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Monowave microwave activation: green formation of carbon-carbon bond in solvent free Tiedtke reaction

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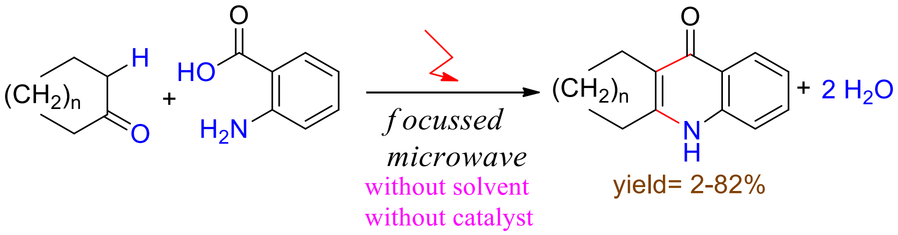
Abstract

The reaction of a mixture of cyclohexanone and anthranilic acid in a closed reactor without solvent or even catalyst, under monomode microwave irradiation in controlled conditions, allows the synthesis of tetrahydroacridones. The reaction is possible with several other cyclic ketones. This reaction under monomode microwave irradiation is an example of green synthesis involving the formation of a C-C bond in the absence of catalyst and solvent with the formation of only a benign water molecule.



Keywords: Green Conditions, Acridones, Monomode Microwave Irradiation, Solventless reaction

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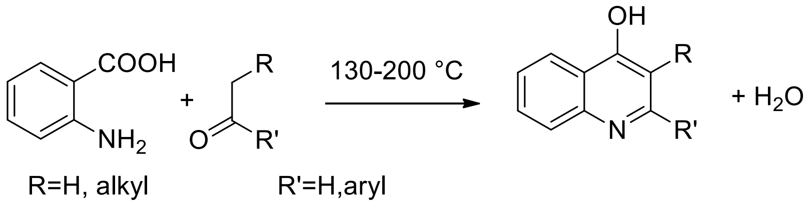
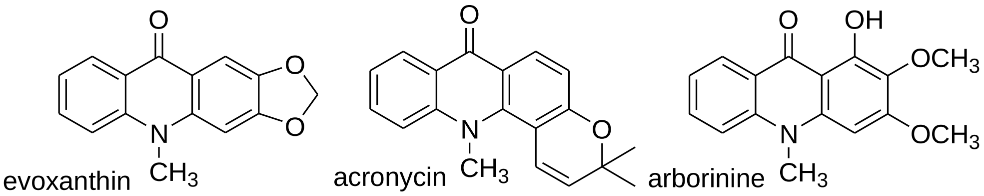
Introduction

There are very few catalyst and solvent-free reactions allowing the formation of carbon-carbon bonds accompanied by only the formation of environmentally benign molecules such as water molecules.[1] The reaction of Tiedtke,[2-5] which is a variant of the reaction of Niementowski with ketones,[6-7] is an example of such reactions.



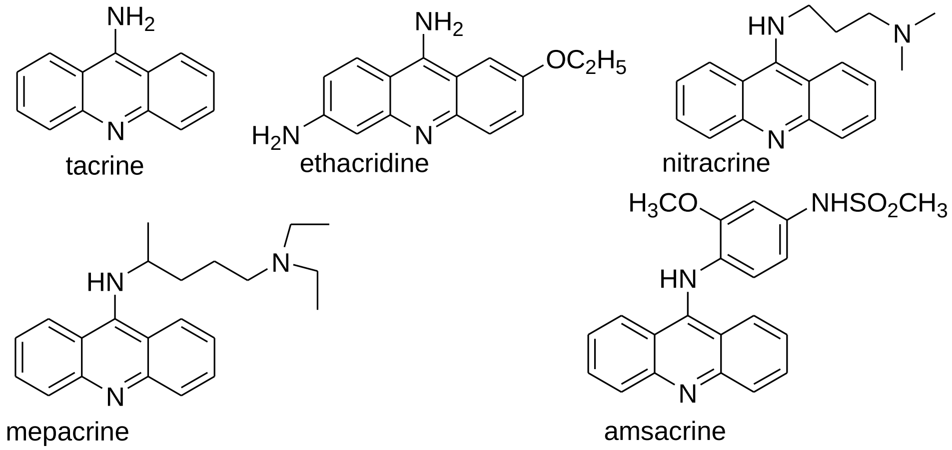
Scheme 1. Niementowski reaction: synthesis of 4-hydroxyquinoleines.

The reaction of Tiedtke is an acylation-condensation allowing the creation of a carbon-carbon bond without involvement of halogen or metal and with the formation of water as the only harmless by-product. Initially, Tiedtke described the reaction of anthranilic acid with cyclohexanone by conventional heating. Then, during their studies of Niementowski reaction, Khajavi *et al* [8] have described the reaction of anthranilic acid with cyclohexanone under microwave irradiation. The low microwave absorption of the initial mixture required the use of aprotic dipolar solvents to carry out the reaction with a multimode oven such as a kitchen one. The conditions used[8] do not appear environmentally friendly: the dipolar aprotic solvents such as dimethylacetamide used in this case, are not only toxic but difficult to remove due to their high boiling point. In addition, under these circumstances, the reaction is possible only with a small quantity of reactant and despite this, the results are not very reproducible, so it is very hard to scale-up for getting larger quantities of products. Moreover, the Tiedtke reaction turned out to be of interest for the synthesis of tetrahydroacridones, precursors of acridones and acridines, which are subject of many researches. Acridones are naturally occurring alkaloids, isolated from various plant sources. These alkaloids possess a broad range of biological activities[9] including antimicrobial, antiviral, anticancer, antiparasitic properties… For instance, arborinine,[10-12] isolated from plants of the Rutaceae family, displays several biological effects, as anticancer and antibacterial activities.



Scheme 2. Examples of acridone alkaloids with biological activities.

In addition, several therapeutic agents are based on amino-9-acridine moiety derivating[13-15] from acridones, such as tacrine, ethacridine (abortifacient), nitracrine (antineoplastic), mepacrine (antimalarial properties), amsacrine…

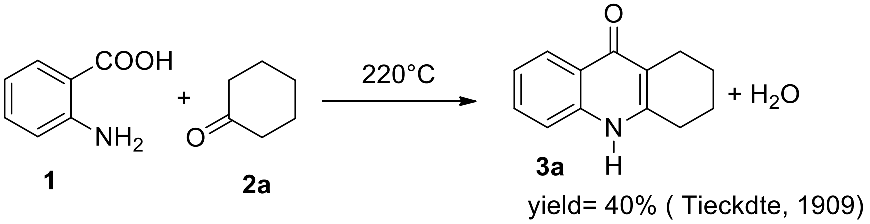


Scheme 3. Examples of amino-9-acridine therapeutics.

Considering the great interest of the reaction of Tiedtke, we decided to resume this reaction under microwave activation by using an adequate reactor (Monowave 300, Anton Paar).[16] The monomode conditions and the controlled emission of microwaves allow reproducible and scaled up experiments. The use of focused microwaves allows the reaction without any solvent[17-19] or catalyst and thus being in green reaction conditions.

Results and Discussion

Tiedtke has described[2] the reaction of anthranilic acid (**1**) with cyclohexanone (**2a**) by conventional heating at 220 °C into 5,6,7,8-tetrahydroacridin-9 (10H)-one (**3a**, Scheme 4).

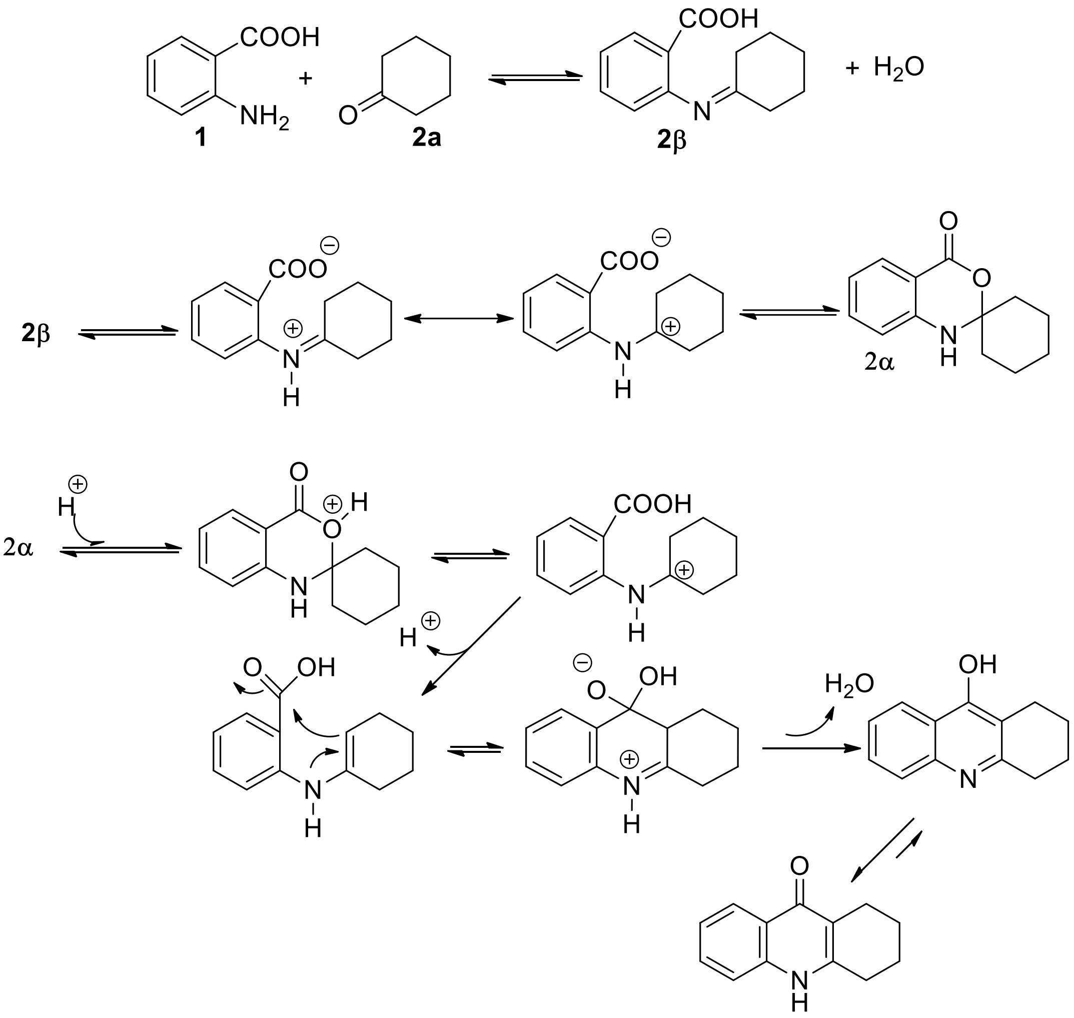


Scheme 4. Original reaction of Tiedtke with anthranilic acid and cyclohexanone.

In our work, we have explored the Tiedtke reaction in green conditions. We have avoided the use of toxic and non volatile dipolar solvent like dimethylacetamide[8] which may cause difficulties for the purification of the product. We have performed reactions without solvent with a monomode microwave cavity Monowave 300[16] able to focus microwave on the stirred reaction mixture. In order to avoid the loss of volatile ketone, the reaction was performed in a closed vessel under pressure, so the mixture was irradiated under very controlled and reproducible conditions; the microwave power was monitored at fixed temperature measured by an infrared thermometer.

According to Tiedtke,[2] the reaction of anthranilic acid and cyclohexanone takes place into two steps: the first one was the formation of a compound (**2**α) at 120 °C and in a second phase, this latter was converted at higher temperature (220 °C) into 1,2,3,4- tetrahydroacridone (**3a**). According to the studies of Badger *et al*,[5] this

compound (**2α**) has a spiro structure. In our experiments, we have isolated and characterised the two compounds (**3a** and **2α**) in relation with heating temperature conditions (Experimental part).
The compound (**2α**) was already used in the synthesis of 9-chloro-1,2,3,4-tetrahydroacridine.[20,21] Clearly the reaction is catalysed by Bronsted acid (provided by trace of anthranilic acid). By analogy with the Friedlander reaction where a mechanism has been reported,[22] we proposed in Scheme 5 the following mechanism for Tiedtke reaction, the key step is an intramolecular acylation of the enamine.



Scheme 5. Proposed mechanism for Tiedtke reaction between anthranilic acid and cyclohexanone with spiro compound as intermediate.

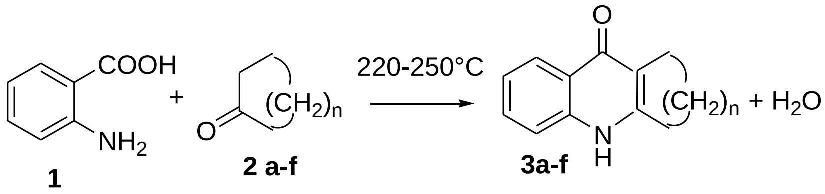
The reaction of Tiedtke can take place with several cyclic ketones (according to Scheme 6) and we have performed it in green conditions, leading to tetrahydroacridones. Some were generally described in the old literature but were poorly documented. We took opportunity of their syntheses to describe and properly attributed the ^{1}H and ^{13}C NMR spectra of the tetrahydroacridones thanks to HSQC, HMBC, COSY and DEPT experiments.

The reactions with cyclopentanone, cycloheptanone and cyclooctanone were previously described and have conducted to the expected products.

More hindered compounds have been then tested requiring more drastic heating and time conditions. It should be noted that often a simple increase of irradiation time, with temperature remaining unchanged, did not permit to get the acridone products.

Interestingly, 3,3,5-trimethylcyclohexanone (**3b**) may lead to two regioisomers. The NMR spectra show unambiguously that only one is formed. The HMBC experiment seems to confirm that the less hindered methylene group promotes the cyclisation into acridone.

In more drastic conditions, the tetramethylcyclohexanone failed to be converted in the expected product. The steric hindrance seems to be too important in this case. Similar remarks can be made with norcamphor and camphor. Norcamphor with anthranilic acid gave an efficient reaction unlike camphor, probably too hindered. The conditions and products obtained are reported in Table 1.



Scheme 6. Generalisation of the Tiedtke reaction with ring ketones under microwave irradiation.

Table 1. Tiedtke reaction with different cyclic ketones with anthranilic acid

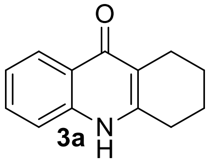
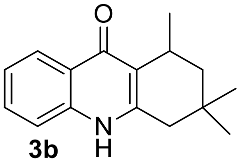
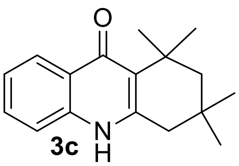
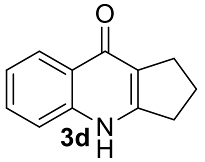
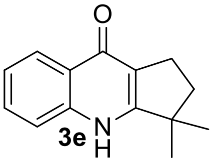
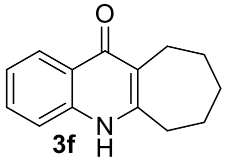
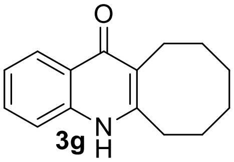
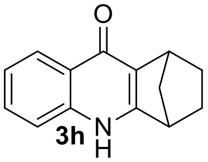
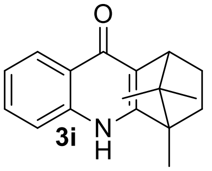
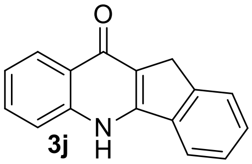
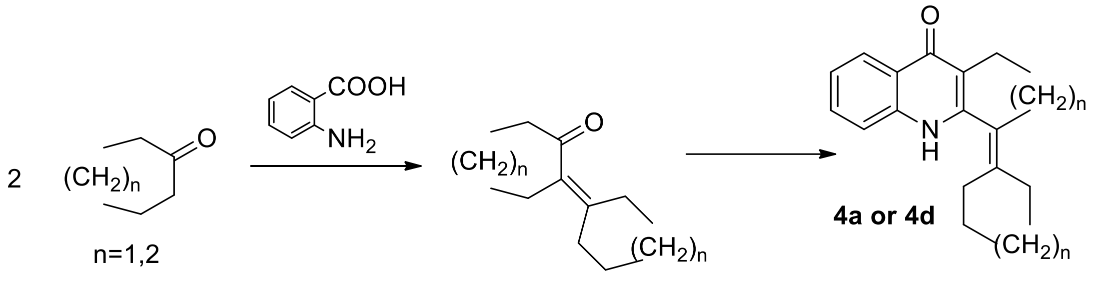
Entry	Ketone	Reaction	Product	Yield %
1	cyclohexanone **2a**	240 °C 5 min	 **3a**	82
2	3,5,5'-trimethylcyclohexanone **2b**	280 °C 5 min	 **3b**	75
3	1,1',4,4'-tetramethyl cyclohexanone **2c**	290 °C 10 min	 **3c**	2
4	cyclopentanone **2d**	190 °C 5 min	 **3d**	70
5	2,2-dimethylcyclopentanone **2e**	210 °C 5 min	 **3e**	80

Table 1. Continued

Entry	Ketone	Reaction	Product	Yield %
6	cycloheptanone **2f**	230 °C 5 min	 **3f**	70
7	cyclooctanone **2g**	220 °C 5min	 **3g**	55
8	norcamphor **2h**	290 °C 5 min	 **3h**	75
9	DL-camphor **2i**	290 °C 10 min	 **3i**	0
10	indanone **2j**	290 °C 5 min	 **3j**	78

*The yields were determined from the isolated products.

In the presence of cyclopentanone, the compound **4d** was already reported by Blount and Plant[23] in the Tiedtke reaction. It corresponds to the result of a rapid selfcondensation of cyclopentanone into enone catalysed by anthranilic acid before the Tiedtke reaction takes place. In our conditions, we did not observe the formation of **4d**, only the expected **3d** product was synthesized, but surprisingly, we have found traces of similar compounds **4a** by mass spectroscopy during the course of the reaction with cyclohexanone **2a**.



Scheme 7. Tiedtke reaction between anthranilic acid and enone resulting from cyclohexanone or cyclopentanone selfcondensation.

The Tiedtke reaction under microwave irradiation is fully reproducible if controlled conditions were used. The reaction without solvent in a closed vessel under pressure allows quasi-quantitative conversion of anthranilic acid into Tiedtke product when a slight excess of volatile ketone was used. The excess of ketone can be recuperated by washing the compound obtained with diethylether and can be recycled after distillation of ether solution. The reaction medium is simply diluted in diethylether and a few drops of methanol are added until complete solubility. Then, the washing with saturated $NaHCO_3$ provokes the precipitation of tetrahydroacridones. at the same time as it permits to eliminate anthranilic acid if necessary. These operatory conditions afforded the expected products in very good purity and no further purification steps are needed.

Conclusions

The reaction of cyclic ketones with anthranilic acid in a closed reactor, under monomode microwave irradiation in controlled conditions allows the efficient synthesis of acridone derivatives. The Tiedtke reaction under these conditions is an example of green synthesis involving the formation of a C-C bond with the formation of a benign water molecule. The reaction takes place without solvent and without catalyst, but the use of a focused microwave irradiation in a single-mode cavity for activation is necessary to be effective. The operatory conditions afforded the expected products by precipitation in very good purity with the minimum use of solvent. New polycyclic compounds obtained can be useful as intermediate of synthesis or pharmaceutical applications.

Experimental Section

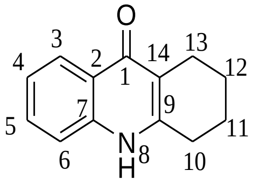
General. The microwave irradiation is monitored with a monomode microwave apparatus Anton Paar Monowave 300, operating at 2450 MHz. The power (power max 800W) was adjusted during the irradiation to maintain the temperature at the indicated value in table 1.
Analytical thin-layer chromatography (TLC) was performed on Merck silica gel 60 plates, 40-63 µm thick with F-254 indicator aluminium sheets. Visualization was accomplished by UV light. IR spectra were recorded with a Perkin-Elmer spectrophotometer equipped with ATR accessory. NMR spectra were recorded at 400, 500 or 600 MHz for ^1H NMR and 100.6, 125.7, 150.9 Hz for ^{13}C NMR with a Bruker AC 400 spectrometer with DMSO-d_6 as solvent and TMS as an internal standard; Chemical shifts (δ) are reported in ppm. The NMR attribution have been made thanks to COSY, DEPT, HMBC and HSQC experiments.

Mass spectra were recorded on a QTOF Micro (Waters) spectrometer with electrospray ionization (ESI, positive mode), lock spray PEG, infusion introduction at 5µL/min, a source temperature of 80°C and desolvatation temperature of 120 °C. Infrared spectra were recorded on a Perkin Elmer "spectrum two" spectrometer.

General procedure. A mixture of anthranilic acid (0.68 g; $4.96\ 10^{-3}$ mol) and cyclic ketone (3 equiv) was stirred and irradiated in a G30 tube under microwave in a Monowave 300 at a specific temperature and during a fixed period (see Table 1) depending on the nature of the ketone. After cooling, the medium was diluted in diethyl ether with a little quantity of methanol (until solubility). Then the solution was washed with saturated $NaHCO_3$, allowing the precipitation of the solid which was obtained by filtration on a Buchner funnel The products obtained were crystallized from a mixture of ethanol and water.

1) Synthesis of 1,2,3,4-tetrahydroacridin-9(10H)-one (3a)[24]

From cyclohexanone according to the general procedure by heating at 240 °C during 5 minutes.

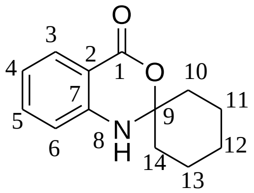


White solid (0.81 g, yield: 82%). mp = 325 °C; mp_{lit}=330-333 °C[24]. IR: ν max (cm^{-1})= 3063, 2784, 1637, 1596, 1550, 1473.^{1}H NMR (500 MHz, DMSO-d_6) δ 8.05 (d, *J*= 7.0 Hz, 1H, **H3**); 7.56 (t, *J*= 7.0 Hz, 1H, **H5**); 7.45 (d, *J*= 7.0 Hz, 1H, **H6**); 7.22 (t, *J*= 7.0 Hz, 1H, **H4**); 2.69 (t, *J*= 6.1 Hz, 2H, **H10**); 2.42 (t, *J*= 6.1 Hz, 2H, **H13**); 1.75 (m, 2H, **H11**); 1.69 (m, 2H, **H12**) ppm. ^{13}C NMR (125 MHz, DMSO-d_6) δ 176.5 (Cq, **C1**); 147.4 (Cq, **C9**); 139.7 (Cq, **C7**); 131.5 (CH, **C5**); 125.3 (CH, **C3**); 123.6 (Cq, **C2**); 122.5 (CH, **C4**); 117.8 (CH, **C6**); 116.0 (Cq, **C14**); 27.6 (CH_2, **C10**); 22.3 (CH_2, **C13**); 22.2 (CH_2, **C12**); 22.0 (CH2, **C11**) ppm. HRMS: Calculated mass for $C_{13}H_{14}NO$ 200.1075; Found: 200.1080.

Traces of 4-cyclohexylidene-1,2,3,4-tetrahydroacridin-9(10H)-one **4a**, the Tiedtke compound obtained after the selfcondensation of cyclohexanone, were observed. HRMS for **(4a)** Calculated mass 280.1701 for $C_{19}H_{22}NO$. Found 280.1701

Synthesis of spiro[benzo[d][1,3]oxazine-2,1'-cyclohexan]-4(1H)-one (2α)[5]

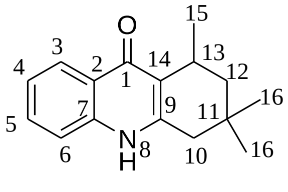
From cyclohexanone according to the general procedure by heating at 130°C during 3 minutes.



White solid. mp=154 °C ; mp_{lit}=155 °C.[5] ^{1}H NMR (500 MHz, DMSO-d_6) δ 7.65 (d, *J*=8.0 Hz, 1H, **H3**), 7.40 (t, *J*=8.0 Hz, 1H, **H5**), 7.35 (s, 1H, **H8**), 6.82 (d, *J*=8.0 Hz, 1H, **H6**), 6.75 (t, *J*=8.0 Hz, 1H, **H4**), 1.92 (m, 2H, H**10**), 1.71 (m, 2H, H**10**), 1.56 (m, 4H, H**11**), 1.47 (m, 1H, **H12**), 1.37 (m, 1H, **H12**) ppm.^{13}C NMR (125 MHz, DMSO-d_6) δ 163.3 (Cq, **C1**) ; 147.2 (Cq, **C7**); 135.9 (CH, **C5**); 129.6 (CH, **C3**); 118.4 (CH, **C4**); 115.9 (CH, **C6**); 111.2 (Cq, **C2**); 90.1 (Cq, **C9**); 35.3 (CH_2, **C10**); 24.8 (CH_2, **C12**); 21.9 (CH_2, **C11**) ppm. HRMS: Calculated mass for $C_{13}H_{16}NO_2$ 218.1181; Found: 218.1186.

2) Synthesis of 1,3,3-trimethyl-1,2,3,4-tetrahydroacridin-9(10H)-one (3b)

From 3,3,5-trimethylcyclohexanone according to the general procedure by heating at 280 °C C during 5 minutes.



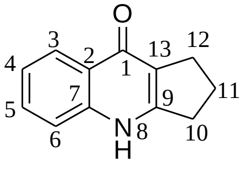
White solid (0.90 g, yield: 75%), mp = 204 °C (dec). IR: ν max (cm^{-1})= 3370, 3091, 2904, 1634, 1588, 1494. ^{1}H NMR (500 MHz, DMSO-d_6) δ 8.03 (dd, *J*= 8.1 and 1.3 Hz, 1H, **H3**), 7.55 (ddd, *J*= 8.0, 6.9 and 1.3 Hz, 1H, **H5**), 7.43 (d, *J*= 8.0 Hz, 1H, **H6**), 7.22 (ddd, *J*= 8.1, 6.9 and 1.0 Hz, 1H, **H4**), 2.84-2.82 (m, 1H, **H13**), 2.62 (d, *J*= 16.2 Hz, 1H, **H10**), 2.33 (dd, *J*= 16.2 and 2.5 Hz, 1H, **H10**), 1.73-1.69 (m, 1H, **H12**), 1.27 (d, *J*= 6.6 Hz, 3H, **H15**), 1.22-1.20 (m, 1H, **H12**), 1.06 (s, 3H, **H16**), 0.85 (s, 3H, **H16**). ^{13}C NMR (125 MHz, DMSO-d_6) δ 176.6 (Cq, **C1**), 147.0 (Cq, **C9**), 139.6 (Cq, **C7**), 131.4 (CH, **C5**), 125.4 (CH, **C3**), 124.6 (Cq, **C2**), 122.6 (CH, **C4**), 118.7 (Cq, **C14**), 117.7 (CH, **C6**), 45.6 (CH_2, **C12**), 41.9 (CH_2, **C10**), 31.0 (CH, **C13**), 30.0 (Cq, **C11**), 26.9 (CH_3, **C16**), 25.3 (CH_3, **C16**), 20.9 (CH_3, **C15**). HRMS: Calculated mass for $C_{16}H_{20}NO$ 242.1545; Found: 242.1541.

3) Synthesis of 1,1,3,3-tetramethyl-1,2,3,4-tetrahydroacridin-9(10H)-one (3c)

From 3,3′,5,5′-tetramethylcyclohexanone according to the general procedure by heating to 290 °C during 10 minutes. Only traces of product **3c** were obtained. HRMS: Calculated mass for $C_{17}H_{22}NO$ 256.1701; Found: 256.1706.

4) Synthesis of 2,3-dihydro-1H-cyclopenta[b]quinolin-9(4H)-one (3d) [25]

From cyclopentanone according to the general procedure by heating at 190 °C during 5 minutes.

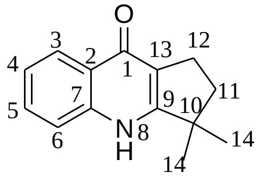


White solid (0.642 g, yield: 70%), mp=320°C; mp^{lit}= 325°C (dec).[25] IR: ν max (cm^{-1})= 3225, 1628. ^1H NMR (400 MHz, DMSO-d_6) δ 8.37–8.40 (m, 2H), 7.78 (t, *J* = 7.6 Hz, 1H) ; 7.58 (t, *J* = 7.6 Hz, 1H) ; 3.47 (t, *J* = 7.6 Hz, 2H); 3.18 (t, *J* = 7.6 Hz, 2H); 2.27 (m, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) 172.9; 156.5; 139.9; 130.8; 124.7; 123.8; 123.3; 120.0; 118.2; 32.1; 27.6; 21.9. HRMS: Calculated mass for $C_{12}H_{12}NO$: 186.0919; Found: 185.0922.

UPLC : column Waters Aquity UPLC CSHC18 1.7μm, Gradient: water+0.01% formic acid/acetonitrile+0.01% formic acid, debit: 0.5 mL/min, temperature column 35°C, temperature sample 20 °C, Retention time of (**3d**) 1.36 min (99%); Retention time of product (**4d**): 2.15 min: (1%) $C_{17}H_{18}NO$ Calculated mass 252.1388; Found 252.1391.

5) Synthesis of 3,3-dimethyl-2,3-dihydro-1H-cyclopenta[b]quinolin-9(4H)-one (3e)

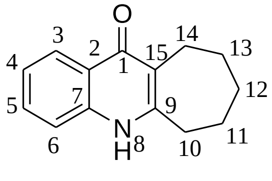
From 2,2-dimethylcyclopentanone according to the general procedure by heating at 210 °C during 5 minutes.



White solid (0.85 g, yield: 80%), mp=192 °C. IR: ν max (cm^{-1})= 2262, 1634, 1584, 1556, 1490, 1470, 1356, 1320.^1H NMR (400 MHz, DMSO-d_6) δ 11.45 (s, 1H, NH); 8.09 (d, *J*= 7.9 Hz, 1H, **H3**); 7.63-7.56 (m, 2H, **H5** and **H6**); 7.26 (t, *J*= 7.9 Hz, 1H, **H4**); 2.64 (t, 2H, **H12**); 1.89 (t, 2H, **H11**); 1.34 (s, 6H, **H14**). ^{13}C NMR (100 MHz, DMSO-d_6) δ 174.6 (Cq, **C1**); 159.8 (Cq, **C9**); 140.5 (Cq, **C7**); 130.7 (CH, **C5**); 125.1 (Cq, **C2**); 124.7 (CH, **C3**); 122.4 (CH, **C4**); 118.2 (CH, **C6**); 117.6 (Cq, **C13**); 44.6 (Cq, **C10**); 38.4 (CH2, **C11**); 26.3 (CH_3, **C14**); 24.8 (CH_2, **C12**). HRMS Calculated mass 214.1232 for C14H16NO. Found 214.1233

6) Synthesis of 7,8,9,10-tetrahydro-5H-cyclohepta[b] quinolin-11(6H)-one (3f)

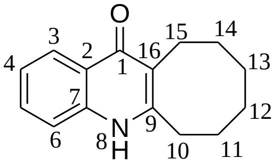
From cycloheptanone according to the general procedure by heating at 230 °C during 5 minutes.



White solid (0.74 g, yield: 70%), mp = 350°C; mp_{lit}=352 °C.[25] IR: ν max (cm^{-1})= 3261, 3058, 2924,1922, 1358. ^1H NMR (500 MHz, DMSO-d_6) δ 8.06 (dd, *J*=8.1 and 1.4 Hz, 1H, **H3**), 7.56 (ddd, *J*=8.1, 6.9 and 1.4 Hz, 1H, **H5**), 7.48 (dd, *J*= 8.1 and 1.0 Hz, 1H, **H6**), 7.25 (ddd, *J*=8.1, 6.9 and 1.0 Hz, 1H, **H4**), 2.82 (m, 2H, **H14**), 2.77 (m, 2H, **H10**), 1.79 (m, 2H, **H12**), 1.65 (m, 2H, **H13**), 1.44 (m, 2H, **H11**). ^{13}C NMR (125 MHz, DMSO-d_6) δ 175.3 (Cq, **C1**), 153.6 (Cq, **C9**), 139.3 (Cq, **C7**), 131.3 (CH, **C5**), 125.8 (CH, **C3**), 123.9 (Cq, **C2**), 123.0 (CH, **C4**), 121.0 (Cq, **C15**), 118.3 (CH, **C6**), 34.0 (CH_2, **C14**), 32.3 (CH_2, **C12**), 27.7 (CH_2, **C11**), 26.3 (CH_2, **C13**), 23.5 (CH_2, **C10**). HRMS: Calculated mass for $C_{14}H_{16}NO$ 214.1232; Found: 214.1224.

7) Synthesis of the 6,7,8,9,10,11-hexahydrocycloocta[b]quinolin-12(5H)-one (3g) [26]

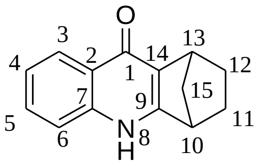
From cyclooctanone according to the general procedure by heating at 220 °C during 5 minutes.



White solid (0.62 g, yield: 55%), mp= 348°C, mp^{lit}=344 °C.[26] IR: ν max= 3091, 3058, 2916, 1633, 1553, 1504, 1477, 1463, 1359. ^1H NMR (400 MHz, DMSO-d_6) δ 11.38 (s, 1H, NH), 8.04 (d, *J*=8.0 Hz, 1H, **H3**), 7.56 (t, *J*=7.6 Hz, 1H, **H5**), 7.47 (d, *J*=8.1 Hz, 1H, **H6**), 7.23 (t, *J*=7.6 Hz, 1H, **H4**), 2.81 (m, 2H, H**10**), 2.68 (m, 2H, H**15**), 1.75 (m, 2H, H**11**), 1.54 (m, 2H, H**14**), 1.42-1.33 (m, 4H, H**12** and H**13**). ^{13}C NMR (100 MHz, DMSO-d_6) δ 175.1 (Cq, **C1**), 149.9 (Cq, **C9**), 139.4 (Cq, **C7**), 130.8 (CH, **C5**), 125.2 (CH, **C3**), 123.4 (Cq, **C2**), 122.2 (CH, **C4**), 118.5 (Cq, **C16**), 117.6 (CH, **C6**), 30.1 (CH2, **C10**), 29.6 (CH2, **C11**), 29.3 (CH_2, **C14**), 26.1 (CH_2, **C13**), 25.6 (CH_2, **C12**), 22.8 (CH_2, **C15**). HRMS: Calculated mass for $C_{15}H_{18}NO$ 228.1388; Found: 228.1395.

8) Synthesis of 1,2,3,4-tetrahydro-1,4-methanoacridin-9(10H)-one (3h)

From norcamphor according to the general procedure by heating at 290 °C during 5 minutes.



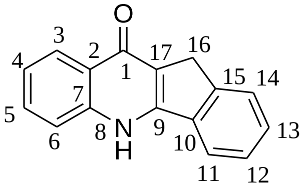
White solid (0.79 g, yield: 75%), mp=325 °C. ν max (cm^{-1})= 3380, 3090, 2904, 1634, 1589, 1494. ^1H NMR (600 MHz, DMSO-d_6) δ 12.19 (s, 1H); 8.09 (dd, *J*= 8.1 and 1.3 Hz, 1H, **H3**); 7.55 (ddd, *J*= 8.3, 6.9 and 1.5 Hz, 1H, **H5**); 7.49 (d, *J*= 8.2 Hz, 1H, **H6**); 7.26 (ddd, *J*= 8.1, 6.9 Hz and 1.2, 1H, **H4**); 3.45 (s, 1H, **H13**); 3.38 (s, 1H, **H10**); 1.97-1.92 (m, 1H, H**11**); 1.89-1.84 (m, 1H, H**12**); 1.66 (d, *J*=8.6 Hz, 1H, **H15**); 1.42 (d, *J*= 8.6 Hz, 1H, **H15'**); 1.24-1.20 (m, 1H, H**11'**); 1.14-1.10 (m, 1H, H**12'**). ^{13}C NMR (150 MHz, DMSO-d_6) δ 171.3 (Cq, **C1**); 159.4 (Cq, **C9**); 139.8 (Cq, **C7**); 130.8 (CH, **C5**); 126.9 (Cq, **C2**); 125.6 (CH, **C3**); 123.2 (Cq, **C14**); 123.0 (CH, **C4**); 118.7 (CH, **C6**); 47.9 (CH, **C15**); 43.8 (CH, **C10**); 38.4 (CH, **C13**); 27.4 (CH_2, **C12**); 26.2 (CH_2, **C11**). HRMS: Calculated mass 212.1075 for $C_{14}H_{14}NO$. Found 212.1075

9) Reaction of camphor

From camphor according to the general procedure by heating at 290 °C during 10 minutes. No product **3i** was obtained.

10) Synthesis of 5H-indeno[2,1-b]quinolin-11(6H)-one (3j)[27]

From 1-indanone according to the general procedure by heating at 290 °C during 5 minutes.



Pale yellow powder (0.91 g, yield: 78%), mp > 300 °C (sublim.) mp^{lit}>300 °C.[27] IR: ν max (cm^{-1})=3069, 2779, 1569, 1469. ^{1}H NMR (500 MHz, DMSO-d_6) δ 8.21 (d, *J*= 8.1 Hz, 1H, **H3**), 8.13 (m, 1H, **Harom**), 7.72-7.68 (m, 3H, **Harom**), 7.54-7.52 (m, 2H, **Harom**), 7.35 (ddd, *J*= 8.1, 6.5 and 1.6 Hz, 1H, **H4**), 3.78 (s, 2H, **H16**). ^{13}C NMR (125 MHz, DMSO-d_6) δ 174.3 (Cq, **C1**), 149.6 (Cq, **C9**), 145.1 (Cq, **C10**); 140.6 (Cq, **C7**), 136.5 (Cq, **C15**), 131.9 (CH, **Carom**), 129.9 (CH, **Carom**), 127.5 (CH, **Carom**), 126.2 (CH, **Carom**), 126.0 (Cq, **C2**), 125.5 (CH, **C3**), 123.3 (CH, **C4**), 121.6 (CH, **Carom**), 120.0 (Cq, **C17**), 118.8 (CH, **Carom**), 33.3 (CH$_2$, **C16**). HRMS: Calculated mass 234.0919 for $C_{16}H_{12}NO$. Found 234.0924

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Supplementary Material

Supplementary material contains NMR spectra.

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