 20.6, 35.1, 64.8, 121.5, 128.3, 134.1, 143.2, 169.1, 170.0. ^{13}C NMR (DMSO, 75.5 MHz): 20.6, 65.3, 101.9, 105.6, 105.6, 137.9, 158.3, 170.0.
- *Glycerol 1,3 diacetate* (**17a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). Spectroscopic data compared to those reported in the literature. [51]
- *n-Butyl acetate* (**18a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). [52]
- 1, 4-Butanediol, diacetate (**19a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). Spectroscopic data compared to those of the pure product. GC-MS (EI): 114.0 (11), 73.0 (20), 71.0 (30), 54.0 (45), 43.0 (100). [53]
- *n-Octyl acetate* (**20a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). Spectroscopic data compared to those of the pure product. GC-MS (EI): 112.0 (10), 84.0 (30), 70.0 (36), 56.0 (30), 43.0 (100).[53]
- *Fmoc-Ser(Ac)-OH* (**21a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). Spectroscopic data compared to those of the pure product.
- *Fmoc-Lys(Ac)-OH* (**22a**): ^{1}H and ^{13}C NMR ($CDCl_3$, 300 MHz, and 75.5 MHz). Spectroscopic data compared to those of the pure product.

4. Conclusions

An effective procedure for the acetylation of various natural compounds has been developed. The reaction showed high selectivity for the acetylation of the primary hydroxyl groups in carbohydrates and diols; in the case of nucleosides, the acetylation reaction led to the formation of 5'-*O*-acetyl derivative.

The procedure, unlike most other acylation methods reported in the literature, allows the use of water as the solvent, thus avoiding the use of organic solvents. Moreover, other advantages of this method are the use of a catalytic amount of $Er(OTf)_3$, short reaction time and high regioselectivity. The catalyst is inexpensive and can be easily and consistently recovered [44]. It was reused for two consecutive cycles without any significant loss in catalytic activity in the synthesis of **1a** (56 and 45%) with negligible release into the environment.

The use of Lewis acid catalysis is a valuable method with respect to the previously reported procedure: [25] the reaction yields are increased, the reaction times are very short and the acylating agent is activated allowing a greater selectivity in the acylation process thus avoiding the formation of by-products. Furthermore, the reagent system is also applicable to base-labile substrates such as *N*-Fmoc amino acids with the formation of the desired side-chain acetylated products without the removal of the α-amino protecting group. Thus, our reaction conditions can be considered orthogonal to the basic conditions reported by Pey et al. [25]

Supplementary Materials: The following are available online, NMR spectra for all new products.

Author Contributions: M.N. and A.P. conceived and designed the experiments; F.O. and P.C. performed the experiments; A.D.N. and L.M. analyzed the data; M.O. contributed reagents/materials/analysis tools; M.N. and M.L.D.G. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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