RSC Advances

PAPER

View Article Online
View Journal | View Issue

Cite this: *RSC Adv.*, 2025, **15**, 31806

Tandem synthesis of dihydronaphthalen-1(2*H*)-one derivatives *via* aldol condensation-Diels–Alder-aromatization sequence of reactions

M. Saeed Abaee, *[a] Yazdanbakhsh L. Nosood, [b] Elaheh Akbarzadeh,[a] Mohammad M. Mojtahedi [a] and Ahmed Al-Harrasi [b]

Received 1st July 2025
Accepted 25th August 2025

DOI: 10.1039/d5ra04673d

rsc.li/rsc-advances

A new series of dihydronaphthalen-1(2*H*)-one derivatives were synthesized in high yields starting from commercially available 3,5,5-trimethylcyclohex-2-en-1-one **1a**, aromatic aldehydes **2**, and diethyl acetylenedicarboxylate. Reaction of **1a** with the aldehydes produced the respective dienones **3**, which could cycloadd to dialkyl acetylenedicarboxylate, either stepwise or *in situ*, under aqueous/organocatalyzed (DMAP) conditions. The respective adducts **4**, were produced efficiently *via* a Diels–Alder-double bond isomerization-oxidative aromatization sequence and were characterized based on the analysis of their ^{1}H and ^{13}C NMR spectra.

Introduction

4-Dimethylaminopyridine (DMAP) is an amine with improved basicity[1] and nucleophilicity,[2] suitable to accelerate various organic transformations conveniently.[3] As a catalyst, DMAP is used in the synthesis of α,β-unsaturated δ-lactones,[4] Buchwald–Hartwig C–N coupling,[5] *N*-vinylation,[6] [4 + 2] cycloadditions,[7] and many other synthetic reactions.[8] DMAP is also conveniently used in domino carbonylation-electrocyclization synthesis of imidazodipyridines[9] and cascade synthesis of α-pyrones.[10] In addition to usual homogeneous uses, DMAP can be used in the form of ionic liquids[11] or immobilized derivatives.[12] The advantages of DMAP in organic chemistry are not limited to its regular basic or nucleophilic properties and are additionally highlighted due to its uses in biological,[13] medicinal,[14,15] and nanoparticle disciplines,[16] while DMAP has shown several applications in chiral catalysis[17] and asymmetric synthesis[18] and has got involved in synthetic protocols as a reactant[19] or the active part of starting materials.[20] Some illustrative cases are highlighted in Fig. 1.

Cyclohexenone derivatives are a group of usually inexpensive commercially available reactants for various convenient transformations to more complex products,[21–23] including the aromatization process to their respective phenol equivalents.[24] Among this group of compounds, the 3-methyl substituted derivative **1** would be a suitable candidate for both aromatization to the respective phenol and chain extension *via* aldol condensation with aldehydes[25] or coupling reactions with vinylogous species[26] at the allylic methyl position. The resulting dienes have the advantages for further synthetic manipulations through cycloaddition reactions with acetylenic dienophiles to access the respective polysubstituted dihydronaphthalen-1-one (A) or naphthol analogues (B), which in turn are useful synthons to access natural[27,28] or synthetic[29] structures (Fig. 2).

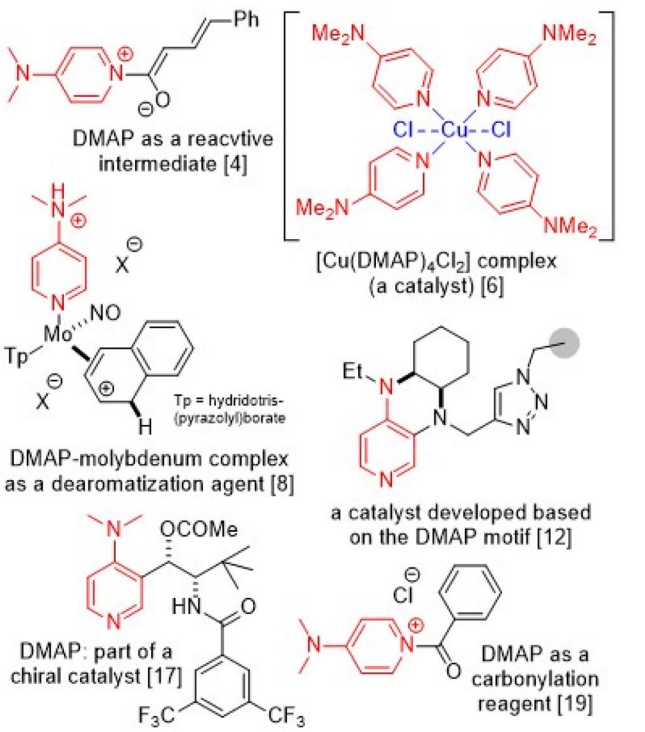


Fig. 1 Some important synthetic roles of DMAP.

[a]*Organic Chemistry Department, Chemistry and Chemical Engineering Research Center of Iran, P.O. Box 14335-186, Tehran, Iran. E-mail: abaee@ccerci.ac.ir*

[b]*Natural and Medical Sciences Research Center, University of Nizwa, P.O. Box 33, Postal Code 616, Birkat Al Mauz, Nizwa, Sultanate of Oman*

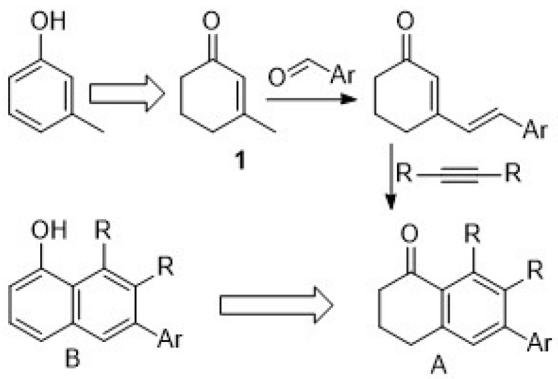


Fig. 2 3-Methylcyclohexenone route to aromatic DA adducts.

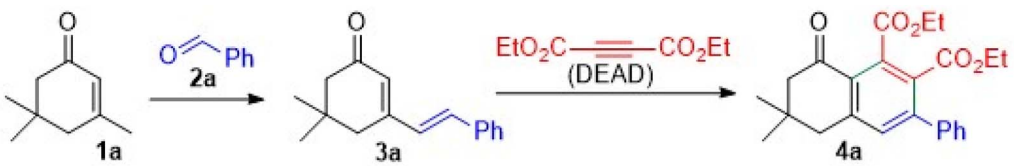
The [4 + 2] Diels–Alder (DA) cycloaddition is a key reaction in synthetic organic chemistry,[30] due to efficient formation of a cyclohexene ring with up to four stereogenic centres with predictable selectivity.[31] Incorporation of this reaction with other important organic transformations into tandem processes multiplies the efficiency of the DA cycloaddition so that many synthetic applications have arisen in recent decades as a result of DA-Hantzsch,[32] Biginelli-DA,[33] Heck-DA,[34] Knoevenagel-DA,[35] aldol condensation-DA,[36] and other sequential reactions.[37,38]

We are interested in the study of DA reactions and have communicated our findings on the synthesis and cycloaddition reactions of the styrylcyclohexene diene system in recent years.[39,40] Based on this background, we were persuaded to extend our study to embark on direct synthesis of the dihydronaphthalen skeleton starting from 3,5,5-trimethylcyclohex-2-en-1-one (**1a**, isophorone). We hereby disclose the synthesis of various derivatives of **4** through a tandem aldol-condensation-Diels–Alder-rearrangement-aromatization sequence of reactions under aqueous/DMAP conditions, as depicted in Scheme 1 for the reaction of **1a** with benzaldehyde and the following cycloaddition step of **3a** with diethyl acetylenedicarboxylate (DEAD).

Results and discussion

We first optimized the conditions for both steps. While a mixture of **1a** and benzaldehyde **2a** in aqueous DMAP gave low quantities of **3a** at room temperature (entry 1), treatment of the same mixture at 60 °C produced 84% of the product after 3 h (entry 2). In contrast, the yield diminished in the absence of either DMAP (entry 3) or water (entry 4). This was also the case when water was replaced with an alcohol (entries 5–6), toluene (entry 7), MeCN (entry 8), or THF (entry 9) as the medium of the reaction.[41] Alternatively, separation of **3a** and its treatment with DEAD in the same H_2O/DMAP medium gave **4a** in much higher quantities at reflux (entry 10).[42] Treatment of the same mixture at lower temperatures was less productive (entries 11 and 12) (Table 1).

Having the two sets of optimized conditions, we next evaluated the generality of the method by using other derivatives of **2** (Table 2). Thus, in addition to unsubstituted aromatic aldehydes (entries 1 and 2), the H_2O/DMAP mediated condensation of various aldehydes bearing electron releasing (entries 3 and 4)



Scheme 1 Typical stepwise reaction pathway for the conversion of **1** to **3** and **3** to **4**.

Table 1 Three-component optimization of the synthesis of **3a**

Entry	Reactants	Conditions[a]	Temperature (°C)	Time (h)	Product	Yield[b] (%)
1	**1a** + **2a**	DMAP, H_2O	rt	3	**3a**	17
2	**1a** + **2a**	DMAP, H_2O	60	3	**3a**	84
3	**1a** + **2a**	H_2O	60	3	**3a**	>5
4	**1a** + **2a**	DMAP	60	3	**3a**	24
5	**1a** + **2a**	DMAP, EtOH	60	3	**3a**	10
6	**1a** + **2a**	DMAP, MeOH	60	3	**3a**	12
7	**1a** + **2a**	DMAP, toluene	60	3	**3a**	>5
8	**1a** + **2a**	DMAP, MeCN	60	3	**3a**	12
9	**1a** + **2a**	DMAP, THF	60	3	**3a**	>5
10	**3a** + DEAD	DMAP, H_2O	100	48	**4a**	81
11	**3a** + DEAD	DMAP, H_2O	80	48	**4a**	38
12	**3a** + DEAD	DMAP, H_2O	60	48	**4a**	22

[a] 10 mol% DMAP was used in all reactions. [b] Isolated yields.

Table 2 Stepwise synthesis of various derivatives of 3 and 4

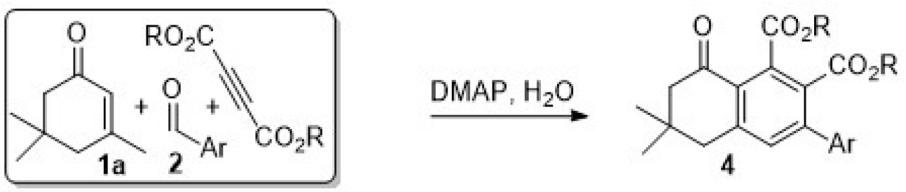
Entry	Conditions[a]	Reactants	Ar	Product	Yield[bb] (%)
1	DMAP, H_2O, 60 °C	**1a** + **2a**	C_6H_5	**3a**	84
2	DMAP, H_2O, 60 °C	**1a** + **2b**	2-Naphthyl	**3b**	84
3	DMAP, H_2O, 60 °C	**1a** + **2c**	4-MeC_6H_4	**3c**	81
4	DMAP, H_2O, 60 °C	**1a** + **2d**	4-$MeOC_6H_4$	**3d**	87
5	DMAP, H_2O, 60 °C	**1a** + **2e**	3-$MeOC_6H_4$	**3e**	78
6	DMAP, H_2O, 60 °C	**1a** + **2f**	4-FC_6H_4	**3f**	82
7	DMAP, H_2O, 60 °C	**1a** + **2g**	4-BrC_6H_4	**3g**	80
8	DMAP, H_2O, 60 °C	**1a** + **2h**	4-$CF_3C_6H_4$	**3h**	81
9	DMAP, H_2O, 60 °C	**1a** + **2i**	3-$O_2NC_6H_4$	**3i**	80
10	DMAP, H_2O, 60 °C	**1a** + **2j**	4-ClC_6H_4	**3j**	83
11	DMAP, H_2O, 60 °C	**1a** + **2k**	2,6-$Cl_2C_6H_3$	**3k**	75
12	DMAP, H_2O, 60 °C	**1a** + **2l**	2-Thienyl	**3l**	79
13	DMAP, H_2O, reflux	**3a** + DMAD	C_6H_5	**4a**	85
14	DMAP, H_2O, reflux	**3a** + DEAD	C_6H_5	**4a′**	83
15	DMAP, H_2O, reflux	**3b** + DEAD	2-Naphthyl	**4b**	78
16	DMAP, H_2O, reflux	**3c** + DEAD	4-MeC_6H_4	**4c**	83
17	DMAP, H_2O, reflux	**3d** + DEAD	4-$MeOC_6H_4$	**4d**	86
18	DMAP, H_2O, reflux	**3e** + DEAD	3-$MeOC_6H_4$	**4e**	77
19	DMAP, H_2O, reflux	**3f** + DMAD	4-FC_6H_4	**4f**	81
20	DMAP, H_2O, reflux	**3g** + DEAD	4-BrC_6H_4	**4g**	78
21	DMAP, H_2O, reflux	**3h** + DEAD	4-$CF_3C_6H_4$	**4h**	82
22	DMAP, H_2O, reflux	**3i** + DEAD	3-$O_2NC_6H_4$	**4i**	80
23	DMAP, H_2O, reflux	**3j** + DEAD	4-ClC_6H_4	**4j**	81
24	DMAP, H_2O, reflux	**3k** + DEAD	2,6-$Cl_2C_6H_3$	**4k**	75
25	DMAP, H_2O, reflux	**3l** + DEAD	2-Thienyl	**4l**	80

[a] 10 mol% DMAP was used in all reactions. [b] Isolated yields.

or electron withdrawing (entries 5–11) and heteroaromatic groups (entry 12) with **1a** gave the respective aldol condensation products in high yields. Alternatively, isolation of **3a–l** and their separate treatment with DEAD (entries 14–18 and 20–25) or dimethyl acetylenedicarboxylate (DMAD) (entries 13 and 19) in the same aqueous DMAP mixtures yielded **4a–l** efficiently.

We then evaluated the feasibility of conducting both steps in a one-pot procedure (Table 3). For this, we examined the

Table 3 One-pot synthesis of derivatives of 4



Entry	Reactants[a]	Ar	R	Product	Yield[b] (%)
1	**1a** + **2a** + DMAD	C_6H_5	Me	**4a**	82
2	**1a** + **2a** + DEAD	C_6H_5	Et	**4a′**	80
3	**1a** + **2b** + DEAD	2-Naphthyl	Et	**4b**	80
4	**1a** + **2c** + DEAD	4-MeC_6H_4	Et	**4c**	77
5	**1a** + **2d** + DEAD	4-$MeOC_6H_4$	Et	**4d**	78
6	**1a** + **2e** + DEAD	3-$MeOC_6H_4$	Et	**4e**	80
7	**1a** + **2a** + DMAD	4-FC_6H_4	Me	**4f**	86
8	**1a** + **2f** + DEAD	4-BrC_6H_4	Et	**4g**	80
9	**1a** + **2g** + DEAD	4-$CF_3C_6H_4$	Et	**4h**	80
10	**1a** + **2a** + DMAD	3-$O_2NC_6H_4$	Et	**4i**	75
11	**1a** + **2a** + DMAD	4-ClC_6H_4	Et	**4j**	85
12	**1a** + **2a** + DMAD	2,6-$Cl_2C_6H_3$	Et	**4k**	81
13	**1a** + **2a** + DMAD	2-Thienyl	Et	**4l**	80

[a] 10 mol% DMAP was used in all reactions. [b] Isolated yields.

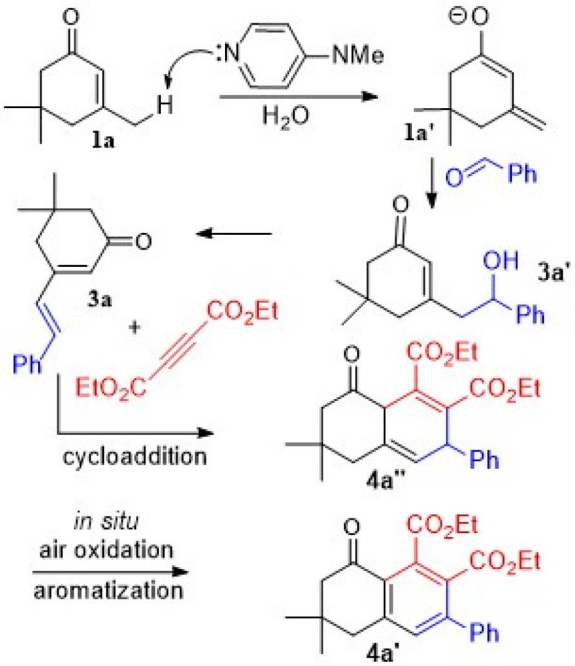


Fig. 3 The proposed mechanism.

conditions for the reaction of **1a** with benzaldehyde and DEAD in a water/DMAP mixture, where initial warming of the mixture of **1a** and **2a** to 60 °C (1 h) and delayed addition of the dienophile DMAD to the mixture and switching the conditions to refluxing temperature produced **4a** in 82% yield within 48 h (entry 1). Successful reactions of other aldehydes with either DMAD or DEAD illustrated the generality of the process by producing their respective adducts in high yields (entries 2–13).

Based on the results obtained here and in view of the basicity of DMAP as an organocatalyst in aqueous media,[43] a mechanism was proposed for the one-pot combination of the reactants, as shown in Fig. 3 for the reaction of benzaldehyde with **1a** and DEAD. Primarily, the DMAP preferably removed the γ acidic proton (Me group) to give the dienolate intermediate (**1a′**). In continuation, the intermediate attacked the aldehyde to complete the aldol step, giving **3a′** and then **3a**. Cycloaddition of **3a** with DEAD followed by *in situ* aromatization of **4a″** produced the final product **4a′**.[44]

Experimental

General

All reagents were commercially available and used as received. Progress of the reactions was monitored by TLC using silica gel coated plates and EtOAc/petroleum ether mixture as the eluent. Melting points are uncorrected and obtained by Buchi Melting Point 530 apparatus. ^{1}H NMR (300 MHz or 600 MHz) and ^{13}C NMR (75 MHz or 150 MHz) spectra are obtained on a FT-NMR Bruker Ultra Shield™ (or Bruker DRX-600) instrument as $CDCl_3$ solutions, and the chemical shifts are expressed as δ units with Me_4Si as the internal standard. Chemical ionization (CI) HRMS data are obtained (with MeOH as the ionization source) using Agilent technologies 6530 Q-TOF-LC-MS. The identity of the known products was confirmed by the comparison of their ^{1}H NMR and ^{13}C NMR spectra with those of authentic compounds reported in the literature.[45,46] All new products were fully characterized based on their spectral data.

Typical synthesis of 3a

A mixture of **1a** (300 μL, 2.0 mmol), benzaldehyde **2a** (284 μL, 2.0 mmol), and DMAP (25 mg, 10 mol%) in water (1.0 mL) was stirred at 60 °C for 3 h. After completion of the reaction (monitored by TLC using EtOAc/hexanes (1 : 4) as the eluent), the mixture was extracted with EtOAc (3 × 5 mL), washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. Product **3a** (380 mg, 84%) was obtained by column chromatography fractionation of the residue using (EtOAc/hexanes, 1 : 4, v/v).

Typical stepwise synthesis of 4a′

A mixture of **3a** (1.0 mmol, 226 mg) and DEAD (255 mg, 1.5 mmol), and DMAP (13 mg, 10 mol%) in H_2O (2.0 mL) was refluxed for 48 h, until TLC showed completion of the process. The product was extracted from the reaction mixture with EtOAc (5.0 mL), washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. Product **4a′** (327 mg, 83%) was obtained by column chromatography fractionation of the residue using (EtOAc/hexanes, 1 : 4, v/v).

Typical one-pot synthesis of 4a′

A mixture of **1a** (150 μL, 1.0 mmol), benzaldehyde **2a** (142 μL, 1.0 mmol), and DMAP (13 mg, 10 mol%) in water (1.0 mL) was stirred at 60 °C for 3 h. At this point, DEAD (255 mg, 1.5 mmol) was added to the mixture and the mixture was refluxed for another 36 h. The product was extracted from the reaction mixture with EtOAc (5.0 mL), washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. Product **4a′** (316 mg, 80%) was obtained by column chromatography fractionation of the residue using (EtOAc/hexanes, 1 : 4, v/v).

Spectral data of new products

(*E*)-5,5-dimethyl-3-(4-(trifluoromethyl)styryl)cyclohex-2-en-1-one 3h. Mp 103–105 °C; IR (KBr): 1324, 1586, 2161, 1655, 2933, 9961 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.12 (s, 6H), 2.33 (s, 2H), 2.49 (s, 2H), 6.12 (s, 1H), 6.99 (s, 2H), 7.59 (d, J = 8.0 Hz, 2H), 7.63 (d, J = 8.0 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.4, 33.3, 38.9, 51.3, 125.7 (q, J = 28 Hz), 127.2, 128.2, 130.3, 130.7, 131.9, 133.0, 139.4, 153.7, 200.1; MS (70 eV) *m*/*z* (%), 294 (M^+), 142, 170, 262, 277; anal. calcd for $C_{17}H_{17}F_3O$: C, 69.38; H, 5.82. Found: C, 69.20; H, 5.79.

(*E*)-3-(2,6-dichlorostyryl)-5,5-dimethylcyclohex-2-en-1-one 3k. Mp 69–71 °C; IR (KBr): 1587, 1616, 1657, 2930, 2947 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$ δ) 1.12 (s, 6H), 2.32 (s, 2H), 2.50 (s, 2H), 6.06 (s, 1H), 6.94 (d, J = 16.5 Hz, 1H), 7.01 (d, J = 16.5 Hz, 1H), 7.13 (t, J = 8.0 Hz, 1H), 7.33 (d, J = 8.0 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.4, 33.2, 38.5, 51.3, 128.2, 128.4, 128.6, 128.9,

133.3, 134.4, 137.7, 153.7, 200.1; MS (70 eV) *m*/*z* (%), 294 (M^+), 176, 204, 260; anal. calcd for $C_{16}H_{16}Cl_2O$: C, 65.10; H, 5.46. Found: C, 64.87; H, 5.37.

Dimethyl 6,6-dimethyl-8-oxo-3-phenyl-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4a). Mp 151–153 °C; IR (KBr): 2949, 1739, 1694, 1588 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): 1.03 (s, 6H), 2.58 (s, 2H), 2.93 (s, 2H), 3.62 (s, 3H), 3.97 (s, 3H), 7.22 (d, $J = 8.0$ Hz, 2H), 7.29 (s, 1H), 7.56 (d, $J = 8.0$ Hz, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): 28.1, 33.7, 43.8, 52.5, 52.6, 53.0, 122.9, 128.5, 129.6, 129.7, 131.7, 132.0, 134.2, 138.2, 144.5, 145.4, 167.4, 169.0, 196.3; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{22}H_{22}O_5 + H]^+$: 367.1540, found: 367.1545.

Diethyl 7,7-dimethyl-5-oxo-5,6,7,8-tetrahydro-[2,2′-binaphthalene]-3,4-dicarboxylate (4b). Mp 124–125 °C; IR (KBr): 2969, 2255, 1726, 1241 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): 0.50 (t, $J = 7.5$ Hz, 3H), 1.14 (s, 3H), 1.17 (s, 3H), 1.41 (t, $J = 7.5$ Hz, 3H), 2.62 (q, $J = 7.5$ Hz, 2H), 2.96 (q, $J = 7.5$ Hz, 2H), 2.93 (s, 2H) 4.46 (q, $J = 7.5$ Hz, 2H), 7.34 (dd, $J = 8.0$ Hz, 1H), 7.36 (s, 1H); 7.45 (dd, $J = 8.0$, 8.0 Hz, 1H), 7.50 (dd, $J = 8.0$, 8.0 Hz, 2H), 7.59 (d, $J = 8.0$ Hz, 1H), 7.89 (d, $J = 8.0$ Hz, 1H), 7.91 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$): 13.0, 13.9, 28.0, 28.3, 33.8, 43.8, 52.7, 61.1, 61.9, 125.0, 125.7, 126.1, 126.3, 126.4, 128.2, 128.4, 128.7, 131.3, 131.5, 133.2, 133.3, 134.4, 137.4, 144.9, 145.0, 166.4, 168.7196.4; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{28}H_{28}O_5 + H]^+$: 445.2009, found: 445.2010.

Diethyl 3-(4-fluorophenyl)-6,6-dimethyl-8-oxo-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4f). Mp 93–95 °C; IR (KBr): 3062, 1729, 1233 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): 1.02 (t, $J = 7.0$ Hz, 3H). 1.11 (s, 6H), 1.40 (t, $J = 7.0$ Hz, 3H), 2.58 (s, 2H), 2.93 (s, 2H), 4.07 (q, $J = 7.0$ Hz, 2H), 4.44 (q, $J = 7.0$ Hz, 2H), 7.11–7.14 (m, 2H), 7.28 (s, 1H), 7.33–7.35 (m, 2H); ^{13}C NMR (150 MHz, $CDCl_3$): 13.6, 13.9, 28.1, 33.8, 43.8, 52.6, 61.8, 62.0, 115.5 (d, $J = 21.0$ Hz), 128.3, 128.8 (d, $J = 9.0$ Hz), 130.3, 131.9, 134.2, 135.5, 144.8 (d, $J = 84.0$ Hz), 144.4 (d, $J = 247.5$ Hz), 145.1 (d, $J = 211.5$ Hz), 196.3; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{24}H_{25}FO_5 + H]^+$: 413.1759, found: 413.1759.

Diethyl 3-(4-bromophenyl)-6,6-dimethyl-8-oxo-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4g). Mp 133–135 °C; IR (KBr): 2981, 1737, 1591 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 0.94 (t, $J = 7.0$ Hz, 3H). 1.04 (s, 6H), 1.31 (t, $J = 7.0$ Hz, 3H), 2.49 (s, 2H), 2.84 (s, 2H), 4.00 (q, $J = 7.0$ Hz, 2H), 4.35 (q, $J = 7.0$ Hz, 2H), 7.14 (d, $J = 7.5$ Hz, 2H), 7.18 (s, 1H), 7.45 (d, $J = 7.5$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 13.6, 13.9, 28.1, 33.8, 43.8, 52.6, 61.8, 62.0, 122.7, 128.5, 129.7, 130.1, 131.6, 131.7, 134.3, 138.4, 144.4, 145.1, 166.9, 167.4, 167.1, 196.2; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{24}H_{25}BrO_5 + H]^+$: 473.0958, found: 473.0964.

Diethyl 6,6-dimethyl-8-oxo-3-(4-(trifluoromethyl)phenyl)-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4h). IR (KBr): 2971, 1728, 1592 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 0.96 (t, $J = 7.0$ Hz, 3H). 1.12 (s, 6H), 1.40 (t, $J = 7.0$ Hz, 3H), 2.58 (s, 2H), 2.93 (s, 2H), 4.04 (q, $J = 7.0$ Hz, 2H), 4.44 (q, $J = 7.0$ Hz, 2H), 7.30 (s, 1H), 7.46 (d, $J = 7.5$ Hz, 2H), 7.69 (d, $J = 7.5$ Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 13.2, 13.6, 27.8, 33.5, 43.6, 52.3, 61.5, 61.8, 122.0 (q, $J = 28.0$ Hz), 125.1, 128.2, 128.5, 129.8, 130.0, 130.4, 131.6, 134.2, 142.9, 143.8, 145.1, 167.1 (d, $J = 125.0$ Hz), 195.9; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{25}H_{25}F_3O_5 + H]^+$: 463.1727, found: 463.1732.

Diethyl 6,6-dimethyl-3-(3-nitrophenyl)-8-oxo-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4i). Mp 140–141 °C; IR (KBr): 2949, 1738, 1587, 1237 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 1.03 (t, $J = 7.0$ Hz, 3H). 1.12 (s, 6H), 1.39 (t, $J = 7.0$ Hz, 3H), 2.58 (s, 2H), 2.94 (s, 2H), 4.08 (q, $J = 7.0$ Hz, 2H), 4.43 (q, $J = 7.0$ Hz, 2H), 7.32 (s, 1H), 7.60 (dd, $J = 7.5$, 7.5 Hz, 1H), 7.67 (dt, $J = 1.5$, 7.5 Hz, 1H), 8.20–8.30 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 13.6, 13.9, 28.1, 33.8, 43.8, 52.5, 61.9, 62.1, 123.0, 123.1, 129.1, 129.4, 129.9, 132.0, 134.1, 134.6, 141.0, 142.9, 145.5, 148.1, 166.3, 168.1, 196.1; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{24}H_{25}NO_7 + H]^+$: 440.1704, found: 440.1709.

Diethyl 3-(2,6-dichlorophenyl)-6,6-dimethyl-8-oxo-5,6,7,8-tetrahydronaphthalene-1,2-dicarboxylate (4k). Mp 182–185 °C; IR (KBr): 2972, 1729, 1593 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 0.95 (t, $J = 7.0$ Hz, 3H). 1.13 (s, 6H), 1.41 (t, $J = 7.0$ Hz, 3H), 2.60 (s, 2H), 2.94 (s, 2H), 4.05 (q, $J = 7.0$ Hz, 2H), 4.45 (q, $J = 7.0$ Hz, 2H), 7.16 (s, 1H), 7.28 (dd, $J = 7.5$, 7.5 Hz, 1H), 7.39 (dd, $J = 1.5$, 7.5 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 13.4, 13.9, 28.1, 33.8, 43.8, 52.7, 61.4, 61.9, 127.1, 129.2, 129.4, 129.5, 132.6, 134.1, 135.4, 138.0, 141.5, 145.9, 165.0, 168.5, 196.4; ESI-HRMS (MeOH) (*m*/*z*): calcd for $[C_{24}H_{24}Cl_2O_5 + H]^+$: 463.1074, found: 463.1079.

Conclusions

In summary, we introduced a novel three-component method for the synthesis of a series of polysubstituted dihydronaphthalene derivatives. Both the diene formation and the cycloaddition steps were performed sequentially in the same pot using all three required reactants. The process was easy to operate by using an aqueous DMAP medium with no extra catalyst or additive needed. Additionally, a single product was obtained for each of the reactions in a good overall yield.

Author contributions

M. S. Abaee conceived and designed the work. Y. L. Nosood and E. Akbarzadeh performed the experiments and collected data. M. M. Mojtahedi reviewed the draft and performed the literature survey. A. Al-Harrasi conducted some of the analyses. All authors analyzed the data, discussed the results, and reviewed the manuscript.

Conflicts of interest

There are no conflicts to declare.

Data availability

The data supporting this article have been included as part of the SI. Supplementary information: Spectra of new compounds (^1H NMR, ^{13}C NMR). See DOI: **https://doi.org/10.1039/d5ra04673d**.

Acknowledgements

We would like to thank CCERCI for financial support of this work (Grant number 1402-102).

Notes and references

1 H. J. Lee, T. T. Nguyen, A. V. Tran, H. S. Kim, Y.-W. Suh, J. Baek and Y. J. Kim, *J. Ind. Eng. Chem.*, 2023, **123**, 140–149.
2 K. L. Jantzi, S. Wiltrakis, L. Wolf, A. Weber, J. Cardinal and K. Krieter, *J. Chem. Educ.*, 2011, **88**, 328–330.
3 C. Grondal, *Synlett*, 2003, **14**, 1568–1569.
4 J. Jin, Q. Xu and W. Deng, *Chin. J. Chem.*, 2017, **35**, 397–400.
5 S. Roy, M. M. Dutta, M. J. Sarma and P. Phukan, *ChemistrySelect*, 2019, **4**, 13094–13098.
6 K. Mondal, S. Patra, P. Halder, N. Mukhopadhyay and P. Das, *Org. Lett.*, 2023, **25**, 1235–1240.
7 D. Li, J. Wu, L. Yang, S. Cai, Y. Tang, Y. Li and S. Xu, *Org. Lett.*, 2025, **27**, 51–56.
8 J. T. Myers, S. J. Dakermanji, T. R. Chastanet, P. J. Shivokevich, L. J. Strausberg, M. Sabat, W. H. Myers and W. D. Harman, *Organometallics*, 2017, **36**, 543–555.
9 K. Zhang, A. El Bouakher, H. Lévaique, J. Bignon, P. Retailleau, M. Alami and A. Hamze, *Adv. Synth. Catal.*, 2020, **362**, 3243–3256.
10 A. Jain, A. Kumari, S. K. Saha, K. Shukla, A. Chauhan, R. K. Metre and N. K. Rana, *J. Org. Chem.*, 2023, **88**, 11346–11351.
11 S. A. Ghumro, S. Saleem, M. al-Rashida, N. Iqbal, R. D. Alharthy, S. Ahmed, S. T. Moin and A. Hameed, *RSC Adv.*, 2017, **7**, 34197–34207.
12 V. D'Elia, Y. Liu and H. Zipse, *Eur. J. Org Chem.*, 2011, 1527–1533.
13 A. Anwar, S. Khalid, S. Perveen, S. Ahmed, R. Siddiqui, N. A. Khan and M. R. Shah, *J. Nanobiotechnol.*, 2018, **16**, 1–8.
14 G. C. Lan, D. Han, Y. G. Wu, Z. B. Han, S. F. Ma, X. Y. Liu, C. L. Chang and J. H. Tan, *Mol. Reprod. Dev.*, 2005, **71**, 380–388.
15 R. Viveiros, J. J. Pinto, N. Costa, W. Heggie and T. Casimiro, *J. Supercrit. Fluids*, 2023, **194**, 105853–105858.
16 J. P. Vivek and I. J. Burgess, *J. Phys. Chem. C*, 2008, **112**, 2872–2880.
17 A. Kinens, M. Sejejs, A. S. Kamlet, D. W. Piotrowski, E. Vedejs and E. Suna, *J. Org. Chem.*, 2017, **82**, 869–886.
18 H. Mandai and S. Suga, Binaphthyl-Based Chiral DMAP Derivatives in Enantioselective Transformations, in *Atropisomerism in Asymmetric Organic Synthesis*, ed. S. Takizawa and M. Salem Wiley-VCH GmbH, 2024, pp. 237–266.
19 P.-L. Lagueux-Tremblay, A. Fabrikant and B. A. Arndtsen, *ACS Catal.*, 2018, **8**, 5350–5354.
20 T. R. Kelly and M. Cavero, *Org. Lett.*, 2002, **4**, 2653–2656.
21 J. Velcicky, E. Ngo, M. R. Bauer, A. Meyer, A. Schlapbach, S. Racine, D. Orain, D. Pflieger, S. Teixeira-Fouchard, C. Dubois, A. Goetz, R. Steiner, M. Palmieri, A. Bussenault, R. Stringer, P. Larger, S. Riek, P. Schmutz, S. Lehmann, C. Scheufler, J.-M. Rondeau, C. Burkhart, T. Knoepfel and N. Gommermann, *ChemMedChem*, 2025, **20**, e202400851.
22 S. Sharma, N. Kanwar, A. G. H. Khan and S. Easwar, *New J. Chem.*, 2025, **49**, 4639–4646.
23 J. W. Boyd, N. Greaves, J. Kettle, A. T. Russell and J. W. Steed, *Angew. Chem., Int. Ed.*, 2005, **44**, 944–946.
24 Y. Jin, P. V. Petrovic, S. Huang, S. Banerjee, A. Nandy, P. T. Anastas and J. C.-H. Lam, *J. Org. Chem.*, 2024, **89**, 3226–3237.
25 J. Gao, S. Bai, Q. Gao, Y. Liu and Q. Yang, *Chem. Commun.*, 2011, **47**, 6716–6718.
26 R. Hidalgo-León, N. Alberro, F. P. Cossío, J. Miguel Sansano and M. de Gracia Retamosa, *Adv. Synth. Catal.*, 2023, **365**, 3253–3259.
27 N. Diddi, L. Lai, C. H. Nguyen, D. Yan, E. Nambara and S. Abrams, *Org. Biomol. Chem.*, 2023, **21**, 3014–3019.
28 T. Rozek, D. K. Taylor, E. R. Tiekink and J. H. Bowie, *Aust. J. Chem.*, 1999, **52**, 129–136.
29 M. J. Petersson, C. Marchal, W. A. Loughlin, I. D. Jenkins, P. C. Healy and A. Almesåker, *Tetrahedron*, 2007, **63**, 1395–1401.
30 A. Rana, A. Mishra and S. K. Awasthi, *RSC Adv.*, 2025, **15**, 4496–4525.
31 T. Hamada, H. Sato, M. Hikota and O. Yonemitsu, *Tetrahedron Lett.*, 1989, **30**, 6405–6408.
32 R. M. Vala and H. M. Patel, in *Advances in Heterocyclic Chemistry*, ed. E. F. V. Scriven and C. A. Ramsden, Academic Press, 2023, vol. 141, pp. 179–208.
33 T. S. Maskrey, M. C. Frischling, M. L. Rice and P. Wipf, *Front. Chem.*, 2018, **6**, 376–384.
34 C. H. Escalante, E. I. Martínez-Mora, C. Espinoza-Hicks, A. A. Camacho-Dávila, F. R. Ramos-Morales, F. Delgado and J. Tamariz, *Beilstein J. Org. Chem.*, 2020, **16**, 1320–1334.
35 G. Frapper, C. Bachmann, Y. Gu, R. C. De Sousa and F. Jérôme, *Phys. Chem. Chem. Phys.*, 2011, **13**, 628–636.
36 B. D. Parmar, T. R. Sutariya, G. C. Brahmbhatt, N. J. Parmar, R. Kant and V. K. Gupta, *J. Org. Chem.*, 2016, **81**, 4955–4964.
37 A. Ratier, R. D. Moulandou-Koumba, M. Anizan, S. Behloul, F. Guegan, G. Frapper, Q. B. Remaury, K. De Oliveira Vigier, J. Zheng and F. Jérôme, *RSC Adv.*, 2023, **13**, 30369–30377.
38 E. Akbarzadeh, M. S. Abaee, Y. L. Nosood, M. M. Mojtahedi, K. Harms and Z. Shabani, *ChemistryOpen*, 2025, **14**, e202500040.
39 M. S. Abaee, S. Alizadeh, P. Azadi, M. M. Mojtahedi and M. R. Halvagar, *ChemistrySelect*, 2024, **9**, e202304060.
40 M. S. Abaee, M. Mohammadi, M. Mojtahedi and M. R. Halvagar, *Tetrahedron Lett.*, 2016, **57**, 4094–4097.
41 K. Erfurt, I. Wandzik, K. Walczak, K. Matuszek and A. Chrobok, *Green Chem.*, 2014, **16**, 3508–3514.
42 A. Biswas, S. Kundu, D. Pal, A. Pal and M. S. Maji, *Synthesis*, 2022, **54**, 887–909.
43 P. Forsythe, R. Frampton, C. D. Johnson and A. R. Katritzky, *J. Chem. Soc. Perkin Trans.*, 1972, **2**, 671–673.
44 For an example of cycloaddition-aromatization sequence using DMAD or DEAD see: Y.-W. Xu, J. Wang, G. Wang and L. Zhen, *J. Org. Chem.*, 2021, **86**, 91–102.
45 M. S. Abaee, E. Doustkhah, M. Mohammadi, M. M. Mojtahedi and K. Harms, *Can. J. Chem.*, 2016, **94**, 733–737.
46 M. S. Abaee, F. Mobayen, M. M. Mojtahedi, F. Saberi and H. R. Khavasi, *Arkivoc*, 2015, 305–315.