Tetrahedron Letters 70 (2021) 153017

Contents lists available at ScienceDirect

Tetrahedron Letters

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

# NaI-mediated oxidative amidation of benzyl alcohols/aromatic aldehydes to benzamides via electrochemical reaction

Tanawat Rerkrachaneekorn [a], Theeranon Tankam [a], Mongkol Sukwattanasinitt [a], Sumrit Wacharasindhu [a,b,*]

[a] Nanotec-CU Center of Excellence on Food and Agriculture, Department of Chemistry, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
[b] Green Chemistry for Fine Chemical Productions STAR, Department of Chemistry, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

ARTICLE INFO

*Article history:*
Received 4 February 2021
Revised 14 March 2021
Accepted 18 March 2021
Available online 23 March 2021

*Keywords:*
Amide
Electroorganic synthesis
Mediator
Oxidative amidation
Undivided cell

ABSTRACT

In this research, we have developed a mild electrochemical process for oxidative amidation of benzyl alcohols/aromatic aldehydes with cyclic amines into the corresponding benzamides. This electroorganic synthetic method proceeds using NaI as a redox mediator under ambient temperature in undivided cell, providing more than 25 examples of amide products in moderate to good yields. The benefits of this reaction include one-pot synthesis, open air condition, proceed in aqueous media and no requirement of external conducting salt, base and oxidant.

## Introduction

The amide bond is not only a backbone of protein but it prevalent in natural products, polymers, materials and pharmaceuticals. Classical preparation of amide involves the coupling reaction between amines and carboxylic acids which required high temperature under acidic condition [1]. Nowadays, therefore, activated carboxylic acid derivatives [2] or peptide coupling agents [3] to facilitate the coupling between amines and carboxylic acids are commonly used due to their mild reaction condition. However, the use of those reagents and conversion of acids into its derivatives cause the generation of hazardous waste/byproduct and also require stoichiometric amount of reagent leading to poor atom economy process. To overcome these problems, non-classical methods for amide synthesis have been developed [4]. For examples, catalytic amidations of carboxylic acids using organoborans [5,6] and transition-metals [7,8] have been demonstrated. Moreover, the use of carboxylic acid surrogates to prepare amides has been employed in many transformations such as aminocarbonylations (alkenes [9] and alkynes [10]), dethioamidations (thioacids [11]) and oxidative amidations (aryl halides [12], nitriles [13], aldoximes [14], ketones [15], alcohols and aldehydes). Of the above methods, the oxidative amidations of alcohols/aldehydes with amines have been extensively investigated due to their wide availability, inexpensiveness and use of less toxic starting materials. The advancements of oxidative amidation in amide preparation from alcohols/aldehydes and amines were summarized in Scheme 1. The process required the use of transition-metals as oxidants such as Ag [16], Au [17,18], Cu [19,20], Fe [21,22], Ln [23], Mn [24], Ni [25], Pd [26,27], Rh [28,29], Ru [30] and Zn [31] or non-metal oxidizing agents such as *N*-heterocyclic carbenes [32], hypervalent iodines [33–35] and peroxide species [36–41]. Recently, the use of photoredox catalysts mediated by visible light using metal complexes or organic dyes has been reported [42,43]. Although, those reaction are efficient and compatible with many functional groups, some processes still face one or more drawbacks such as long reaction time, high temperature, inert condition, the use of expensive metal/catalyst, and toxic oxidizing reagent. Therefore, the development of environmentally benign and mild oxidative amidation still remains a challenge.

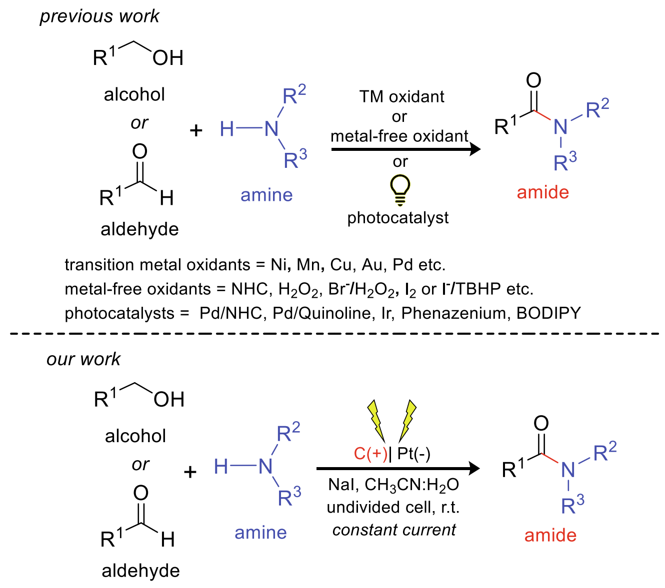
Nowadays, electroorganic synthesis has attracted the interest of synthetic chemists due to its environmentally friendly behavior as it can replace the use of hazardous oxidants by electric current, or “clean” electrons [44–46]. With this benefit, this method has been applied in many organic transformations especially in oxidation replacing typical use of hazardous oxidizing agents [47–51]. In previously reported electrosynthesis processes, the use of iodine as redox mediators was founded to be very useful as it can decrease redox potential and increase selectivity [52–59]. Based on the pre-

---

* Corresponding author at: Nanotec-CU Center of Excellence on Food and Agriculture, Department of Chemistry, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand.

*E-mail address:* sumrit.w@chula.ac.th (S. Wacharasindhu).

https://doi.org/10.1016/j.tetlet.2021.153017



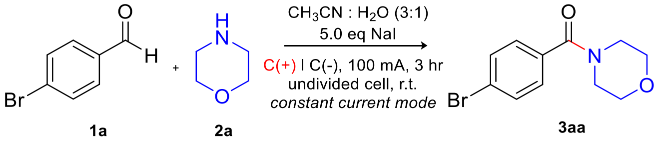
**Scheme 1.** Oxidative amidation for preparation of amides from alcohols/aldehydes and amines.

vious works on oxidative amidation of alcohols/aldehydes with amines mediated by iodine [36,37] or iodide [39,40] along with peroxide reagents in stoichiometric amount, in this work, we would like to apply NaI as sole redox mediator in electrooxidative amidation process [59–61]. The methodology offers several benefits such as 1) a simple reaction set up in undivided electro-cell under ambient temperature and open air 2) use of inexpensive and non-hazardous NaI as electrolyte/mediator and most importantly 3) no requirement of additional base and oxidizing agent.

## Results and discussion

To investigate electrochemical NaI-promoted amidation, we selected 4-bromobenzaldehyde (**1a**) and morpholine (**2a**) as a model substrate for the optimization study. The results were summarized in Table 1 and Table S1. The first reaction was carried out using 5.0 equivalents of NaI in mixed solvent of $CH_3CN$:$H_2O$ with graphite rods as both anode and cathode at constant current (100 mA) for 3 h under room temperature. The corresponding amide **3aa** were isolated in 67% (table 1, entry 1). Changing redox mediator into LiI gave **3aa** in a comparable yield while in case of KI provided a lower yield (Table 1, entries 2 and 3). Switching to $NH_4I$ and TBAI (Table S1, entries 1 and 2), we isolated target amide in much lower yield suggesting that cationic metals play a crucial role as electrolyte for balancing charge in the reaction. When $TBABF_4$ was used instead of NaI, the reaction did not proceed and mostly starting material aldehyde **1a** remained intact (Table 1, entry 4). This result suggested that iodide was required as a mediator and reaction may proceed in indirect electrolysis fashion. Based on above results, we selected NaI for further optimization study because of its low cost and toxicity. Next, various aqueous solvent systems were screened (Table 1, entries 5, 6 and 7 and Table S1, entries 4 and 5). Among them, mixed solvent of $CH_3CN/H_2O$ (3:1) proved to be the best choice and was selected for further study. In the neat $CH_3CN$, the product **3aa** were also obtained in good yield (70%), however, the voltage was also increased significantly from ca. 7 to 14 V under this reaction condition (Table S1, entry 6). This result suggested the high resistance from the reaction media was developed and water is required to maintain voltage at low level for the safeness. Next, we investigated the effect of electrode and current, when Pt plate was tested as both electrodes, the yield of **3aa** significantly dropped to 23% (Table 1, entry 8). Surprisingly, the use of Pt plate as anode while remain graphite rod at cathode resulted in much better yield and amide **3aa** were isolated at 83% yield (Table 1, entry 9). Reducing the current from 100 mA to 80 mA resulted in lower yield (Table 1, entry 10) and we observed unreacted starting material. Increasing the current to 150 mA provided similar yield (Table 1, entry 11) suggesting that the product is highly stable under this electrolysis condition. In order to lower the number of excess reagents in our electrochemical amidation, we then reduced the amount of NaI to 2.5 equivalent. The product **3aa** were delivered in similar yield as in case of 5.0 equivalent of NaI (Table 1, entry 12). Therefore, we select this condition as our optimized condition (Table 1, entry 12). We would like to note that the attempt to lower the amount of amine nucle-

**Table 1**
Optimization of electrochemical amidation for aldehyde.[a]



| Entry | Deviation from the above condition | Yield(%)[b] |
|---|---|---|
| 1 | None | 67 |
| 2 | LiI instead of NaI | 70 |
| 3 | KI instead of NaI | 42 |
| 4 | $TBABF_4$ instead of NaI | N.R [c] |
| 5 | DMSO:$H_2O$ (3:1) instead of $CH_3CN$:$H_2O$ (3:1) | 50 |
| 6 | THF:$H_2O$ (3:1) instead of $CH_3CN$:$H_2O$ (3:1) | 40 |
| 7 | EtOH:$H_2O$ (3:1) instead of $CH_3CN$:$H_2O$ (3:1) | 33 |
| 8 | Pt(+) Pt(-) instead of C(+) C(-) | 23 |
| 9 | C(+) Pt(-) instead of C(+) C(-) | 83 |
| 10 | C(+) Pt(-), 80 mA | 58 |
| 11 | C(+) Pt(-), 150 mA | 79 |
| 12 | C(+) Pt(-) and 2.5 eq NaI instead of 5.0 eq NaI | 78 |

[a] Unless otherwise noted, the reaction conditions were as followed: 4-bromobenzaldehyde (1.0 eq, 0.30 mmol), morpholine (5.0 eq, 1.50 mmol), NaI (2.5 eq, 0.75 mmol), $CH_3CN$:$H_2O$ (3 mL:1 mL), graphite rod ($\phi$ = 5 mm, immersed 1.0 cm) as anode, platinum plate (5x5x0.1 mm) as cathode, 100 mA, 3 h at room temperature, undivided cell.
[b] Isolated yield.
[c] No reaction.

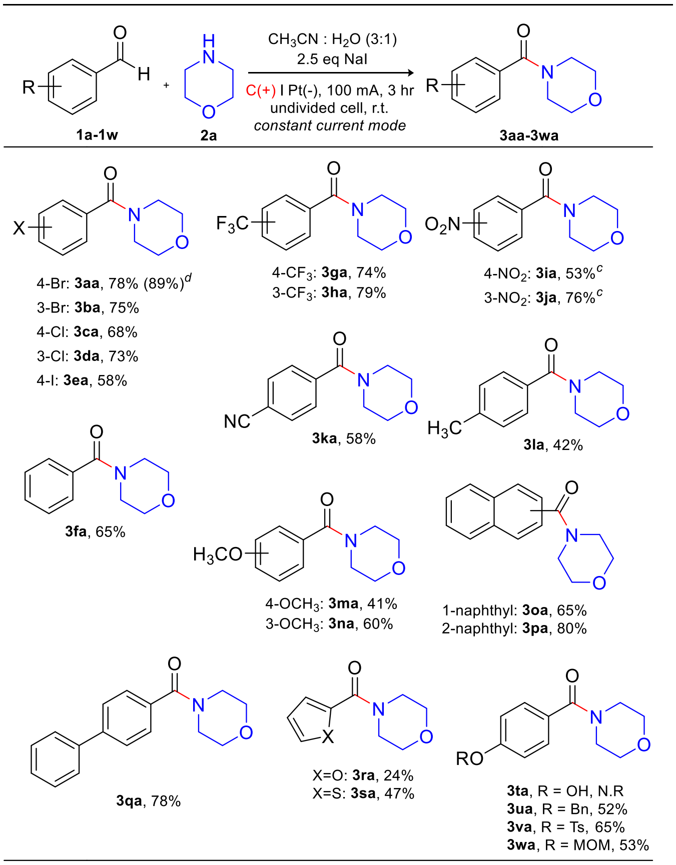
ophile from 5.0 to 3.0 equivalents giving unsatisfactory yield even though the reaction temperature were raised form room temperature to 45 °C (Table S1, entries 9 and 10). This result suggested that the addition step where amine react with aldehyde to generate the corresponding hemiaminal could be a rate determining step, which we will elaborate in more detail later.

With the optimized condition in hands, we then expand the scope of this electrochemical NaI-mediated oxidative amidation to other aldehydes. Aromatic aldehydes (**1a-1w**) were subjected to the optimized condition (Table 1, entry 12) and amide derivatives (**3aa-3wa**) were obtained in fair to excellent yields in general as demonstrated in Table 2. Notably, a decrease in the yield of aromatic aldehydes carrying electron donating group such as 4-methoxy group (**1m**) is a foreseeable result because electronic effect discourages the addition of amine. In case of 4-hydroxybenzaldehyde (**1t**), decomposition was observed as phenol group was perhaps oxidized under the reaction condition. However, once the protecting groups such as benzyl, tosyl and MOM group (**1u-1w**) were applied, corresponding amides (**3ua-3wa**) were isolated in good yields (52–65%) suggesting those functional groups are compatible and tolerated under our condition. We also would like to note here that this electooxidative amidation reaction can be performed in gram-scale synthesis. 1.0 g of **1a** was subjected to the optimized condition (see the Fig. S2 for reaction set up) and carried for 24 h. Target amide **3aa** were obtained in 89% yield.

To expand the scope of this electrochemical amidation, a panel of secondary amines were tested with 4-bromobenzaldehyde (**1a**) under the optimized condition (Table 3). Cyclic amines (**2b**, **2c** and **2e**) reacted smoothly with 4-bromobenzaldehyde (**1a**) to form the corresponding amides **3ab**, **3ac** and **3ae** in good yields. Thiomorpholine (**2d**), on the other hand, gave low yield of amide product **3ad** which probably caused by the over oxidation of sulfur atom under reaction condition. Amines carrying base sensitive group such as ester (**2f**) and Boc protecting group (**2g**) were tolerated under our electrochemical condition and generated amides **3af** and **3ag** in moderate to excellent yields. Unfortunately, acyclic amine such as **2h** and primary amine such as **2i** did not undergo electrooxidative amidation to **3ah** and **3ai** and only starting material aldehyde were remained in the reaction. This result is governed by the poor nucleophilicity of amine prohibiting the formation of hemiaminal in the amination step.

To simplify the operation of our electrochemical amidation, we replaced the use of complicated power supply as electrochemical power source into inexpensive portable power charger as demonstrated in Scheme 2. The electrochemical amidation between 4-

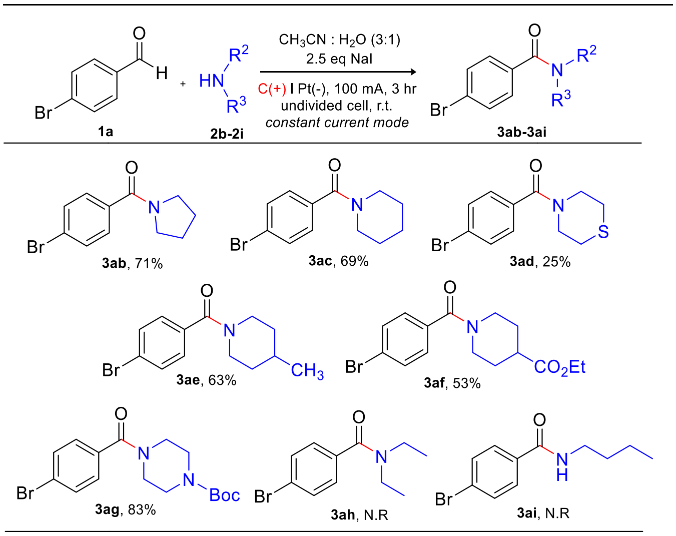
**Table 2**
Scope of aromatic aldehydes.[a,b]



---

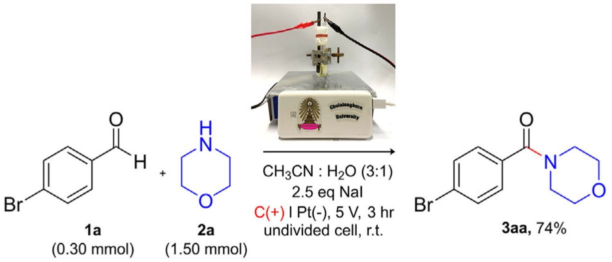
[a] Unless otherwise noted, the reaction conditions were as followed: aromatic aldehydes (1.0 eq, 0.30 mmol), morpholine (5.0 eq, 1.50 mmol), NaI (2.5 eq, 0.75 mmol), CH$_3$CN:H$_2$O (3 mL:1 mL), graphite rod (ϕ = 5 mm, immersed 1.0 cm) as anode, platinum plate (5x5x0.1 mm) as cathode, 100 mA, 3 h at room temperature, undivided cell.
[b] Isolated yield.
[c] NaI (5.0 eq, 1.50 mmol).
[d] gram-scale synthesis.

**Table 3**
Scope of secondary amines.[a,b]



---

[a] Unless otherwise noted, the reaction conditions were as followed: 4-bromobenzaldehyde (1.0 eq, 0.30 mmol), secondary amines (5.0 eq, 1.50 mmol), NaI (2.5 eq, 0.75 mmol), CH$_3$CN:H$_2$O (3 mL:1 mL), graphite rod (ϕ = 5 mm, immersed 1.0 cm) as anode, platinum plate (5x5x0.1 mm) as cathode, 100 mA, 3 h at room temperature, undivided cell.
[b] Isolated yield.

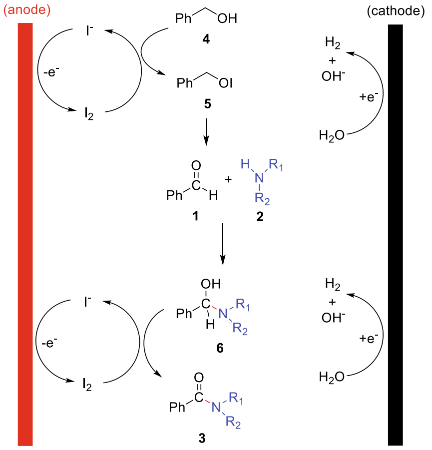


**Scheme 2.** Using portable power charger for electrochemical reaction.

bromobenzaldehyde (**1a**) and morpholine (**2a**) was demonstrated using standard portable USB type power charger having 10,000 mAh capacity and 5 V for 3 h under the optimized condition. We are obtained the amide product **3aa** in 74%. This reaction is proven that it can perform using commonly portable power charger for smart phone which will be a very useful set up for academic teaching laboratory.

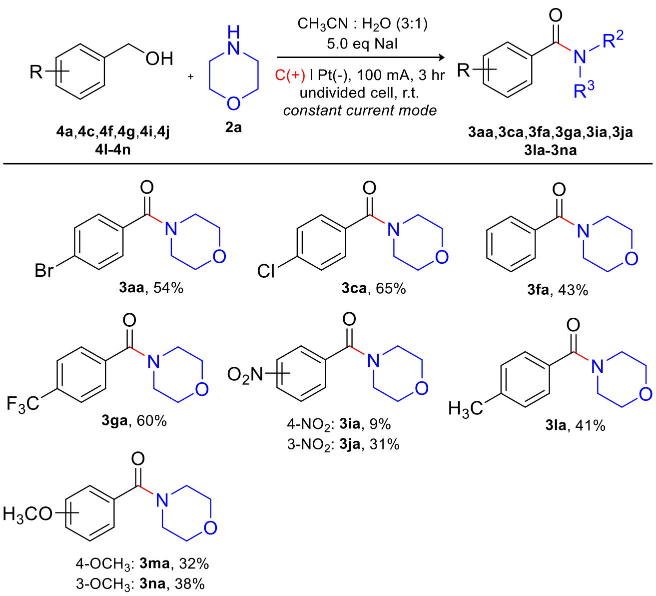
We further expanded the applicability of our electrochemical amidation to benzyl alcohol derivatives. The advantages of using benzyl alcohols as a starting material include its chemical availability, and better stability comparing to corresponding aromatic aldehydes which are prone to oxidation. We performed NaI-mediated electrochemical amidation directly from various benzyl alcohols and morpholine (**2a**) as seen Table 4. In general, benzyl alcohols carrying electron withdrawing groups such as bromo (**4a**), chloro (**4c**) and trifluoromethyl (**4 g**) provided corresponding amides in higher yields (54–65% yield) than benzyl alcohols carrying electron donating groups such as methyl (**4l**, 41% yield) and methoxy (**4m**, 32% yield and **4n**, 38% yield). This trend was also observed in oxidative amidation from aldehydes in previous section. This similar trend could be caused by slow addition of amines to the corresponding aldehyde intermediates. Interestingly, in case of strong electron withdrawing group such as nitro (**4i** and **4j**), the amide products were generated only in 9% and 31% yields, respectively. We hypothesized that the oxidation of such benzyl alcohols into the corresponding aldehydes were relative sluggish due to the electronic effect from the nitro substituent on the starting materials. This will be elaborated in the proposed mechanism.

The mechanism underlying the electrochemical amidation of benzyl alcohols or aldehydes with amines was proposed as shown in Scheme 3. It involves three main steps: 1) the oxidation of benzyl alcohols **4** to aldehydes **1** with iodine via the formation of intermediate **5** followed by the elimination of iodide [62] 2) addition of amines **2** to aldehydes **1** to form hemiaminals **6** 3) oxidation of hemiaminals **6** to amides. To shed the light on this electrooxidation mechanism, control experiments were performed as seen in Scheme 4. Reacting **4a** or **1a** in the absence of electricity provided no products, confirming that the reaction is indeed mediated by electricity (Scheme 4, eq. 1–2). In the proposed mechanism, we hypothesized that hemiaminals **6** were generated in the reaction. Therefore, we simply mixed 4-cyanobenzaldehyde (**1k**) and mor-



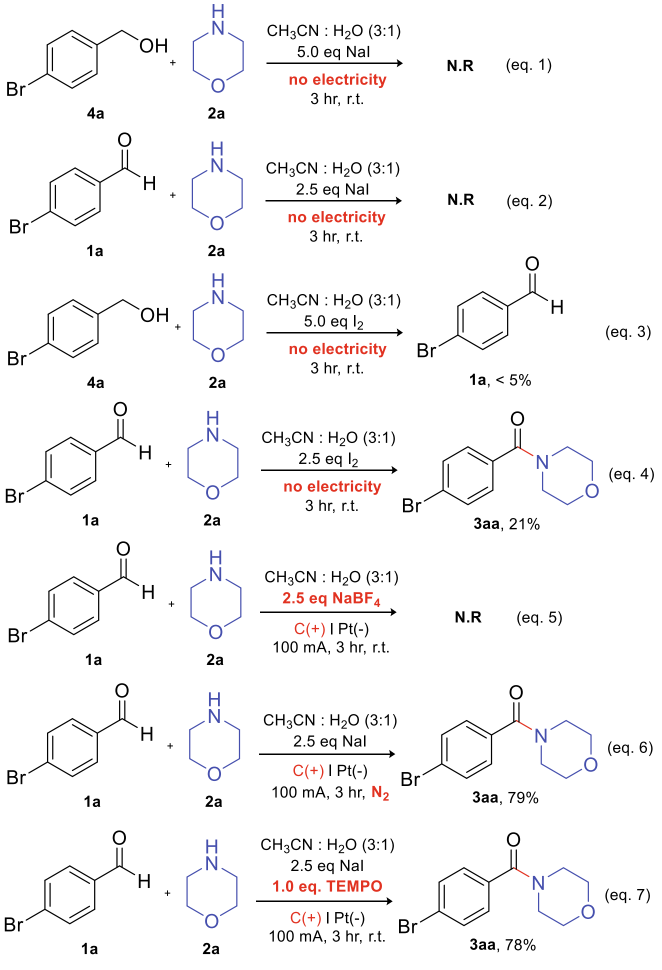
**Scheme 3.** Proposed mechanism.

**Table 4**
Scope of benzyl alcohols.[a,b]



---

[a] Unless otherwise noted, the reaction conditions were as followed: benzyl alcohols (1.0 eq, 0.30 mmol), morpholine (5.0 eq, 1.50 mmol), NaI (5.0 eq, 1.50 mmol), $CH_3CN:H_2O$ (3 mL:1 mL), graphite rod ($\phi$ = 5 mm, immersed 1.0 cm) as anode, platinum plate (5x5x0.1 mm) as cathode, 100 mA, 3 h at room temperature, undivided cell.



**Scheme 4.** Control experiments.

pholine (**2a**) in $CD_3CN$ solvent and monitored the reaction by NMR. The $^1H$ NMR data confirmed the existence of the corresponding hemiaminal **6kc** providing the peak at 7.69/7.34 ppm (aromatic protons), 5.26 ppm (alcohol proton) and 3.73 ppm (benzylic protons) (Fig. S3). According to this proposed mechanism, the active oxidizing species could be $I_2$ or $I^-$ which could be produced at the anode site. The oxidative amidation was thus carried out without applying electricity and replacing NaI with $I_2$. The reaction between benzyl alcohol (**4a**) and morpholine (**2a**) provide aldehyde **1a** in only 5% yield while starting from aldehyde **1a**, the amide **3aa** were received in 21% yield (Scheme 4, eq. 3–4). Although, those two experiments did not provide a concrete result that $I_2$ could serve as a true oxidant due to achieving low yield of the amide product (**3aa**). However, unlike the condition in the electrochemical reaction where $I_2$ is slowly generated, in the control experiment, high concentration of $I_2$ was added at once. We hypothesized that highly concentrated $I_2$ in the control experiment may react with amine nucleophiles to form its quaternary ammonium salt which prohibits the addition of such amines to aldehydes to form hemiaminals **6**. To confirm the role of iodide, we replaced NaI with $NaBF_4$. It resulted in no reaction and we observed only starting **1a** (Scheme 4, eq. 5). Also, when we performed the reaction under the nitrogen atmosphere, the amide **3aa** was isolated in 79% yield which is similar to the optimized condition under open air (Scheme 4, eq. 6). This result suggested that the oxygen may not involve in our electrochemical amidation. Moreover, the addition of radical scavenger, TEMPO, into this electrochemical amidation was performed. It resulted in similar yield of amide **3aa** as optimized condition indicating that radical species may not be involved or may not be the major pathway (Scheme 4, eq. 7). Based on those observations, we concluded that this electrochemical is an indirect electrolysis process where $I_2$ is slowly generated from NaI and serve as an oxidant in the reaction.

## Conclusion

In conclusion, we developed an electrochemical method for amide synthesis through NaI-mediated oxidative amidation between alcohols/aldehydes and amines under mild condition. Furthermore, the mechanistic investigation revealed that hemiaminal is the key intermediate which could be oxidized by *in situ* generated $I_2$ from NaI via electrochemical oxidation. Our electrochemical method offers several benefits over conventional methods such as mild operating condition at room temperature under ambient atmosphere and use of low cost as well as low toxicity reagent. This reaction can be easily scaled up and can be powered by standard power charger to provide amide product in good yield. There is a strong potential for applications in both academia and industry.

## Declaration of Competing Interest

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

## Acknowledgement

This study was financially supported by National Research Council of Thailand (NRCT): NRCT5-RSA63001-16, Thailand Research Fund (RTA6180007) and National Nanotechnology Centre (NANOTEC), NSTDA, Ministry of Science and Technology, Thailand, through its program of the Centre of Excellence Network. This work was also partially supported by a Grant for International Research Integration: Chula Research Scholar and Center of Excellence on Petrochemical and Materials Technology (PETROMAT), Thailand. Finally, we would like to thank Dr. Komthep Silpcharu and Mr. Taweesak Gulchatchai for their help during manuscipt revision.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tetlet.2021.153017.

## References

[1] A.O. Porras, A.H. Santana, D.G. Sanchez, Green Chem. 17 (2015) 3157–3163.
[2] A.R. Katrizky, C. Cai, S.K. Singh, J. Org. Chem. 71 (2006) 3375–3380.
[3] J.R. Dunetz, J. Magano, G.A. Weisenburger, Org. Process Res. Dev. 20 (2016) 140–177.
[4] R.M.D. Figueiredo, J.-S. Suppo, J.-M. Campange, Chem. Rev. 116 (2016) 12029–12122.
[5] T.M.E. Dine, W. Erb, Y. Berhault, J. Rouden, J. Blanchet, J. Org. hem. 80 (2015) 4532–4544.
[6] S. Fatemi, N. Gernigon, D.G. Hall, Green Chem. 17 (2015) 4016–4028.
[7] H. Lundberg, F. Tinnis, H. Adolfsson, Synlett 23 (2012) 2201–2204.
[8] L.T.M. Hoang, L.H. Ngo, H.L. Nguyen, H.T.H. Nguyen, C.K. Nguyen, B.T. Nguyen, Q.T. Ton, H.K.D. Nguyen, K.E. Cordova, T. Truong, Chem. Commun. 51 (2015) 17132–17135.
[9] S. Liu, H. Wang, X. Dai, F. Shi, Green Chem. 20 (2018) 3457–3462.
[10] H. Chen, M. He, Y. Wang, L. Zhai, Y. Cui, Y. Li, Y. Li, H. Zhou, X. Hong, Z. Deng, Green Chem. 13 (2011) 2723–2726.
[11] S.M. Mali, R.D. Bhaisare, H.N. Gopi, J. Org. Chem. 78 (2013) 5550–5555.
[12] P. Nanayakkara, H. Alper, Chem. Commun. (2003) 2384–2385.
[13] X. Li, Z. Li, H. Dang, X. Zhou, Tetrahedron Lett. 54 (2013) 2212–2216.
[14] S. Park, Y.-A. Choi, H. Han, S.H. Yang, S. Chang, Chem. Commun. (2003) 1936–1937.
[15] C. Zhu, W. Wei, P. Du, X. Wan, Tetrahedron 70 (2014) 9615–9620.
[16] K.-I. Shimizu, K. Ohshima, A. Satsuma, Chem. Eur. J. 15 (2009) 9977–9980.
[17] G.-L. Li, K.-K.-Y. Kung, M.-K. Wong, Chem Commun. 48 (2012) 4112–4114.
[18] J.-F. Soule, H. Miyamura, S. Kobayashi, Chem. Asian. J. 8 (2013) 2614–2626.
[19] S.C. Ghosh, J.S.Y. Ngiam, A.M. Seayad, D.T. Tuan, C.L.L. Chai, A. Chen, J. Org. Chem. 77 (2012) 8007–8015.
[20] A. Darvishi, M.K. Miraki, M. Arefi, A. Heydari, New. J. Chem. 44 (2020) 11777–11785.
[21] A. Singh, C.S. Azad, A.K. Narula, ChemistrySelect 5 (2020) 9417–9423.
[22] M. Arefi, D. Saberi, M. Karimi, A. Heydari, A.C.S. Comb, Sci. 17 (2015) 341–347.
[23] C. Wang, L. Huang, M. Lu, B. Zhao, Y. Wang, Y. Zhang, Q. Shen, Y. Yao, RSC Adv. 5 (2015) 94768–94775.
[24] N.W. Gilman, Chem. Commun. (1971) 733–734.
[25] B. Goel, V. Vyas, N. Tripathi, A.K. Singh, P.W. Menezes, A. Indra, S.K. Jain, ChemCatChem 12 (2020) 5743–5749.
[26] M. Saikia, L. Saikia, RSC Adv. 6 (2016) 14937–14947.
[27] S. Rostamnia, E. Doustkhah, H.G. Hosseini, B. Zeynizadeh, H. Xin, R. Luque, Catal. Sci. Technol. 6 (2016) 4124–4133.
[28] A. Tillack, I. Rudloff, M. Beller, Eur. J. Org. Chem. (2001) 523–528.
[29] T. Zweifel, J.-V. Naubron, H. Grutzmacher, Angew. Chem. Int. Ed. 48 (2009) 559–563.
[30] Y. Uozumi, R. Niimi, Synfacts 16 (2020) 1460.
[31] X.-F. Wu, M. Sharif, A.P. Davtyan, P. Langer, K. Ayub, M. Beller, Eur. J. Org. Chem. (2013) 2783–2787.
[32] V. Kumar, S.J. Connon, Chem. Commun. 53 (2017) 10212–10215.
[33] Y.B. Sutar, S.B. Bhagat, V.N. Telvekar, Tetrahedron Lett. 56 (2015) 6768–6771.
[34] S. Koguchi, A. Mihoya, M. Mimura, Tetrahedron 72 (2016) 7633–7637.
[35] W. Phakhodee, S. Wangngae, M. Pattarawarapan, RSC Adv. 6 (2016) 60287–60290.
[36] J.-J. Shie, J.-M. Fang, J. Org. Chem. 68 (2003) 1158–1160.
[37] K. Xu, Y. Hu, S. Zhang, Z. Zha, Z. Wang, Chem. Eur. J. 18 (2012) 9793–9797.
[38] J. Gu, Z. Fang, C. Liu, X. Li, P. Wei, K. Guo, RSC Adv. 6 (2016) 72121–72126.
[39] R. Deshidi, M.A. Rizvi, B.A. Shah, RSC Adv. 5 (2015) 90521–90524.
[40] M. Karimi, D. Saberi, K. Azizi, M. Arefi, A. Heydari, Tetrahedron Lett. 55 (2014) 5351–5353.
[41] J. Liang, J. Lv, Z.-C. Shang, Tetrahedron 67 (2011) 8532–8535.
[42] G. Pandey, S. Koley, R. Talukdar, P.K. Sahani, Org. Lett. 20 (2018) 5861–5865.
[43] H. Deol, M. Kumar, V. Bhalla, RSC Adv. 8 (2018) 31237–31245.
[44] M. Yan, Y. Kawamata, P.S. Baran, Chem. Rev. 117 (2017) 13230–13319.
[45] M.D. Karkas, Chem. Soc. Rev. 47 (2018) 5786–5865.
[46] A. Wiebe, T. Gieshoff, S. Mohle, E. Rodrigo, M. Zirbes, S.R. Waldvogel, Angew. Chem. Int. Ed. 57 (2018) 5594–5619.
[47] P. Wang, S. Tang, A. Lei, Green Chem. 19 (2017) 2092–2095.
[48] D.M.M.M. Dissanayake, A.D. Melville, A.K. Vanucci, Green Chem. 21 (2019) 3165–3171.
[49] L. Tang, J.H. Matuska, Y.-H. Huang, Y.-H. He, Z. Guan, ChemSusChem 12 (2019) 2570–2575.
[50] Y. Wu, H. Ding, M. Zhao, Z.-H. Ni, J.-P. Cao, Green Chem. 22 (2020) 4906–4911.
[51] S.-M. Yang, T.-J. He, D.-Z. Lin, J.-M. Huang, Org. Lett. 21 (2019) 1958–1962.

[52] K. Liu, C. Song, A. Lei, Org. Biomol. Chem. 16 (2018) 2375–2387.
[53] J. Chen, W.-Q. Yan, C.M. Lam, C.-C. Zeng, L.-M. Hu, R.D. Little, Org. Lett. 17 (2015) 986–989.
[54] W.-C. Li, C.-C. Zeng, L.-M. Hu, H.-Y. Tian, Adv. Synth. Catal. 355 (2013) 2884–2890.
[55] X.-J. Sun, S.-F. Yang, Z.-T. Wang, S. Liang, H.-Y. Tian, S.-X. Yang, Y.-G. Liu, B.-G. Sun, C.-C. Zeng, ChemistrySelect 5 (2020) 4637–4641.
[56] Z.-Q. Wang, X.-J. Meng, Q.-Y. Li, H.-T. Tang, H.-S. Wang, Y.-M. Pan, Adv. Synth. Catal. 360 (2018) 4043–4048.
[57] C.-C. Sun, K. Xu, C.-C. Zeng, ACS Sustainable Chem. Eng. 7 (2019) 2255–2261.
[58] F. Wang, J.B. Gerken, D.M. Bates, Y.J. Kim, S.S. Stahl, J. Am. Chem. Soc. 142 (2020) 12349–12356.
[59] Y. Kurose, Y. Imada, Y. Okada, K. Chiba, During the manuscript preparation, the oxidative amidation using electrochemical process to prepare amides from aldehydes were also reported using $NaClO_4$ as mediator, Eur. J. Org. Chem. (2020) 3844–3846.
[60] J.-Y. Chen, H.-Y. Wu, Q.-W. Gui, X.-R. Han, Y. Wu, K. Du, Z. Cao, Y.-W. Lin, W.-M. He, Org. Lett. 22 (2020) 2206–2209.
[61] Z. Zhang, J. Su, Z. Zha, Z. Wang, Chem. Commun. 49 (2013) 8982–8984.
[62] P. Gogoi, D. Konwar, Org. Biomol. Chem. 3 (2005) 3473–3475.