Synthesis and styrene copolymerization of novel ring-substituted isobutyl phenylcyanoacrylates

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ABSTRACT

Novel ring-substituted isobutyl phenylcyanoacrylates, $RPhCH=C(CN)CO_2CH_2CH(CH_3)_2$, where R is 2-fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methyl were synthesized by the piperidine catalyzed Knoevenagel condensation of ring-substituted benzaldehydes and isobutyl cyanoacetate and characterized by CHN analysis, IR, ^{1}H and ^{13}C NMR. The acrylates were copolymerized with styrene in solution with radical initiation (ABCN) at 70°C. The compositions of the copolymers were calculated from nitrogen analysis.

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1. Introduction

Fluoro-iodo ring-substitued compounds, like 2-ethenyl-1-fluoro-3-iodobenzene was involved in a variety of reactions: regioselective tandem C-H alkylation/coupling reaction of ortho-iodophenylethylenes via C,C-Pallada(II)cycles [1], synthesis of dibenzo[b,f]oxepins by ring-closing metathesis [2], convergent synthesis of (-)-quinocarcin based on the combination of Sonogashira coupling and gold(I)-catalyzed 6-endo-dig hydroamination [3], total synthesis of (-)-quinocarcin by gold(I)-catalyzed regioselective hydroamination [4], preparation of heteroaromatic macrocyclic ether chemotherapeutic agents for treatment of cancer [5], Lewis acid catalyzed formal intramolecular [3 + 3] cross-cycloaddition of cyclopropane 1,1-diesters for construction of benzobicyclo[2.2.2]octane skeletons [6]. Trifluoromethyl styrenes are reported in several recent publications: visible light-mediated tandem addition/elimination reaction of iododifluoromethyl ketones and alkenes [7], palladium-catalyzed radical tandem dearomatization of indoles with unactivated alkenes [8], photoinitiated multicomponent anti-Markovnikov alkoxylation over graphene oxide [9], electrochemical ring-opening dicarboxylation of strained carbon-carbon single bonds with CO_2 leading to synthesis of diacids and derivatization into polyesters [10]. Cu-catalyzed alkylation-cyanation type difunctionalization of styrenes with aliphatic aldehydes and TMSCN via decarbonylation [11]. Trifluoromethoxy ring-substituted styrenes also reported in tuning the latent behavior of molybdenum imido alkylidene N-heterocyclic carbene complexes in dicyclopentadiene polymerization [12], in superbase-catalyzed anti-Markovnikov alcohol addition reactions to aryl alkenes [13], in study of effects of the chelating alkoxy ligand modifications on the structure and catalytic activity of ruthenium carbene complexes [14], in preparation of substituted anthranilic acids as potent dihydroorotate dehydrogenase inhibitors [15]. 2,4,6-Trimethyl ring-substituted cyanophenylacrylate is reported in study of the mass spectra of ethyl α-cyano-β-(2- or 4-substituted phenyl)acrylates [16] and in catalyst study of the Knoevenagel condensation [17]. Another similar compound, ethyl ester of 2-cyano-3-(2,4,6-trimethylphenyl)-2-butenoic acid was used in preparation of ethyl α-cyano-β-(o-tolyl)acrylate and ethyl α-cyano-β-methyl-β-mesitylacrylate [18]. 2-Ethenyl-1,3,5-trimethylbenzene was involved in (1) cathodic regioselective coupling of unactivated aliphatic ketones with alkenes [19], (2) in iodine-initiated dioxygenation of aryl alkenes using tert-butylhydroperoxides and water leading to vicinal diols and bisperoxides [20], (3) in Palladium(II) catalyzed site-selective C-H olefination of imidazo[1,2-a]pyridines [21], (4) in hydroboration of terminal alkenes and trans-1,2-diboration of terminal alkynes catalyzed by a manganese(I) alkyl complex [22], (5) in catalytic asymmetric [3+2] annulation of Hantzsch esters with racemic N-sulfonylaziridines [23], (6) in hydroalkylation of styrenes with benzylamines by potassium hydride [24]. 3-Ethenyl-1,2,4,5-tetramethylbenzene is reported in synthesis of cyclopropyl ring by action of sodium amide on exo-methyleneammonium ions obtained from rearrangement of certain 2,6-dimethylbenzyltrimethylammonium ions [25], and in studies of thermal reactivity of polynuclear aromatic hydrocarbons [26]. 1-Ethenyl-2,3,4,5,6-pentamethylbenzene was active in Manganese-catalysed divergent silylation of alkenes [27], in photoredox divergent 1,2-difunctionalization of alkenes with gem-dibromides [28], in mechanistic studies on Platinum(II) catalyzed hydroarylation of alkynes [29], in studies of conductivity molecular nanostructures assembled from charge-transfer complexes grafted onto silicon surfaces [30], in polymerization yielding poly(pentamethylstyrene) [31].

In this work we have prepared novel isobutyl phenylcyanoacrylates (IPCA), $RPhCH{=}C(CN)CO_2CH_2CH(CH_3)_2$, where R is 2-fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methyl, and explored the feasibility of their copolymerization with styrene. To the best of our knowledge, there have been no reports on either synthesis of these compounds, nor their copolymerization with styrene [32].

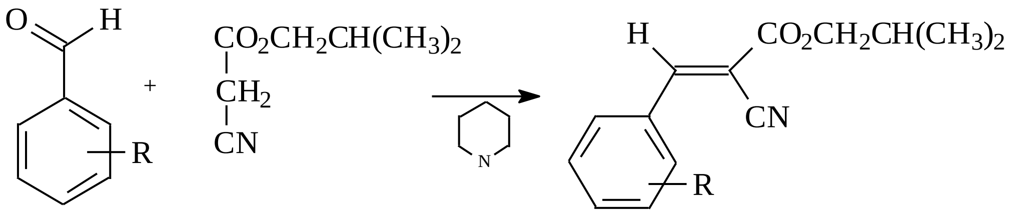
2. Experimental

2-Fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methylbenzaldehydes, isobutyl cyanoacetate, piperidine, styrene, 1,1'-azobis(cyclohexanecarbonitrile) (ABCN), and toluene supplied from Sigma-Aldrich Co., were used as received. Instrumentation is reported in [33].

3. Results and discussion

3.1. Synthesis and characterization of isobutyl phenylcyanoacrylates

All isobutyl phenylcyanoacrylates compounds were synthesized by Knoevenagel condensation [34] of appropriate benzaldehydes with isobutyl cyanoacetate, catalyzed by base, piperidine (Scheme 1).



Scheme 1. Synthesis of isobutyl R-phenylcyanoacrylates, where R is 2-fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methyl.

The preparation procedure was essentially the same for all the monomers. In a typical synthesis, equimolar amounts of isobutyl cyanoacetate and an appropriate benzaldehyde were mixed in equimolar ratio in a 20 mL vial. A few drops of piperidine were added with stirring. The reactions was allowed to proceed 48 hrs at r.t. The product of the reaction was isolated by filtration and purified by crystallization from 2-propanol. The condensation reaction proceeded smoothly, yielding products, which were purified by conventional techniques. Melting points of the compounds in crystalline state were measured by DSC. The compounds were characterized by IR, ^{1}H and ^{13}C NMR spectroscopies. No stereochemical analysis of the novel ring-substituted IPCA was performed since no stereoisomers (*E* or/and *Z*) of known configuration were available.

3.1.1. *Isobutyl 2-fluoro-5-iodophenylcyanoacrylate*

Yield: 76.3%; ^{1}H NMR: δ 8.6 (s, 1H, CH=), 8.3-6.6 (m, 3H, Ph), 4.1 (d, 2H, CH_2), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 167 (C=O), 159 (HC=), 145, 145, 141, 138, 124, 122 (Ph), 115 (CN), 107 (C=), 74 (CH_2), 30 (CH), 19 (CH_3); IR: (cm^{-1}) 2987 (m, C-H), 2224 (m, CN), 1738 (s, C=O), 1627 (s, C=C), 1244 (s, C-O-CH_3), 825, 744 (s, C-H out of plane). Anal. calcd. for $C_{14}H_{13}FINO_2$: C, 45.06; H, 3.51; N, 3.75; Found: C, 45.88; H, 3.76; N, 3.87.

3.1.2. *Isobutyl 2-fluoro-6-iodophenylcyanoacrylate*

Yield 87.1%; ^{1}H NMR: δ 7.8 (s, 1H, CH=), 7.3-6.7 (m, 3H, Ph), 4.1 (d, 2H, CH_2), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 165 (C=O), 156 (HC=), 137, 136, 135, 134 (Ph), 116 (CN), 105 (C=), 73 (CH_2), 28 (CH), 19 $(CH_3)_2$; IR: (cm^{-1}) 3124-2809 (m, C-H), 2225 (m, CN), 1740 (s, C=O), 1636 (s, C=C), 1281 (s, C-O-CH_3), 832 (s, C-H out of plane). Anal. calcd. for $C_{14}H_{13}FINO_2$: C, 45.06; H, 3.51; N, 3.75; Found: C, 43.78; H, 3.98; N, 3.84.

3.1.3. *Isobutyl 2-trifluoromethylphenylcyanoacrylate*

Yield 78.3%; ^{1}H NMR: δ 8.7 (s, 1H, CH=), 8.3-7.2 (m, 4H, Ph), 4.2 (d, 2H, CH_2), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 166 (C=O), 151 (HC=), 147, 132, 130, 127, 125, 118 (Ph), 123 (CF_3), 116 (CN), 109 (C=), 70 (CH_2), 28 (CH), 19 $(CH_3)_2$; IR: (cm^{-1}) 2961 (m, C-H), 2250, 2231 (m, CN), 1734 (s, C=O), 1653 (s, C=C), 1255 (s, C-O-CH_3), 789 (s, C-H out of plane). Anal. calcd. for $C_{15}H_{14}F_3NO_2$: C, 60.61; H, 4.75; N, 4.71; Found: C, 59.86; H, 5.22; N, 5.25.

3.1.4. *Isobutyl 3-trifluoromethylphenylcyanoacrylate*

Yield 87.2%; mp 89.1°C; ^{1}H NMR δ 8.3 (s, 1H, CH=), 8.1-7.6 (m, 4H, Ph), 4.1 (d, 2H, CH_2), 2.0 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR δ 162 (C=O), 153 (HC=), 133, 132, 130, 128, 125, 121, 120 (Ph), 115 (CN), 123 (CF_3), 106 (C=), 72 (CH_2), 28 (CH), 19 (CH_3); IR (cm^{-1}): 2984 (m, C-H), 2229 (m, CN), 1718 (s, C=O), 1618 (s, C=C), 1269 (s, C-O-CH_3), 785, 739 (s, C-H out of plane). Anal. Calcd. for $C_{15}H_{14}F_3NO_2$: C, 60.61; H, 4.75; N, 4.75; Found: C, 60.90; H, 4.72; N, 4.74.

3.1.5. *Isobutyl 4-trifluoromethylphenylcyanoacrylate*

Yield 91.4%; mp 67°C; ^{1}H NMR: δ 8.3 (s, 1H, CH=), 8.2-7.0 (m, 4H, Ph), 4.1 (d, 2H, CH_2), 2.1 (m, 1H, CH), 0.9 (d, 6H, CH_3); ^{13}C NMR: δ 162 (C=O), 153 (HC=), 135, 131, 129, 126, (Ph), 115 (CN), 106 (C=), 73 (CH_2), 28 (CH), 19 (CH_3); IR: (cm^{-1}) 2963 (m, C-H), 2222 (m, CN), 1719 (s, C=O), 1672 (s, C=C), 1259 (s, C-O-CH_3), 847, 722 (s, C-H out of plane). Anal. calcd. for $C_{15}H_{14}F_3NO_2$: C, 60.61; H, 4.75; N, 4.71; Found: C, 58.48; H, 4.75; N, 4.78.

3.1.6. *Isobutyl 2-trifluoromethoxyphenylcyanoacrylate*

Yield 79.1%; mp 51°C; ^{1}H NMR: δ 8.6 (s, 1H, CH=), 7.6-7.0 (s, 4H, Ph), 4.1 (d, 2H, CH_2), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 162 (C=O), 147 (HC=), 134, 130, 127, 125 (Ph), 121 (CF_3), 114 (CN), 106 (C=), 73 (CH_2), 28 (CH), 19 $(CH_3)_2$; IR: (cm^{-1}) 2968 (m, C-H), 2229 (m, CN), 1732 (s, C=O), 1605 (s, C=C), 1238 (s, C-O-CH_3), 768 (s, C-H out of plane). Anal. calcd. for $C_{15}H_{14}F_3NO_3$: C, 57.51; H, 4.50; N, 4.47; Found: C, 56.75; H, 4.89; N, 4.86.

3.1.7. *Isobutyl 3-trifluoromethoxyphenylcyanoacrylate*

Yield 78%; mp 71.9°C; ^{1}H NMR δ 8.3 (s, 1H, CH=), 8.0-7.3 (m, 4H, Ph), 4.1 (d, 2H, CH_2), 2.1 (m, 1H, CH), 0.9 (d, 6H, CH_3) ; ^{13}C NMR δ 162 (C=O), 153 (HC=), 133, 131, 129, 125, 123 (Ph), 119 (CF_3), 115 (CN), 105 (C=), 73 (CH_2), 28 (CH), 19 $(CH_3)_2$; IR (cm^{-1}): 3412 (m, C-H), 2225 (m, CN), 1744 (s, C=O), 1614 (s, C=C), 1228 (s, C-O-CH_3), 812 (s, C-H out of plane). Anal. Calcd. for $C_{15}H_{14}F_3NO_3$: C, 57.51; H, 4.50; N, 4.47; Found: C, 57.29; H, 4.62; N, 4.75.

3.1.8. *Isobutyl 4-trifluoromethoxyphenylcyanoacrylate*

Yield 46%; ^{1}H NMR δ 8.3 (s, 1H, CH=), 8.1-7.2 (s, 4H, Ph), 4.1 (s, 2H, CH_2), 2.0 (m, 1H, CH), 1.0 (d, 6H, $(CH_3)_2$; ^{13}C NMR δ 162 (C=O), 153 (HC=), 133, 130, 122, 121 (Ph), 119 (CF_3), 115 (CN), 104 (C=), 73 (CH_2), 28 (CH), 20 $(CH_3)_2$; IR (cm^{-1}): 2936 (m, C-H), 2224 (m, CN), 1738 (s, C=O), 1657 (s, C=C), 1276 (s, C-O-CH_3), 841 (s, C-H out of plane). Anal. Calcd. for $C_{15}H_{14}F_3NO_3$: C, 57.51; H, 4.50; N, 4.47; Found: C, 58.29; H, 4.62; N, 4.67.

3.1.9. *Isobutyl 2,4,5-trimethylphenylcyanoacrylate*

Yield: 89%; ^{1}H NMR: δ 8.7 (s, 1H, CH=), 8.1, 7.0 (2H, Ph), 4.1 (d, 2H, CH_2), 2.3 (s, 9H, CH_3), 2.2 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 163 (C=O), 153 (HC=), 149, 142, 138, 135, 132, 130, 128 (Ph), 116 (CN), 102 (C=), 72 (CH_2), 31 (CH), 19 (CH_3); IR (cm^{-1}) 3507 (m, C-H), 2225 (m, CN), 1719 (s, C=O), 1656 (s, C=C), 1276 (s, C-O-CH_3), 828 (s, C-H out of plane). Anal. calcd. for $C_{17}H_{21}NO_2$: C, 75.25; H, 7.80; N, 5.16; Found: C, 72.62; H, 7.90; N, 6.02.

3.1.10. *Isobutyl 2,4,6-trimethylphenylcyanoacrylate*

Yield 72%; ^{1}H NMR: δ 7.8 (s, 1H, CH=), 6.9 (2H, Ph), 4.1 (d, 2H, CH_2), 2.3 (s, 9H, CH_3Ph), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 162 (C=O), 158 (HC=), 140, 136, 129 (Ph), 115 (CN), 110 (C=), 73 (CH_2), 28 (CH), 23, 22, 20, 19 $(CH_3)_2$; IR: (cm^{-1}) 3447 (m, C-H), 2233 (m, CN), 1710 (s, C=O), 1636 (s, C=C), 1284 (s, C-O-CH_3), 838 (s, C-H out of plane). Anal. calcd. for $C_{17}H_{21}NO_2$: C, 75.25; H, 7.80; N, 5.16; Found: C, 70.79; H, 7.41; N, 5.37.

3.1.11. *Isobutyl 2,3,5,6-tetramethylphenylcyanoacrylate*

Yield 72%; ^{1}H NMR: δ 8.5 (s, 1H, CH=), 7.0 (s, 1H, Ph), 4.2 (d, 2H, CH_2), 2.2 (s, 12H, CH_3Ph), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 162 (C=O), 160 (HC=), 134, 133, 131 (Ph), 114 (CN), 111 (C=), 73 (CH_2), 28 (CH), 19,17 $(CH_3)_2$; IR: (cm^{-1}) 2964 (m, C-H), 2233 (m, CN), 1730 (s, C=O), 1658 (s, C=C), 1271 (s, C-O-CH_3), 781 (s, C-H out of plane). Anal. calcd. for $C_{18}H_{23}NO_2$: C, 75.76; H, 8.12; N, 4.91; Found: C, 75.86; H, 8.22; N, 4.25.

3.1.12. *Isobutyl pentamethylphenylcyanoacrylate*

Yield 91%; mp 78°C; ^{1}H NMR δ 8.6 (s, 1H, CH=), 4.1 (d, 2H, CH_2), 2.2 (s, 15H, CH_3Ph), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR δ 162 (C=O), 155 (HC=), 137, 133, 131, 129, 117 (Ph), 114 (CN), 123 (CF_3), 106 (C=), 72 (CH_2), 28 (CH), 19-16 (CH_3); IR (cm^{-1}): 2976 (m, C-H), 2233 (m, CN), 1729 (s, C=O), 1647 (s, C=C), 1267 (s, C-O-CH_3), 785 (s, C-H out of plane). Anal. Calcd. for $C_{19}H_{25}NO_2$: C, 76.22; H, 8.42; N, 4.68; Found: C, 74.92; H, 8.48; N, 4.84.

3.1.13. *Isobutyl 2,3-dimethyl-4-methoxyphenylcyanoacrylate*

Yield 80.4%; mp 123.4°C; ^{1}H NMR: δ 8.7 (s, 1H, CH=), 8.3, 6.9 (s, 2H, Ph), 4.2 (d, 2H, CH_2), 4.0 (s, 3H, OCH_3), 2.2 (s, 6H, CH_3Ph), 2.1 (m, 1H, CH), 0.9 (d, 6H, CH_3); ^{13}C NMR: δ 163 (C=O), 154 (HC=), 140, 133, 128, 126, 123, 108 (Ph), 116 (CN), 101 (C=), 72 (CH_2), 56 (OCH_3), 28 (CH), 19, 16, 15, 12 (CH_3); IR: (cm^{-1}) 2963 (m, C-H), 2222 (m, CN), 1719 (s, C=O), 1672 (s, C=C), 1259 (s, C-O-CH_3), 847, 722 (s, C-H out of plane). Anal. calcd. for $C_{17}H_{21}NO_3$: C, 71.06; H, 7.37; N, 4.87; Found: C, 70.35; H, 7.35; N, 5.08.

3.1.14. *Isobutyl 2,5-dimethyl-4-methoxyphenylcyanoacrylate*

Yield 89%; mp 80.3°C; ^{1}H NMR: δ 8.5 (s, 1H, CH=), 8.2, 6.7 (s, 2H, Ph), 4.2 (d, 2H, CH_2), 3.9 (s, 3H, OCH_3), 2.2 (s, 6H, CH_3Ph), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3); ^{13}C NMR: δ 164 (C=O), 151 (HC=), 141, 131, 126, 123, 112 (Ph), 116 (CN), 106 (C=), 72 (CH_2), 56 (OCH_3), 28 (CH), 20, 19, 16 (CH_3); IR: (cm^{-1}) 2962 (m, C-H), 2218 (m, CN), 1717 (s, C=O), 1621 (s, C=C), 1245 (s, C-O-CH_3), 782 (s, C-H out of plane). Anal. calcd. for $C_{17}H_{21}NO_3$: C, 71.06; H, 7.37; N, 4.87; Found: C, 70.35; H, 7.35; N, 4.96.

3.1.15. ***Isobutyl 2,4-dimethoxy-3-methylphenylcyanoacrylate***

Yield 71%; mp 92.7°C; ^{1}H NMR δ 8.7 (s, 1H, CH=), 8.2, 6.8 (s, 2H, Ph), 4.1 (d, 2H, CH_2), 3.8 (s, 6H, OCH_3), 2.3 (s, 3H, CH_3), 2.1 (m, 1H, CH), 1.0 (d, 6H, CH_3) ; ^{13}C NMR δ 164 (C=O), 149 (HC=), 128, 121, 118, 107 (Ph), 117 (CN), 100 (C=), 72 (CH_2), 63, 56 (OCH_3), 28 (CH), 19 $(CH_3)_2$, 9 ($PhCH_3$); IR (cm^{-1}): 3114 (m, C-H), 2220 (m, CN), 1718 (s, C=O), 1664 (s, C=C), 1283 (s, C-O-CH_3), 811 (s, C-H out of plane). Anal. Calcd. for $C_{17}H_{21}NO_4$: C, 67.31; H, 6.98; N, 4.62; Found: C, 66.74; H, 6.87; N, 4.45.

3.1.16. ***Isobutyl 2,4-dimethoxy-6-methylphenylcyanoacrylate***

Yield 87%; mp 85.7°C; ^{1}H NMR δ 8.3 (s, 1H, CH=), 7.3 (s, 2H, Ph), 4.1 (s, 2H, CH_2), 3.9 (s, 6H, OCH_3), 2.3 (s, 3H, $PhCH_3$), 2.0 (m, 1H, CH), 1.0 (d, 6H, (CH_3); ^{13}C NMR δ 163 (C=O), 151 (HC=), 141, 114, 108, 107 (Ph), 116 (CN), 96 (C=), 72 (CH_2), 56, 55, 53 (OCH_3), 28 (CH), 21, 19 (CH_3); IR (cm^{-1}): 3261 (m, C-H), 2220 (m, CN), 1718 (s, C=O), 1697 (s, C=C), 1286 (s, C-O-CH_3), 848 (s, C-H out of plane). Anal. Calcd. for $C_{17}H_{21}NO_4$: C, 67.31; H, 6.98; N, 4.62; Found: C, 67.88; H, 6.83; N, 4.65.

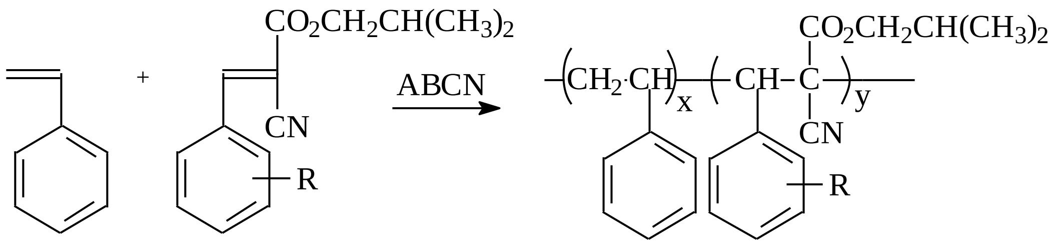
3.3. ***Synthesis and characterization of styrene – IPCA copolymers***

Copolymers of the styrene (ST) and the IPCA compounds, P(ST-co-IPCA) were prepared in 25-mL glass screw cap vials at ST/IPCA = 3 (mol) the monomer feed using 0.12 mol/L of ABCN at an overall monomer concentration 2.44 mol/L in 10 mL of toluene. The copolymerization was conducted at 70ºC. After a predetermined time, the mixture was cooled to room temperature, and precipitated dropwise in methanol. The composition of the copolymers was determined based on the nitrogen content. The novel synthesized IPCA compounds copolymerized readily with ST under free-radical conditions (Scheme 2) forming white flaky precipitates when their solutions were poured into methanol. The conversion of the copolymers was kept between 10 and 20% to minimize compositional drift (Table 1).

Table 1. Copolymerization of isobutyl phenylcyanoacrylates with styrene.

R	Yield[a] (wt%)	N (wt%)	ST in copol. (mol%)	IPCA in copol. (mol%)
2-F-5-I	13.6	1.39	85.9	14.1
2-F-6-I	10.2	1.42	85.5	14.5
2-CF_3	12.2	2.46	72.3	27.7
3- CF_3	11.4	2.71	67.9	32.1
4- CF_3	15.6	2.61	69.7	30.3
2-OCF_3	13.2	2.05	78.1	21.9
3-OCF_3	15.4	2.18	76.0	24.0
4-OCF_3	11.4	2.64	67.6	32.4
2,4,5-Trimethyl	11.1	2.23	77.4	22.6
2,4,6-Trimethyl	13.4	1.31	88.5	11.5
2,3,5,6-Tetramethyl	13.6	0.89	92.5	7.5
Pentamethyl	10.8	1.01	91.3	8.7
2,3-Dimethyl-4-methoxy	12.7	2.17	77.5	22.5
2,5-Dimethyl-4-methoxy	12.1	1.92	81.0	19.0
2,4-Dimethoxy-3-methyl	12.9	1.94	80.1	19.9
2,4-Dimethoxy-6-methyl	15.3	1.51	85.7	14.3

Nitrogen elemental analysis showed that between 7.5 and 32.4 mol% of IPCA is present in the copolymers, which is indicative of relatively high reactivity of the IPCA monomers towards ST radical. Since IPCA monomers do not homopolymerize, the most likely structure of the copolymers would be isolated alternating IPCA monomer (y = 1) units with short ST sequences (x > 1) (Scheme 2).



Scheme 2. Copolymerization of ST and the ring-substituted isobutyl phenylcyanoacrylates, RPhCH = $C(CN)CO_2CH_2CH(CH_3)_2$, R = 2-fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methyl.

The copolymers prepared in the present work are all soluble in ethyl acetate, THF, DMF and $CHCl_3$ and insoluble in methanol, ethyl ether, and petroleum ether.

4 Conclusions

Novel ring-substituted isobutyl phenylcyanoacrylates, $RPhCH=C(CN)CO_2CH_2CH(CH_3)_2$ (where R is 2-fluoro-5-iodo, 2-fluoro-6-iodo, 2-trifluoromethyl, 3-trifluoromethyl, 4-trifluoromethyl, 2-trifluoromethoxy, 3-trifluoromethoxy, 4-trifluoromethoxy, 2,4,5-trimethyl, 2,4,6-trimethyl, 2,3,5,6-tetramethyl, pentamethyl, 2,3-dimethyl-4-methoxy, 2,5-

dimethyl-4-methoxy, 2,4-dimethoxy-3-methyl, 2,4-dimethoxy-6-methyl) were synthesized and copolymerized with styrene. The compositions of the copolymers were calculated from nitrogen analysis.

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References

1. Regioselective Tandem C-H Alkylation/Coupling Reaction of ortho-Iodophenylethylenes via C,C-Pallada(II)cycles. Zhu, Bin-Bin; Ye, Wen-Bo; He, Zhi-Tao; Zhang, Shu-Sheng; Feng, Chen-Guo; Lin, Guo-Qiang. ACS Catalysis (2021), 11(19), 12123-12132.
2. An efficient synthesis of dibenzo[b,f]oxepins by ring-closing metathesis. Bharath, Yada; Thirupathi, Barla; Ranjit, Gurram; Mohapatra, Debendra K. Asian Journal of Organic Chemistry (2013), 2(10), 848-851.
3. Convergent synthesis of (-)-quinocarcin based on the combination of Sonogashira coupling and gold(I)-catalyzed 6-endo-dig hydroamination. Chiba, Hiroaki; Sakai, Yuki; Ohara, Ayako; Oishi, Shinya; Fujii, Nobutaka; Ohno, Hiroaki. Chemistry - A European Journal (2013), 19(27), 8875-8883.
4. Total Synthesis of (-)-Quinocarcin by Gold(I)-Catalyzed Regioselective Hydroamination. Chiba, Hiroaki; Oishi, Shinya; Fujii, Nobutaka; Ohno, Hiroaki.

Angewandte Chemie, International Edition (2012), 51(36), 9169-9172, S9169/1-S9169/68.

5. Preparation of heteroaromatic macrocyclic ether chemotherapeutic agents for treatment of cancer. Tang, Xinxing; Horan, Joshua Courtney; Mente, Scot Richard; Pelish, Henry Efrem; Shair, Matthew D.; Tangpeerachaikul, Anupong. PCT Int. Appl. (2021), WO 2021226208 A2 20211111.
6. Lewis Acid Catalyzed Formal Intramolecular [3 + 3] Cross-Cycloaddition of Cyclopropane 1,1-Diesters for Construction of Benzobicyclo[2.2.2]octane Skeletons. Ma, Weiwei; Fang, Jie; Ren, Jun; Wang, Zhongwen. Organic Letters (2015), 17(17), 4180-4183.
7. Visible Light-mediated Tandem Addition/Elimination Reaction of Iododifluoromethyl Ketones and Alkenes. Wu, Fanhong; Li, Zhi; Huang, Guozhi; Wu, Jihong; Wu, Jingjing; Yu, Yanyan. European Journal of Organic Chemistry (2022), 2022(5), e202101486.
8. Visible-Light-Driven Palladium-Catalyzed Radical Tandem Dearomatization of Indoles with Unactivated Alkenes. Chen, Su; Van Meervelt, Luc; Van der Eycken, Erik V.; Sharma, Upendra K. Organic Letters (2022), 24(5), 1213-1218.
9. Photoinitiated Multicomponent Anti-Markovnikov Alkoxylation over Graphene Oxide. Nie, Liang; Peng, Xiangjun; He, Haiping; Hu, Jian; Yao, Zhiyang; Zhou, Linyi; Yang, Ming; Li, Fan; Huang, Qing; Liu, Liangxian. Molecules (2022), 27(2), 475.

10. Electrochemical Ring-Opening Dicarboxylation of Strained Carbon-Carbon Single Bonds with CO2: Facile Synthesis of Diacids and Derivatization into Polyesters. Liao, Li-Li; Wang, Zhe-Hao; Cao, Ke-Gong; Sun, Guo-Quan; Zhang, Wei; Ran, Chuan-Kun; Li, Yiwen; Chen, Li; Cao, Guang-Mei; Yu, Da-Gang. Journal of the American Chemical Society (2022),
11. Cu-Catalyzed alkylation-cyanation type difunctionalization of styrenes with aliphatic aldehydes and TMSCN via decarbonylation. Zhou, Yu-Ling; Chen, Jun-Jia; Cheng, Jing; Yang, Luo. Organic & Biomolecular Chemistry (2022), 20(6), 1231-1235.
12. Tuning the Latent Behavior of Molybdenum Imido Alkylidene N-Heterocyclic Carbene Complexes in Dicyclopentadiene Polymerization. Momin, Mohasin; Musso, Janis V.; Frey, Wolfgang; Buchmeiser, Michael R. Organometallics (2021), 40(2), 253-265.
13. Superbase-Catalyzed anti-Markovnikov Alcohol Addition Reactions to Aryl Alkenes. Luo, Chaosheng; Bandar, Jeffrey S. Journal of the American Chemical Society (2018), 140(10), 3547-3550.
14. Probing of the ligand anatomy: effects of the chelating alkoxy ligand modifications on the structure and catalytic activity of ruthenium carbene complexes. Barbasiewicz, Michal; Bieniek, Michal; Michrowska, Anna; Szadkowska, Anna; Makal, Anna; Wozniak, Krzysztof; Grela, Karol. Advanced Synthesis & Catalysis (2007), 349(1+2), 193-203.

15. Preparation of substituted anthranilic acids as potent dihydroorotate dehydrogenase inhibitors. Joensson, Stig; Andersson, Gunnar; Wellmar, Ulf; Fritzon, Ingela. PCT Int. Appl. (2005), WO 2005075410 A1 20050818.
16. Analysis of the mass spectra of ethyl α-cyano-β-(2- or 4-substituted phenyl) acrylates. Nagai, Wakatu; Hirata, Yumiko. Nagoya Kogyo Daigaku Gakuho (1971), 23, 147-57.
17. Catalyst study of the Knoevenagel condensation. Prout, Franklin S.; Abdel-Latif, Ata A.; Kamal, Marwan R. Journal of Chemical and Engineering Data (1963), 8(4), 597-9.
18. Preparation of ethyl α-cyano-β-(o-tolyl)acrylate and ethyl α-cyano-β-methyl-β-mesitylacrylate. Hirata, Yumiko; Nagai, Wakatu. Nippon Kagaku Kaishi (1972), 8(7), 1341-2.
19. Cathodic Regioselective Coupling of Unactivated Aliphatic Ketones with Alkenes. Wu, Hongting; Chen, Weihao; Deng, Weijie; Yang, Ling; Li, Xinling; Hu, Yunfei; Li, Yibiao; Chen, Lu; Huang, Yubing. Organic Letters (2022), Ahead of Print.
20. Iodine-Initiated Dioxygenation of Aryl Alkenes Using tert-Butylhydroperoxides and Water: A Route to Vicinal Diols and Bisperoxides. Gao, Xiaofang; Lin, Jiani; Zhang, Li; Lou, Xinyao; Guo, Guanghui; Peng, Na; Xu, Huan; Liu, Yi. Journal of Organic Chemistry (2021), 86(21), 15469-15480.
21. Palladium(II) catalyzed site-selective C-H olefination of imidazo[1,2-a]pyridines. Tali, Javeed Ahmad; Kumar, Gulshan; Singh, Davinder; Shankar, Ravi. From Organic & Biomolecular Chemistry (2021), 19(43), 9401-9406.

22. Hydroboration of Terminal Alkenes and trans-1,2-Diboration of Terminal Alkynes Catalyzed by a Manganese(I) Alkyl Complex. Weber, Stefan; Zobernig, Daniel; Stoger, Berthold; Veiros, Luis F.; Kirchner, Karl. Angewandte Chemie, International Edition (2021), 60(46), 24488-24492.
23. Catalytic Asymmetric [3+2] Annulation of Hantzsch Esters with Racemic N-Sulfonylaziridines. Zhu, Guo-Sheng; Yang, Pei-Jun; Ma, Chen-Xue; Yang, Gaosheng; Chai, Zhuo. Organic Letters (2021), 23(20), 7933-7937.
24. Hydroalkylation of Styrenes with Benzylamines by Potassium Hydride. Pang, Jia Hao; Wang, Bin; Watanabe, Kohei; Takita, Ryo; Chiba, Shunsuke. Helvetica Chimica Acta (2021), 104(10), e2100120.
25. Formation of cyclopropyl ring by action of sodium amide on exo-methyleneammonium ions obtained from rearrangement of certain 2,6-dimethylbenzyltrimethylammonium ions. Watanabe, Hamao; Jones, Frank Norton; Hauser, Charles R. Journal of Organic Chemistry (1969), 34(8), 2393-7.
26. Thermal reactivity of polynuclear aromatic hydrocarbons. Lewis, Irwin C.; Edstrom, T. Journal of Organic Chemistry (1963), 28(8), 2050-7.
27. Manganese-catalysed divergent silylation of alkenes. Dong, Jie; Yuan, Xiang-Ai; Yan, Zhongfei; Mu, Liying; Ma, Junyang; Zhu, Chengjian; Xie, Jin. Nature Chemistry (2021), 13(2), 182-190.
28. Photoredox Divergent 1,2-Difunctionalization of Alkenes with gem-Dibromides. Cheng, Jian; Cheng, Yixiang; Xie, Jin; Zhu, Chengjian. Organic Letters (2017), 19(23), 6452-6455.

29. Mechanistic Studies on Platinum(II) Catalyzed Hydroarylation of Alkynes. Hahn, Christine; Miranda, Mayra; Chittineni, Nagendra P. B.; Pinion, Trent A.; Perez, Ricardo. Organometallics (2014), 33(12), 3040-3050.
30. Conducting molecular nanostructures assembled from charge-transfer complexes grafted onto silicon surfaces. Stires, John C.; Kasibhatla, Bala S. T.; Siegel, Dustin S.; Kwong, Jinny C.; Caballero, Jonathan B.; Labonte, Andre P.; Reifenberger, Ronald G.; Datta, Supriyo; Kubiak, Clifford P. Proceedings of SPIE-The International Society for Optical Engineering (2003), 5223(Physical Chemistry of Interfaces and Nanomaterials II), 85-99.
31. New monomers and polymers. II. Poly(pentamethylstyrene) and poly(pentamethylstyrene oxide). Field, Nathan D.; Capaldi, Eugene C.; Borchert, Alfred E. Makromolekulare Chemie (1967), 104(1), 120-4.
32. SciFinder, structure search, Mar 11, 2022.
33. Synthesis and styrene copolymerization of novel alkyl ring-substituted isobutyl 2-cyano-3-phenyl-2-propenoates. Schjerven, William S.; Groy, Randi; Antonishina, Yekaterina S.; Black, Claire I.; Bolin, Madysen P.; Caniglia, John; Daroach, Deepak P.; Farooqui, Farah T.; Feiz, Yalda; Garcia, Sam; Gasparini, Gabriella; Kharas, Gregory B. Abstracts of Papers, 259th ACS National Meeting & Exposition, Philadelphia, PA, United States, March 22-26, (2020), POLY-0388.
34. Smith, M. B.; March, J. *Addition to Carbon-Hetero Multiple Bonds*, In March's Advanced Organic Chemistry, J. Wiley & Sons: New York, Ch.16, 1225 (2001).