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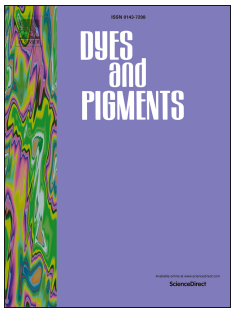

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PII: S0143-7208(18)32720-7

DOI: https://doi.org/10.1016/j.dyepig.2019.02.039

Reference: DYPI 7373

To appear in: *Dyes and Pigments*

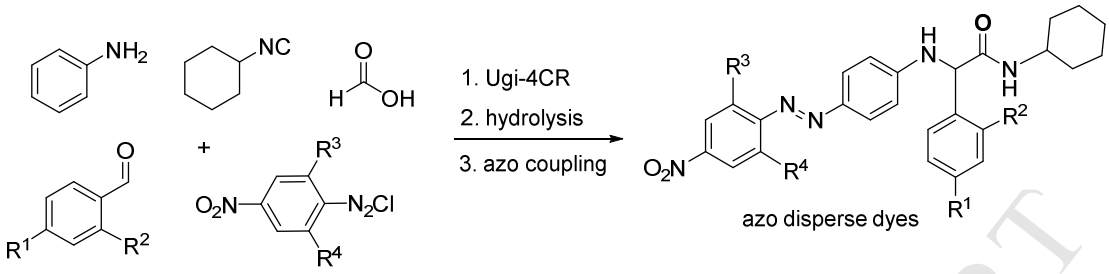
Received Date: 18 December 2018

Revised Date: 18 February 2019

Accepted Date: 23 February 2019

Please cite this article as: Li H, Qian H-F, Feng G, Diversity-oriented synthesis of azo disperse dyes with improved fastness properties via employing Ugi four-component reaction, *Dyes and Pigments* (2019), doi: https://doi.org/10.1016/j.dyepig.2019.02.039.

Graphical Abstract：



Diversity-Oriented Synthesis of Azo Disperse Dyes with Improved Fastness Properties via Employing Ugi Four-component Reaction

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Abstract: A novel approach has been established for accessing structurally diverse azo disperse dyes with improved fastness properties by employing an Ugi four-component reaction (Ugi-4CR). The process includes three steps: (1) Ugi-4CR of aniline, cyclohexyl isocyanide, formic acid, and an aromatic aldehyde; (2) selective hydrolysis of amide functionality in the Ugi product; and (3) coupling the hydrolysis product with an aryl diazonium salt. Employing Ugi four-component reaction herein had advantages over easily controlling the molecular weight/size of the dye. Six new azo disperse dyes were synthesized and their structures were fully characterized by ^{1}H NMR, ^{13}C NMR, MS, and FT-IR. It was found that the washing and sublimation fastness properties of the obtained azo disperse dyes on both poly(ethylene terephthalate) (PET) and nylon fibers were remarkably improved as compared with conventional C.I. Disperse Orange 3. The improved fastness properties should be attributed to the moderately increased molecular weight/size and the amide functionality introduced in Ugi-4CR.

Keywords: diversity-oriented synthesis; azo disperse dye; Ugi four-component reaction; fastness properties

1. Introduction

Disperse dyes are one of the most important dye categories and of great significance in textile industry [1-4]. Among disperse dyes, azo disperse dyes have attracted particular attention and they have been widely applied for dyeing natural and

synthetic fibers [5,6]. Synthetically, azo disperse dyes are easily prepared through coupling electron-poor diazonium salts with electron-rich aromatics to form a Donor-π-Acceptor system. A broad range of colors could be readily obtained by tuning the electronic properties of substituents on both coupling partners. Recently, with the development of new fibers, the existing azo disperse dyes show some relative drawbacks in color fastness. Thus, developing new synthetic approaches to rapidly access structurally diverse azo disperse dyes with good to excellent dyeing properties is highly desirable.

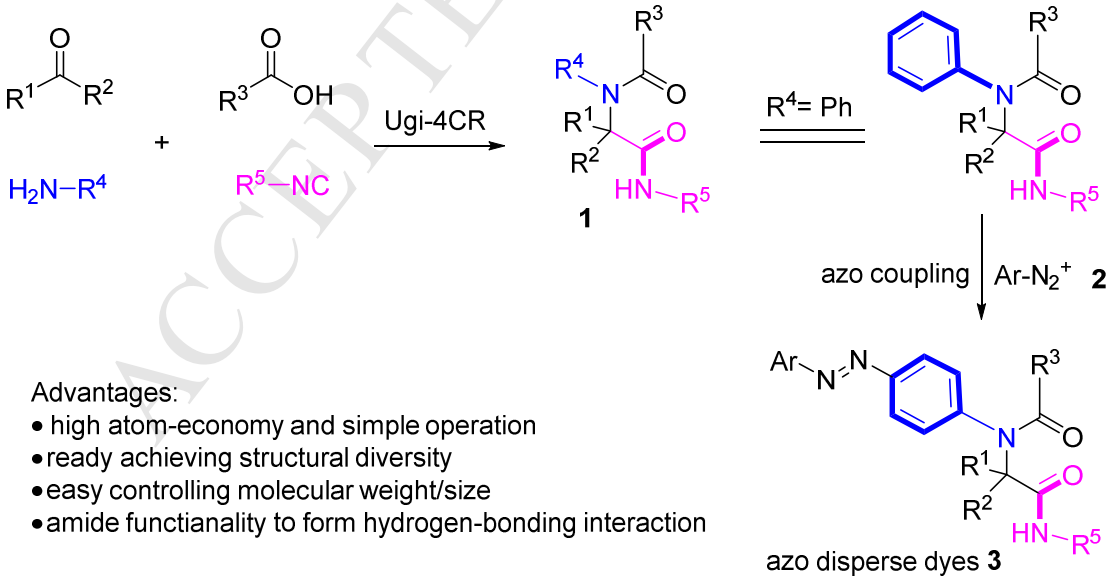
It has been demonstrated that increasing the interaction between fiber and disperse dye reduces dye migration, leading to improved dyeing properties [7,8]. Generally, there are two ways to minimize the degree of migration and improve dye fastness properties: one is the moderate increase of the disperse dye molecular weight/size. As the weight/size of disperse dye becomes larger, the van der Waals force between disperse dye and fiber becomes stronger once a disperse dye penetrates into the fiber [9-13]. The other is introducing special functional groups, such as ester, amide, and urethane that can form hydrogen bonding with fibers. Therefore, to design disperse dyes with good dyeing properties, a moderate increase of molecular weight/size along with introducing functional groups that can form hydrogen-bonding interactions with fibers are two generally useful principles.

Diversity-oriented synthesis [14-16] (DOS) has emerged as a powerful approach to access a library of skeletally and stereochemically diverse small molecules for discovering prospective drug candidates through high-throughput screening. Multicomponent reactions [17,18] (MCRs) assemble three or more reactants in a highly atom-economic manner and provide an excellent platform for efficient generation of molecules with diversity and complexity through changing one of the reactants or post-manipulations of the resulting products[19-21]. Ugi four-component reaction (Ugi-4CR)[22], the condensation of an aldehyde, an amine, an isocyanide, and a carboxylic acid for rapid providing α-aminoacyl amide derivatives **1** (Scheme 1), features with mild reaction conditions, 100% atom economy, and easy generation of structural diversity. It has been widely applied in diversity-oriented synthesis of

heterocycles [23], drug candidates [24], natural products [25,26], polymers [27-29], and so on. However, it has not been yet reported, to the best of our knowledge, in the synthesis and application of disperse dyes.

We envisaged that a Ugi product **1** is an ideal azo coupling partner (R^4 = Ph) to be coupled with an aryl diazonium salt **2** for the synthesis of structurally diverse azo disperse dyes with controlled molecular weight/size and good fastness properties (Scheme 1). The azo disperse dyes obtained through this method have several advantages: (1) the structure diversity and the controlling molecular weight/size of dye could be easily achieved by changing one or more of the four inputs; (2) the amide subunit introduced in Ugi-4CR can form hydrogen-bonding interactions with fibers and it is good for improving fastness properties. Connecting our ongoing research on developing novel disperse dyes [7,8], we report herein diversity-oriented synthesis of azo disperse dyes with controlled molecular weight/size and improved fastness properties by employing an Ugi-4CR.

Scheme 1. Ugi four-component reaction and it's application in azo disperse dye synthesis.



2. Experimental

2.1. General

C.I. Disperse Orange 3 was provided by Zhejiang Longsheng Chemical Co., Ltd (China) and purified by repeated recrystallization in acetone before use. The structure is illustrated in Fig. 1.

Dispersing agent sodium salt of polycondensated naphthalenesulfonic acid [MF] was obtained from Zhejiang Longsheng Co., Ltd (China). Acetone, *N*,*N*-dimethylformamide, sodium hydroxide, ammonium sulfate and sodium dithionite were purchased from Aladdin industrial corporation and used as received. In addition, other chemical reagents used in the synthesis and characterization were laboratory reagent grades.

^{1}H NMR and ^{13}C NMR spectra were recorded on Brucker AVANCE 400MHz spectrometer (400 MHz for ^{1}H NMR and 100 MHz for ^{13}C NMR, respectively). NMR chemical shifts are expressed in δ values with reference to the residual solvent peaks or TMS as internal standard. IR spectra were measured on Shimadzu prestige 21 FT-IR spectrophotometer. MS analysis was carried out on Agilent Technologies 1200 Series LC-MS system. UV-visible absorption spectra were measured in 1 cm quartz cells on a UV 2450 spectrophotometer (JPN, SHIMADZU).

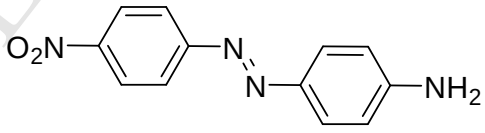


Fig. 1. Structure of C.I. Disperse Orange 3

2.2 Synthesis

Synthetic procedures for the six azo disperse dyes **3** are depicted in Scheme 2. The sequence includes three steps: (1) Ugi four-component reaction; (2) selective amide hydrolysis of Ugi products; and (3) coupling with aryl diazonium salts. It is

noteworthy that direct azo coupling of an Ugi product with a diazonium salt was not successful. Thus, a three-step sequence was employed.

2.2.1 Ugi four-component reaction

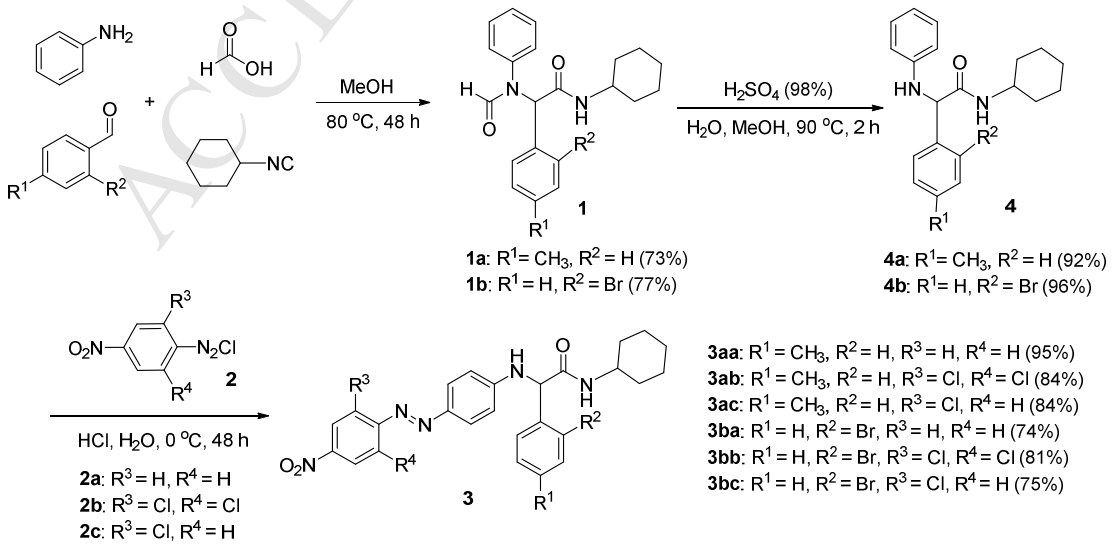
A general procedure for synthesis of **1a**: A 250 mL round bottom flask was charged with anhydrous methanol (150 mL), aniline (4.39 mL, 48.16 mmol, 1.05 eq), *p*-methylbenzaldehyde (4.9 mL, 48.16 mmol, 1.05 eq), formic acid (2.07 mL, 55.04 mmol, 1.2 eq), and cyclohexyl isocyanide (5.69 mL, 45.87 mmol, 1.0 eq) sequentially. The resultant mixture was heated at 80 □ in an oil bath for 48 h until the reaction went to completion according to TLC analysis. The reaction mixture was firstly cooled to room temperature, and then put in refrigerator to precipitate the product as a white solid. The solid was obtained as the desired Ugi product **1a** (7.09 g) through a sequence of filtration, washing with a mixture of EtOAc and petroleum ether (1:5), and drying under vacuum. The solvent of filtrate was then removed with rotavapor under reduced pressure, and the other portion of product (4.66 g) was obtained with high quality according to ^{1}H NMR analysis. The overall yield of **1a** was 73%. Ugi product **1b** was synthesized in 77% yield by following the same procedure as described for **1a**.

2.2.2 Selective amide hydrolysis of Ugi product

A general procedure for synthesis of **4a:** A 100 mL round bottom flask was charged with Ugi product **1a** (7.09 g, 20.26 mmol) and methanol (70 mL), followed by slowly adding a mixture of water (17.5 mL) and concentrated sulfuric acid (98%, 17.5 mL) at room temperature. After stirring at 90 □ in an oil bath for 2 h, the reaction went to completion according to TLC analysis. The reaction mixture was firstly neutralized with aqueous NaOH (5 mol/L) and then extracted with ethyl acetate three times. The organic layers were combined and then concentrated under reduced pressure. After drying under vacuum, the hydrolysis product **4a** (6.02 g, 92% yield) was obtained in high quality according to ^{1}H NMR analysis. The hydrolysis product **4b** was synthesized in 96% yield by following the same procedure as described for **4a**.

2.2.3 Coupling with diazonium salts (Synthesis of azo disperse dyes)

A general procedure for synthesis of azo disperse dye **3aa**: A 50 mL round bottom flask was charged with deionized water (4 mL), concentrated hydrochloric acid (36.5%, 4 mL) and 4-nitroaniline (0.64 g, 4.65 mmol, 1.5 eq). The resultant mixture was firstly heated at 40~60 □ for 2 h, then cooled to 0 □ in an ice bath. The mixture was then treated with aqueous sodium nitrite (0.32 g, 4.65 mmol, 1.5 eq, 4 mL) and stirred at the same temperature for 2 h to form 4-nitrophenyldiazonium salt **2a**. Diazonium salts **2b** and **2c** were synthesized by following the same procedure as described for **2a**. A 50 mL round bottom flask was charged with the hydrolysis product **4a** (1.00 g，3.10 mmol，1.0 eq), methanol (10 mL), deionized water (5 mL), and acetic acid (2 mL). After cooling to 0 ℃ in an ice bath, 4-nitrophenyldiazonium salt prepared above was added slowly and the resultant mixture was stirred at room temperature for 24 h until the coupling reaction went to completion according to TLC analysis. The mixture was neutralized with aqueous NaOH (5 mol/L) and filtered. The solid obtained was washed with a mixture of EtOAc and petroleum ether (1:5). After recrystallization from ethyl acetate, followed by drying under vacuum, the desired azo disperse dye **3aa** was obtained (1.39 g, 95% yield). Azo disperse dyes **3ab** (84% yield), **3ac** (84% yield), **3ba** (74% yield), **3bb** (81% yield), **3bc** (75% yield) were synthesized by following the same procedure as described for **3aa**.



Scheme 2. Synthesis of azo disperse dyes **3**

2.3 Characterization

The structures of Ugi products (**1a**, **1b**), hydrolysis products (**4a**, **4b**), and the final azo disperse dyes (**3aa**, **3ab**, **3ac**, **3ba**, **3bb**, **3bc**) were ambiguously confirmed by ^{1}H NMR, ^{13}C NMR, MS, and IR analysis.

N-Cyclohexyl-2-(*N*-phenylformamido)-2-(*p*-tolyl)acetamide **1a**: white solid, 73% yield, mp 163–164 ^{o}C. IR λ_{max} (KBr)/cm^{-1} 3273, 3085, 2926, 1668, 1652, 1559, 700 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 8.39 (s, 1H), 7.26–7.24 (m, 3H), 7.19–7.16 (m, 2H), 7.12 (d, *J* = 8.0 Hz, 2H), 7.06 (d, *J* = 8.0 Hz, 2H), 5.96 (s, 1H), 5.77 (br d, *J* = 8.0 Hz, 1H), 3.88-3.81 (m, 1H), 2.30 (s, 1H), 1.95–1.88 (m, 2H), 1.70–1.57 (m, 3H), 1.41–1.30 (m, 2H), 1.17–1.05 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.1, 163.1, 139.5, 138.4, 131.2, 129.6 (×2), 129.3 (×2), 128.9 (×2), 128.2 (×2), 127.8, 63.6, 48.8, 32.8, 32.7, 25.5, 24.8, 24.7, 21.1. MS (+ESI): m/z (%) = 351 (100) [M+H^{+}], 373 (60) [M+Na^{+}]. Found: C, 75.18; H, 7.45; N, 7.92%; $C_{22}H_{26}N_2O_2$ requires C, 75.40; H, 7.48; N, 7.99%.

2-(2-Bromophenyl)-*N*-cyclohexyl-2-(*N*-phenylformamido)acetamide **1b**: white solid, 77% yield, mp 166–167 ^{o}C. IR λ_{max} (KBr)/cm^{-1} 3347, 2929, 1692, 1663, 766, 700 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.42 (s, 1H), 7.50 (d, *J* = 6.8 Hz, 1H), 7.31–7.29 (m, 3H), 7.19–7.18 (m, 3H), 7.12–7.06 (m, 2H), 6.32 (s, 1H), 5.78 (d, *J* = 6.8 Hz, 1H), 3.89–3.87 (m, 1H), 2.06–1.92 (m, 2H), 1.75–1.60 (m, 3H), 1.37–1.35 (m, 2H), 1.25–1.06 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ.167.6, 163.0, 138.3, 133.5, 133.0, 131.8, 130.2, 128.7 (×2), 128.4 (×2), 127.9, 127. 3, 125.8, 62.5, 49.1, 32.7 (×2), 25.5, 24.8, 24.7. MS (+ESI): m/z (%) = 415 (100) [M+H^{+}], 417 (100) [M+2+H^{+}]. Found: C, 60.54; H, 5.53; N, 6.67%; $C_{21}H_{23}BrN_2O_2$ requires C, 60.73; H, 5.58; N, 6.74 %.

N-Cyclohexyl-2-(phenylamino)-2-(*p*-tolyl)acetamide **4a**: white solid, 92% yield, mp 123–124 ^{o}C. IR λ_{max} (KBr)/cm^{-1} 3300, 2930, 2854, 1647, 1505, 749 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, *J* = 8.4 Hz, 2H), 7.23–7.19 (m, 4H), 6.82 (dd, *J* = 7.6, 7.2 Hz, 1H), 6.68 (br d, *J* = 7.6 Hz, 1H), 6.65 (d, *J* = 7.6 Hz, 2H), 4.69 (s, 1H),

3.87–3.78 (m, 1H), 2.37 (s, 3H), 1.93–1.81 (m, 2H), 1.72–1.58 (m, 3H), 1.40–1.29 (m, 2H), 1.22–1.01 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.2, 146.8, 138.3, 136.0, 129.8 (×2), 129.3 (×2), 127.3 (×2), 119.1, 113.9 (×2), 64.1, 48.1, 33.0, 32.8, 25.4, 24.8, 24.7, 21.2. MS (+ESI): m/z (%) =323 (100) [M+H$^+$]. Found: C, 78.13; H, 8.08; N, 8.75%; $C_{21}H_{26}N_2O$ requires C, 78.22; H, 8.13; N, 8.69%.

2-(2-Bromophenyl)-*N*-cyclohexyl-2-(phenylamino)acetamide **4b**: white solid, 96% yield, mp 134–135 ^{o}C. IR λ_{max}(KBr)/cm^{-1} 3396, 3349, 2932, 1674, 1603, 1508, 747 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.8 Hz, 1H), 7.49 (d, *J* = 9.2 Hz, 1H), 7.31 (d, *J* = 8.4, 7.6 Hz, 1H), 7.21–7.14 (m, 3H), 6.75 (dd, *J* = 7.2, 7.2 Hz, 1H), 6.57 (d, *J* = 8.4 Hz, 1H), 6.41 (br d, *J* = 7.2 Hz, 1H), 5.27 (s, 1H), 5.06 (br s, 1H), 3.86-3.78 (m, 1H), 1.97 (d, *J* = 15.2 Hz, 1H), 1.77–1.70 (m, 2H), 1.60–1.58 (m, 2H), 1.45–1.12 (m, 5H), 1.08–1.02 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.0, 146.1, 138.5, 133.1, 129.8, 129.3, 128.7 (×2), 128.5, 123.8, 118.4, 113.5 (×2), 61.2, 48.4, 32.8, 32.5, 25.4, 24.5, 24.4. MS (+ESI): m/z (%) = 386 (100) [M$^+$]. Found: C, 62.20; H, 6.01; N, 7.27%; $C_{20}H_{23}BrN_2O$ requires C, 62.02; H, 5.99; N, 7.23%.

(*E*)-*N*-Cyclohexyl-2-((4-((4-nitrophenyl)diazenyl)phenyl)amino)-2-(*p*-tolyl)acetamide **3aa**: dark red solid, 95% yield, mp 198–199 ^{o}C. IR λ_{max} (KBr)/cm^{-1} 3401, 2932, 1667, 1515, 1339, 1141, 860 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 8.34 (d, *J* = 9.2 Hz, 2H), 7.93 (d, *J* = 9.2 Hz, 2H), 7.84 (d, *J* = 9.2 Hz, 2H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.23 (d, *J* = 8.0 Hz, 2H), 6.68 (d, *J* = 8.8 Hz, 2H), 5.89 (br d, *J* = 8.4 Hz, 1H), 5.66 (d, *J* = 3.6 Hz, 1H), 4.85 (d, *J* = 3.6 Hz, 1H), 3.84–3.76 (m, 1H) , 2.38 (s, 3H), 1.93 (d, *J* = 12.0 Hz, 1H), 1.78–1.58 (m, 4H), 1.39-1.32 (m, 2H), 1.20–1.11 (m, 2H), 1.04-0.95 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.1, 156.5, 150.4, 147.7, 145.4, 138.7, 135.3, 130.2 (×2), 127.0 (×2), 126.0 (×2), 124.7 (×2), 122.8 (×2), 113.5 (×2), 62.1, 48.6, 32.9, 32.6, 25.3, 24.7, 24.5, 21.2.MS (+ESI): m/z (%) = 588 (100), 472 (35) [M+H$^+$]. Found: C, 68.93; H, 6.25; N, 14.80%; $C_{27}H_{29}N_5O_3$ requires C, 68.77; H, 6.20; N, 14.85%.

(*E*)-*N*-Cyclohexyl-2-((4-((2,6-dichloro-4-nitrophenyl)diazenyl)phenyl)amino)-2-(*p*-tol yl)acetamide **3ab**: red solid, 84% yield, mp 215–216 ^{o}C. IR λ_{max}(KBr)/cm^{-1} 2984, 1739, 1373, 1238, 1046 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (s, 2H), 7.83 (d, *J* =

8.8 Hz, 2H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.22 (d, *J* = 8.0 Hz, 2H), 6.67 (d, *J* = 8.8 Hz, 2H), 5.92 (d, *J* = 8.0 Hz, 1H), 4.88 (s, 1H), 3.84–3.75 (m, 1H), 2.37 (s, 3H), 1.94 (d, *J* = 9.2 Hz, 1H), 1.77–1.68 (m, 2H), 1.60 (d, *J* = 10.0 Hz, 2H), 1.40–1.25 (m, 2H), 1.18–1.12 (m, 2), 1.02–0.96 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.0, 153.8, 151.1, 145.3, 144.9, 138.8, 135.2, 130.2 (×2), 127.9 (×2), 127.0 (×2), 126.2 (×2), 124.2 (×2), 113.3 (×2), 61.7, 48.8, 32.9, 32.6, 25.3, 24.7, 24.6, 21.2. MS (+ESI): m/z (%) = 392 (100), 540 (52) [M+H$^+$]. Found: C, 59.98; H, 5.03; N, 12.92%; $C_{27}H_{27}Cl_2N_5O_3$ requires C, 60.01; H, 5.04; N, 12.96%.

(*E*)-2-((4-((2-Chloro-4-nitrophenyl)diazenyl)phenyl)amino)-*N*-cyclohexyl-2-(*p*-tolyl)acetamide **3ac**: dark red solid, 84% yield, mp 149–151 ^{o}C. IR λmax(KBr)/cm^{-1} 3389, 3341, 2928, 1687, 1603, 1516, 1142 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, *J* = 2.0 Hz, 1H), 8.14 (dd, *J* = 8.8, 2.4 Hz, 1H), 7.86 (d, *J* = 8.8 Hz, 2H), 7.74 (d, *J* = 8.8 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 7.22 (d, *J* = 7.6 Hz, 2H), 6.67 (d, *J* = 8.8 Hz, 2H), 5.87 (br s, 1H), 5.85 (br s, 1H), 4.87 (s, 1H), 3.83–3.76 (m, 1H), 2.37 (s, 3H), 1.94 (d, *J* = 9.2 Hz, 1H), 1.77–1.68 (m, 2H), 1.60 (d, *J* = 12.0 Hz, 2H), 1.42–1.28 (m, 2H), 1.21–1.12 (m, 2H), 1.04–0.96 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.0, 152.9, 150.8, 147.5, 145.8, 138.7, 135.3, 134.3, 130.2 (×2), 127.0 (×2), 126.0, 122.6 (×2), 118.1, 113.5 (×2), 61.8, 48.7, 32.9, 32.6, 25.3, 24.7, 24.5, 21.2. MS (+ESI): m/z (%) = 506 (15) [M+H$^+$], 529 (100). Found: C, 64.25; H, 5.59; N, 13.89%; $C_{27}H_{28}ClN_5O_3$ requires C, 64.09; H, 5.58; N, 13.84%;

(*E*)-2-(2-Bromophenyl)-*N*-cyclohexyl-2-((4-((4-nitrophenyl)diazenyl)phenyl)amino)acetamide **3ba**: dark red solid, 74% yield, mp 153–154 ^{o}C. IR λ_{max}(KBr)/cm^{-1} 3308, 2930, 1676, 1601, 1333, 1136 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 8.33 (d, *J* = 8.8 Hz, 2H), 7.91 (d, *J* = 8.8 Hz, 2H), 7.83 (d, *J* = 8.8 Hz, 2H), 7.66 (dd, *J* = 8.0, 0.8 Hz, 1H), 7.49 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.33 (dd, *J* = 7.6, 7.6 Hz, 1H), 7.22 (ddd, *J* = 7.6, 7.6, 1.2 Hz, 1H), 6.60 (d, *J* = 8.8 Hz, 1H), 6.12 (d, *J* = 4.8 Hz, 1H), 6.10 (d, *J* = 7.6 Hz, 1H), 5.45 (d, *J* = 4.8 Hz, 1H), 3.84–3.75 (m, 1H), 1.99–1.95 (m, 1H), 1.73–1.69 (m, 2H), 1.62–1.57 (m, 2H), 1.46–1.19 (m, 4H), 1.11–1.01 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.8, 156.3, 149.7, 147.6, 145.0, 137.6, 133.2, 130.2, 128.9, 128.3, 126.4, 124.7, 123.2, 122.7, 113.3, 59.4, 48.7, 32.7, 32.3, 25.3, 24.4, 24.3.

MS (+ESI): m/z (%) = 536 (45) [M+H$^+$], 538 (53) [M+2+H$^+$]. Found: C, 58.09; H, 4.94; N, 13.13%; $C_{26}H_{26}BrN_5O_3$ requires C, 58.22; H, 4.89; N, 13.06%.

(*E*)-2-(2-Bromophenyl)-*N*-cyclohexyl-2-((4-((2,6-dichloro-4-nitrophenyl)diazenyl)phenyl)amino)acetamide **3bb**: red solid, 81% yield, mp 215–216 ^{o}C. IR λ_{max}(KBr)/cm^{-1} 2927, 1602, 1515, 1137, 906, 780 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.26 (s, 2H), 7.83 (d, *J* = 8.8 Hz, 2H), 7.66 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.49 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.34 (dd, *J* = 6.8, 6.8 Hz, 1H), 7.23 (ddd, *J* = 8.0, 8.0, 2.0 Hz, 1H), 6.60 (d, *J* = 8.8 Hz, 2H), 6.26 (d, *J* = 4.8 Hz, 1H), 6.08 (d, *J* = 8.0 Hz, 1H), 5.47 (d, *J* = 4.8 Hz, 1H), 3.83–3.75 (m, 1H), 1.99-1.95 (m, 1H), 1.72–1.69 (m, 2H), 1.62–1.56 (m, 2H), 1.43–1.19 (m, 4H), 1.11–1.01 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.7, 153.8, 150.2, 145.3, 144.8, 137.6, 133.2, 130.2, 128.9, 128.3, 127.9, 126.4, 124.2, 123.1, 113.1, 59.2, 48.7, 32.7, 32.3, 29.7, 26.9, 25.3, 24.4, 24.3. MS (-ESI): m/z (%) = 602 (75) [M-H$^+$], 604 (100), 606 (39). Found: C, 51.54; H, 3.94; N, 11.42%; $C_{26}H_{24}BrCl_2N_5O_3$ requires C, 51.59; H, 4.00; N, 11.57%.

(*E*)-2-(2-Bromophenyl)-2-((4-((2-chloro-4-nitrophenyl)diazenyl)phenyl)amino)-*N*-cyclohexylacetamide **3bc**: dark red solid, 75% yield, mp 180–181 ^{o}C. IR λ_{max}(KBr)/cm^{-1} 3406, 3324, 1677, 1604, 1519, 1137, 1114 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.39 (d, *J* = 2.0 Hz, 1H), 8.15 (dd, *J* = 8.8, 2.0 Hz, 1H), 7.86 (d, *J* = 8.4 Hz, 2H), 7.74 (d, *J* = 8.8 Hz, 1H), 7.66 (d, *J* = 7.6 Hz, 1H), 7.48 (d, *J* = 7.2 Hz, 1H), 7.33 (dd, *J* = 8.0, 8.0 Hz, 1H), 7.23 (dd, *J* = 8.0, 8.0 Hz, 1H), 6.59 (d, *J* = 8.8 Hz, 2H), 6.25 (br d, *J* = 4.4 Hz, 1H), 6.10 (br d, *J* = 8.0 Hz, 1H), 5.47 (d, *J* = 4.8 Hz, 1H), 3.83–3.76 (m, 1H), 1.97 (d, *J* = 9.2 Hz, 1H), 1.71–1.57 (m, 4H), 1.45–1.19 (m, 4H), 1.10–1.02 (m, 1H). ^{13}C NMR (100 MHz, CDCl3) δ 167.7, 152.9, 150.0, 147.5, 145.7, 137.6, 134.2, 133.2, 130.2, 128.9, 128.3, 126.8, 126.0, 123.1, 122.6, 118.1, 113.3, 59.3, 48.7, 32.7, 32.3, 25.3, 24.4, 24.2. MS (-ESI): m/z (%) = 568 (57) [M-H$^+$], 570 (100). Found: C, 54. 59; H, 4.48; N, 12.34%; $C_{26}H_{25}BrClN_5O_3$ requires C, 54.70; H, 4.41; N, 12.27%.

2.4. Dyeing and fastness measurement

The PET and PA fibers used in this study were provided by Zhejiang Longsheng

Chemical Co., Ltd. (China). The PA fibers were scoured with 2 g/L of soap powder and 1 g/L of sodium carbonate at 100 °C for 30 minutes before use, and the bath ratio was 30:1, then rinsed with water and dried at room temperature.

The purified dyes and dispersing agent MF (weight ratio 1:1) were milled to dye dispersions having an average particle size of less than 0.5μm. For each of new dyes, a series of dye baths containing different initial concentration of dye ranging from 0.125% to 5% o.w.f and 1 g/L ammonium sulfate were prepared, respectively, and all the liquor ratios were 100:1. Dyeings were performed in an IR laboratory dyeing machine (RAPID, China). The dyeing procedure on PET fibers was carried out by raising the dye bath temperature from 70 °C to 130 °C at a rate of 1 □/min, maintained at this temperature for 180 min, and then reduced to 85 □. The dyeing process on PA fibers was started at 40 □, and the temperature was raised from 40 □ to 110 □ at rate of 1 □/min, maintained for 60 min at the final temperature, and then reduced to 85 □. In order to remove the adsorbed dyestuff molecules from the dyed fabrics, dyed PET and PA fibers were cleaned through reduction with an aqueous solution containing sodium hydroxide (2 g/L) and sodium hydrosulphite (2 g/L) at 85 □ using a liquor ratio of 50:1 for 15 min, and then rinsed with water and dried at room temperature. Dyeings of 1:1 standard depth on PET and PA fibers for each of dyes were obtained.

The test methods used for measurement of fastness were ISO 105-C06 for washing, ISO 105-X12 for rubbing, and ISO 105-P01 for sublimation.

3. Results and discussion

3.1 Spectra properties

Visible absorption experiments of C.I. Disperse Orange 3, **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, and **3bc** were carried out and the results are summarized in Table 1. Compared azo disperse dye **3aa** with **3ba**, **3ab** with **3bb**, and **3ac** with **3bc**, it is evident that the maximum visible absorption wavelengths are similar. Thus, we can conclude that the

coupling partner obtained through a sequence of Ugi-4CR and hydrolysis is very suitable for synthesizing a library of structurally diverse and molecular weight/size controlled azo disperse dyes. On the other hand, comparing azo disperse dyes **3aa**, **3ab**, and **3ac** (or **3ba**, **3bb**, and **3bc)**, the maximum visible absorption wavelengths are quite different, indicating the color of the azo disperse dye obtained is mainly dependent on diazonium salt counterparts. Therefore, a broad range of colors can be achieved by tuning the electron-withdrawing properties of the substitutions on diazonium salt counterparts. It is noteworthy that the dichloro-substituted dyes **3ab** and **3bb** show hypsochromic shift as comparing with nonchloro-substituted dyes **3aa** and **3ba**, which is reasoned by the fact that benzene rings on both sides of -N=N- group were twisted to a certain extent and the conjugation of donor-π-acceptor system was lowered due to the steric hindrance of two chlorine substitutions at the *ortho* positions of diazonium group.

Table 1 Visible absorption of C.I. Disperse Orange 3, **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, and **3bc** in DMF.

dyes	λ_{max}	$W_{1/2}$(nm) [a]	Ɛ(l·mol^{-1}·cm^{-1})
C.I. Disperse Orange 3	467	123	30777
3aa	464	124	29393
3ab	420	144	23891
3ac	489	124	38512
3ba	461	116	34323
3bb	416	142	26158
3bc	484	125	36237

[a] $W_{1/2}$:Peak width at half height.

3.2 Fastness properties

The color fastness testing results of C.I. Disperse Orange 3, **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, **3bc** on nylon and PET fibers are shown in Tables 2 and 3, respectively. As

shown in Table 2, the washing and sublimation fastness properties of C.I. Disperse Orange 3 on nylon were extremely poor, especially, the grades of staining ratings on acetate cellulose and nylon were only 1, while the grade of the staining rating of sublimation was 1-2. To our delight, it was found that both the washing and sublimation fastness properties of the synthesized dyes **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, **3bc** on nylon were good to excellent. Particularly, the staining ratings on acetate cellulose and nylon were increased from 1 to 3, or even higher than 3, and the staining ratings of sublimation were improved to 4-5, or even 5. Similarly, the six synthesized dyes also exhibited excellent washing and sublimation fastness on PET fiber as shown in Table 3. It was noteworthy that the staining ratings of sublimation on PET were greatly improved to 4, or even higher, as compared with that of C.I.Disperse Orange 3. We reasoned that the improvements should be attributed to appropriate increase of the dye molecular weight/size and the amide functionality introduced in Ugi reaction, resulting in the enhanced van der Waals force and the formation of hydrogen-bonding interaction of dyes with fibers, respectively.

Table 2. Fastness testing of C.I.Disperse Orange 3, **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, and **3bc** on nylon fibers.

Dyes	Washing fastness							Sublimation fastness	
	Shade change	Staining						Shade change	Staining
		1	2	3	4	5	6		
Orange 3	4	1	3-4	1	2-3	3-4	2-3	3-4	1-2
3aa	4	3-4	4-5	3	3-4	4-5	4	4-5	4-5
3ab	4-5	5	5	5	3-4	5	4-5	4-5	4-5
3ac	4-5	3-4	4-5	3	3-4	4-5	3-4	4-5	4-5
3ba	4	4	4-5	3	3-4	4-5	3-4	4	5
3bb	4	5	5	4-5	4-5	5	4-5	4-5	5
3bc	4-5	4-5	5	3-4	4	4-5	4-5	4-5	5

1: staining acetate cellulose; 2: staining cotton; 3: staining nylon; 4: staining polyester; 5: staining

polyacrylonitrile; 6: staining wool.

Table 3 Fastness testing of C.I.Disperse Orange 3, **3aa**, **3ab**, **3ac**, **3ba**, **3bb**, and **3bc** on PET fibers.

Dyes	Washing fastness							Sublimation fastness	
	Shade change	Staining						Shade change	Staining
		1	2	3	4	5	6		
Orange 3	4-5	4	5	4	4-5	5	4-5	5	1
3aa	4-5	5	5	5	5	5	4-5	4-5	4
3ab	5	5	5	5	5	5	4-5	5	5
3ac	5	5	5	4-5	4-5	5	4-5	5	4-5
3ba	4-5	5	5	4-5	5	5	4-5	5	4
3bb	4-5	5	5	5	5	5	4-5	4-5	5
3bc	5	5	5	5	5	5	4-5	4-5	4-5

1: staining acetate cellulose; 2: staining cotton; 3: staining nylon; 4: staining polyester; 5: staining polyacrylonitrile; 6: staining wool

4. Conclusion

In conclusion, we have developed a novel and general protocol for efficient synthesis of structurally diverse azo disperse dyes with good to excellent fastness properties though a sequence of Ugi four-component reaction, selective hydrolysis of amide, and azo coupling with diazonium salts. Introducing the Ugi four-component reaction in disperse dye synthesis has advantages of easy tuning the dye molecular weight/size, introducing amide functionality for forming hydrogen-bonding interactions with fiber, and achieving structural diversity of the final azo disperse dyes for screening. It has been demonstrated that six azo disperse dyes obtained through the protocol exhibited good to excellent color fastness on both nylon and PET fibers. The improved fastness properties should be attributed to the appropriate increased molecular weight/size and the introduced amide functionality in Ugi four-component

reaction. Thus, it is an appealing new protocol for synthesizing a library of azo disperse dyes with excellent fastness properties and will be of significant value towards practical application.

Acknowledgements

We gratefully acknowledge the financial support from the National Natural Science Foundation of China (21376149 and 21676166).

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Highlights:

1. Diversity-oriented synthesis of azo disperse dyes was achieved through employing Ugi four-component reaction.
2. The new approach featured easy control of molecular weight/size and introduction of amide functionality in the final dye.
3. Dramatically improved fastness properties of the new azo disperse dyes were observed.
4. Improvements were attributed to both the increased van der Waals force and the formation of hydrogen-bonding interaction of dyes with fibers.
5. It is an attractive approach to synthesize a library of structurally diverse azo disperse dyes for screening.