

Full Paper

Synthesis of 3-indolylacetamide derivatives and evaluation of their plant growth regulator activity

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Abstract: Some 3-indolylacetamide derivatives were synthesised via the coupling of indole-3-acetic acid (IAA) with aminobenzene derivatives and were screened for their plant growth regulator activities on rice seedling. The results show that some of the compounds synthesised possess considerable growth promoting activities in the concentration range of 1.7-0.17 ppm compared to IAA.

Keywords: 3-indolylacetamides, indole-3-acetic acid, plant growth regulator, rice seedling

INTRODUCTION

Plant growth regulators comprise a large number of structurally diverse compounds capable of regulating many biological processes including cell division, differentiation and enlargement, chloroplast development, and senescence. Their wide use in agriculture and plant biotechnology gives them a relevant role in science and technology. Among them, auxins play an important role in plant growth regulation, especially the ability to promote cell division, hasten root initiation, and increase the number and quality of roots [1-4]. The most widely occurring natural auxin, indole-3-acetic acid (IAA), is found in both the free form and the covalently bound via its carboxyl group to yield esters, glycosides and/or peptides of surprising structural diversity [5-6]. Other compounds such as derivatives of indole, naphthalenes, phenoxyacetic acids and some benzoic acids are known as synthetic growth regulators that elicit auxin-type responses in cell growth and cell division [7]. A halogen substituted on the benzene ring of benzoic acid was reported to increase the growth regulator activity quite markedly [8]. In order to access compounds with improved growth regulating properties in comparison to the original auxin and also to establish their structure-activity relationship, the search for potential plant growth regulators is of particular interest. Indoleacetic

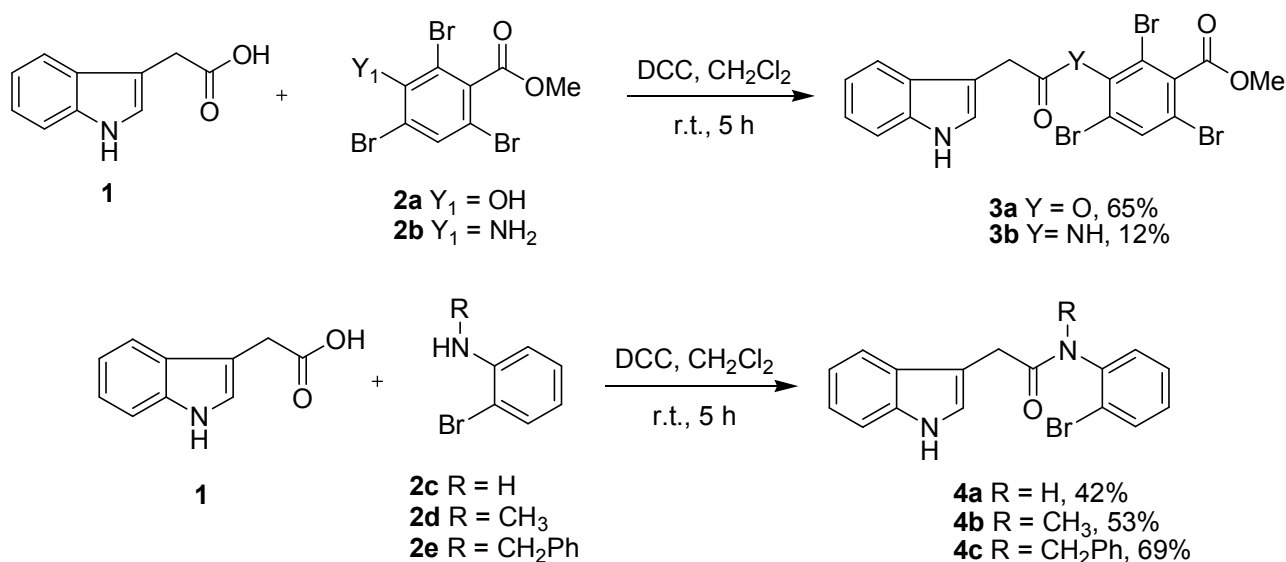
acid incorporated with aminobenzene derivatives via an amide link have been brought to our attention since both moieties possess plant growth promoting properties. Thus, they might reinforce the plant growth regulating properties of the resulting compounds. In this study some of such compounds, 3-indolylacetamide derivatives, obtained from indole-3-acetic acid conjugated with aminobenzene derivatives are reported and their plant growth regulator activities on rice seedling are investigated.

SYNTHESIS OF 3-INDOLYLACETAMIDE DERIVATIVES

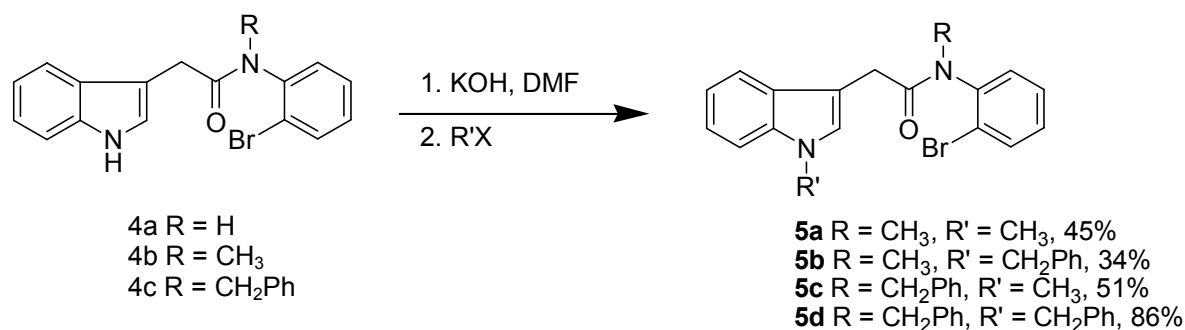
Discussion

The indole derivatives (**3a-b**, **4a-c**) were synthesised via the coupling of indole-3-acetic acid (**1**) and phenols or aromatic amines at room temperature (Scheme 1). The benzene derivatives (**2a** and **2b**) were prepared [9] for use as starting materials. Reductive amination [10] of *o*-bromoaniline (**2c**) using formaldehyde or benzaldehyde with sodium cyanoborohydride rapidly afforded the corresponding *N*-substituted-*o*-bromoanilines (**2d** and **2e**) in moderate yields. The benzene derivatives were then acylated by indole-3-acetic acid (**1**) at room temperature in the presence of DCC in dichloromethane to give **3a-b** and **4a-c** (Scheme 1). The structures of these synthesised compounds were characterised by their spectral data.

In order to study the structure-activity relationship of the synthesised compounds, *N*-alkylation on the indole ring of compounds **4a-c** was performed using alkyl halides in the presence of potassium hydroxide to give compounds **5a-d** in moderate to high yields (Scheme 2).



Scheme 1. Preparation of methyl 3-(2-(1*H*-indol-3-yl)acetoxy)-2,4,6-tribromobenzoate (3a) and some 3- indolylacetamides (3b, 4a-c)



Scheme 2. *N*-alkylation on the indole ring of 3-indolylacetamides (4a-c)

Experimental

Melting points were determined on a Stuart Scientific SMP 2 melting point apparatus and were uncorrected. Infrared spectra were recorded as CH₂Cl₂-film with a Perkin-Elmer GX FT-IR spectrophotometer. ¹H- and ¹³C-NMR spectra were recorded in CDCl₃ at 300 MHz for ¹H and 75 MHz for ¹³C with a Bruker Avance 300 spectrometer. TMS was used as internal standard. Mass spectra were recorded on a Polaris Q or Hewlett Packard 5973 mass spectrometer. Reagents were purchased from Sigma-Aldrich or Fluka and were used as received. All solvents used were of analytical reagent grade except dichloromethane, which was distilled over CaH₂ under nitrogen prior to use.

Methyl 3-(2-(1*H*-indol-3-yl)acetoxyl)-2,4,6-tribromobenzoate (**3a**)

N,N'-dicyclohexylcarbodiimide (DCC) (0.10 g, 0.48 mmol) was added to a stirred solution of 3-indolyl acetic acid (0.07 g, 0.40 mmol) and methyl 2,4,6-tribromo-3-hydroxybenzoate (**2a**) (0.20 g, 0.53 mmol) in dry CH₂Cl₂ (5.0 mL) at 0° under argon atmosphere. The reaction mixture was stirred at room temperature for 24 hr. The precipitate was filtered and washed with CH₂Cl₂. The filtrate was evaporated to give a crude product which was purified by column chromatography (silica gel; hexane: EtOAc = 4:1) to give a yellow oil (0.14 g, 65%): IR 1079, 1095, 1152, 1222, 1271, 1570, 1739, 3407 cm⁻¹; ¹H-NMR δ 3.94 (s, 3H), 4.13 (s, 2H), 7.11-7.22 (m, 3H), 7.33 (d, *J*=7.8 Hz, 1H), 7.66 (d, *J*=7.5 Hz, 1H), 7.76 (s, 1H), 8.20 (br s, 1H, NH) ppm; ¹³C-NMR δ 30.7, 53.2, 106.6, 111.2, 116.0, 118.8, 119.3, 119.8, 122.3, 123.7, 127.1, 135.5, 136.0, 138.1, 146.2, 165.4, 167.7 ppm; HRES-MS *m/z* calculated for [M+H]⁺ C₁₈H₁₂Br₃NO₄ = 565.8214, found 565.8214.

General Procedure for Preparation of *N,N*-Disubstituted-2-(1*H*-indol-3-yl)acetamides (**3b**, **4a-c**) [11]

To a solution of 3-indolylacetic acid (1 eq.) and methyl 2,4,6-tribromo-3-aminobenzoate or 2-bromoaniline derivative (1 eq.) in dry CH₂Cl₂ was added *N,N'*-dicyclohexyl carbodiimide (DCC) (1 eq.). The reaction mixture was stirred for 5 hr at room temperature under argon atmosphere. The reaction mixture was then filtered and the filtrate was evaporated *in vacuo* to give the crude product which was purified by column chromatography (silica gel; hexane: EtOAc= 4:1) to afford a pure *N*-(substituted phenyl)-2-(1*H*-indol-3-yl)acetamide.

Methyl 3-(2-(1H-indol-3-yl)acetamido)-2,4,6-tribromobenzoate (3b)

According to the general procedure, treatment of 3-indolylacetic acid (0.090 g, 0.52 mmol) and 2,4,6-tribromo-3-amino benzoate (**2b**) (0.20 g, 0.52 mmol) in dry CH₂Cl₂ (26.0 mL) with DCC (0.10 g, 0.52 mmol) under argon atmosphere gave **3b** as yellow oil (0.034 g, 12%): IR 1010, 1095, 1163, 1624, 1730, 2850, 2925, 3057, 3047 cm⁻¹; ¹H-NMR δ 3.69 (s, 3H), 3.78 (s, 2H), 7.10-7.21 (m, 3H), 7.24 (s, 1H), 7.33 (d, *J*=7.5 Hz, 1H), 7.60 (d, *J*=7.8 Hz, 1H), 8.14 (br s, 1H, NH) ppm; ¹³C-NMR δ 31.1, 51.9, 108.4, 111.2, 111.3, 118.6, 119.7, 119.8, 120.1, 122.1, 122.2, 122.5, 123.0, 123.4, 127.2, 136.1, 172.5 ppm; HRES-MS *m/z* calculated for [M+H]⁺ C₁₈H₁₃Br₃N₂O₃= 564.8374, found 564.8304.

N-(2-Bromophenyl)-2-(1H-indol-3-yl)acetamide (4a) [11]

According to the general procedure, treatment of 3-indolylacetic acid (0.10 g, 0.57 mmol) and 2-bromoaniline (**2c**) (0.10 g, 0.58 mmol) in dry CH₂Cl₂ (25.0 mL) with DCC (0.24 g, 1.16 mmol) under argon atmosphere gave **4a** as a yellow solid (0.078 g, 42%), mp. 95.9-104.5°: IR 1023, 1302, 1434, 1520, 1589, 1672, 3332 cm⁻¹; ¹H-NMR δ 3.94 (s, 2H), 6.88 (td, *J*=1,2 Hz, 6.0 Hz, 1H), 7.16 (td, *J*=0.9 Hz, 6.9 Hz, 1H), 7.22-7.28 (m, 3H), 7.35 (dd, *J*=1.2 Hz, 8.1 Hz, 1H), 7.37 (d, *J*=8.1 Hz, 1H), 7.62 (d, *J*=7.8 Hz, 1H), 8.03 (br s, 1H, NH), 8.37 (dd, *J*=1.2 Hz, 8.4 Hz, 1H), 8.51 (br s, 1H, NH) ppm; ¹³C-NMR δ 34.66, 108.36, 111.39, 113.17, 118.82, 120.31, 121.34, 122.90, 124.01, 124.97, 126.95, 128.22, 132.09, 135.58, 136.45, 169.81 ppm.

N-(2-Bromophenyl)-N-methyl-2-(1H-indol-3-yl)acetamide (4b)

According to the general procedure, treatment of 3-indolylacetic acid (0.082 g, 0.47 mmol) and *N*-methyl-2-bromoaniline (**2d**) (0.085 g, 0.45 mmol) in dry CH₂Cl₂ (23.0 mL) with DCC (0.10 g, 0.48 mmol) under argon atmosphere gave **4b** as a pale yellow solid (0.083 g, 53%), mp. 152.0-154.5°: IR 564, 1383, 1432, 1582, 1651, 2882, 3301 cm⁻¹; ¹H-NMR δ 3.22 (s, 3H), 3.51 (br s, 1H), 3.52 (br s, 1H), 6.95 (s, 1H), 7.03 (t, *J*=6.9 Hz, 1H), 7.11-7.37 (m, 6H), 7.69 (d, *J*=8.1 Hz, 1H), 8.03 (s, 1H, NH) ppm; ¹³C-NMR δ 31.1, 36.1, 109.3, 110.9, 119.4, 121.9, 123.0, 124.0, 127.5, 128.8, 129.7, 130.1, 133.8, 135.9, 142.6 ppm; HRES-MS *m/z* calculated for [M+H]⁺ C₁₇H₁₆BrN₂O= 365.0265, found 365.0260.

N-(2-Bromophenyl)-N-benzyl-2-(1H-indol-3-yl)acetamide (4c)

According to the general procedure, treatment of 3-indolylacetic acid (0.18 g, 1.01 mmol) and *N*-benzyl-2-bromoaniline (**2e**) (0.27 g, 1.0 mmol) in dry CH₂Cl₂ (50.0 mL) with DCC (0.20 g, 1.0 mmol) under argon atmosphere gave **4c** as a pale yellow solid (0.293 g, 69%), mp. 146.3-148.3°: IR 699, 1030, 1583, 1654, 2850, 2928, 3059, 3313 cm⁻¹; ¹H-NMR δ 3.51 (br s, 1H), 3.52 (br s, 1H), 4.06 (d, *J*=14.4 Hz, 1H), 5.66 (d, *J*=14.4 Hz, 1H), 6.67 (dd, *J*=1.5 Hz, 9.0 Hz, 1H), 6.94 (s, 1H), 7.00-7.37 (m, 11H), 7.68 (dd, *J*=1.5 Hz, 9.0 Hz, 1H), 8.08 (br s, 1H, NH) ppm; ¹³C-NMR δ 31.3, 51.7, 109.1, 109.6, 110.9, 118.8, 119.3, 121.9, 123.1, 124.0, 127.4, 128.1, 128.2, 128.3, 129.3, 129.7, 131.7, 133.8, 134.136.0, 137.0, 140.8, 171.1 ppm; HRES-MS *m/z* calculated for [M+H]⁺ C₂₃H₁₉BrN₂O= 441.0578, found 441.0578.

General Procedure for Preparation of N,N-Disubstituted-2-(1-substituted-1H-indol-3-yl)acetamides (5a-d)

A solution of *N,N*-disubstituted-2-(1*H*-indol-3-yl)acetamide (1 eq.) and KOH (1.5 eq.) in DMSO or DMF was stirred for 10-20 min. at room temperature under argon atmosphere. Benzyl chloride or methyl iodide (2 eq.) was then added at 0°. The reaction mixture was stirred at room temperature for 2-3 hr and then added to ice water and diluted with EtOAc or Et₂O. The organic layer was washed with saturated NaCl solution, dried with anhydrous Na₂SO₄ and concentrated *in vacuo* to give the crude product which was purified by column chromatography (silica gel; hexane: EtOAc = 4:1) to afford a pure *N,N*-disubstituted-2-(1-substituted-1*H*-indol-3-yl)acetamide.

N-(2-Bromophenyl)-*N*-methyl-2-(1-methyl-1*H*-indol-3-yl)acetamide (**5a**)

According to the general procedure, treatment of *N*-(2-bromophenyl)-2-(1*H*-indol-3-yl)acetamide (**4a**) (0.088 g, 0.27 mmol) and KOH (0.090 g, 1.6 mmol) in DMSO (4.0 mL) with methyl iodide (0.20 g, 1.5 mmol) under argon atmosphere gave (**5a**) [11] as a colourless oil (0.033 g, 45%): IR 129, 740, 1373, 1476, 1583, 1651, 1666, 3024, 3054 cm⁻¹; ¹H-NMR δ 3.21 (s, 3H), 3.49 (br s, 1H), 3.50 (br s, 1H), 3.70 (s, 3H), 6.84 (s, 1H), 6.99 (d, J=1.2 Hz, 1H), 7.01 (t, J=1.2 Hz, 1H), 7.14-7.33 (m, 5H), 7.68 (dd, J=1.2 Hz, 7.8 Hz, 1H) ppm; ¹³C-NMR δ 30.85, 32.57, 36.10, 107.50, 108.96, 118.79, 118.88, 121.39, 123.58, 127.78, 128.78, 129.63, 130.14, 133.80, 136.80, 142.92, 166.10 ppm; HRES-MS m/z calculated for [M+H]⁺ C₁₈H₁₇BrN₂O = 356.0524, found 356.0524.

N-(2-Bromophenyl)-*N*-methyl-2-(1-benzyl-1*H*-indol-3-yl)acetamide (**5b**)

According to the general procedure, treatment of *N*-(2-bromophenyl)-*N*-methyl-2-(1*H*-indol-3-yl)acetamide (**4b**) (0.24 g, 0.69 mmol) and KOH (0.090 g, 1.6 mmol) in DMF (7.0 mL) with benzyl chloride (0.20 mL, 1.73 mmol) under argon atmosphere gave **5b** as a pale yellow oil (0.10 g, 34%): IR 1464, 1664, 2923 cm⁻¹; ¹H-NMR δ 3.21 (s, 3H), 3.51 (br s, 1H), 3.52 (br s, 1H), 5.22 (s, 2H), 6.83 (s, 1H), 7.01 (t, J=0.8 Hz, 1H), 7.02 (d, J=0.8 Hz, 1H), 7.12 (td, J=2.3 Hz, 7.8 Hz, 4H), 7.17-7.27 (m, 5H), 7.39 (d, J=7.8 Hz, 1H), 7.62-7.66 (m, 1H) ppm; ¹³C-NMR δ 31.2, 36.1, 49.9, 77.2, 108.3, 109.4, 119.1, 119.2, 121.6, 123.6, 126.9, 127.1, 127.5, 128.0, 128.6, 128.7, 129.6, 130.2, 133.8, 136.4, 137.6, 142.8, 171.1 ppm; HRES-MS m/z calculated for [M+H]⁺ C₂₄H₂₁BrN₂O = 455.0735, found 455.0732.

N-Benzyl-*N*-(2-bromophenyl)-2-(1-methyl-1*H*-indol-3-yl)acetamide (**5c**)

According to the general procedure, treatment of *N*-(2-bromophenyl)-*N*-benzyl-2-(1*H*-indol-3-yl)acetamide (**4c**) (0.29 g, 0.69 mmol) and KOH (0.10 g, 1.78 mmol) in DMSO (6.0 mL) with methyl iodide (0.10 mL, 1.60 mmol) under argon atmosphere gave **5c** as a yellow oil (0.15 g, 51%): IR 561, 1474, 1583, 1661, 2925, 3058 cm⁻¹; ¹H-NMR δ 3.51 (br s, 1H), 3.52 (br s, 1H), 3.70 (s, 3H), 4.05 (d, J=14.4 Hz, 1H), 5.68 (dd, J=1.2 Hz, 7.2 Hz, 1H), 6.85 (s, 1H), 7.01 (t, J=7.2 Hz, 1H), 7.10 (tt, J=1.2 Hz, 1H), 7.16-7.32 (m, 9H), 7.68 (d, J=7.8 Hz, 1H) ppm; ¹³C-NMR δ 31.2, 32.6, 51.7, 107.4, 107.9, 118.8, 118.9, 121.4, 124.0, 124.9, 127.4, 127.8, 127.9, 128.9, 128.1, 128.3, 129.3, 129.4, 129.6, 133.7, 133.8, 137.0, 140.8, 171.1 ppm; HRES-MS m/z calculated for [M+H]⁺ C₂₄H₂₁BrN₂O = 455.0735, found 455.0748.

N-(2-Bromophenyl)-*N*-benzyl-2-(1-benzyl-1*H*-indol-3-yl)acetamide (**5d**)

According to the general procedure, treatment of *N*-(2-bromophenyl)-*N*-benzyl-2-(1*H*-indol-3-yl)acetamide (**4c**) (0.10 g, 0.24 mmol) and KOH (0.020 g, 0.36 mmol) in DMF (2.4 mL) with benzyl chloride (0.060 g, 0.48 mmol) under argon atmosphere gave **5d** as a pale yellow oil (0.10 g, 86%): IR 698, 1585, 1613, 1660, 2849, 2917, 3060 cm^{-1} ; $^1\text{H-NMR}$ δ 3.51 (br s, 1H), 3.52 (br s, 1H), 4.04 (d, $J=14.4$ Hz, 1H), 5.22 (s, 2H), 5.64 (d, $J=14.4$ Hz, 1H), 6.62 (dd, $J=1.5$ Hz, 7.8 Hz, 1H), 6.86 (s, 1H), 6.98-7.27 (m, 15H), 7.37 (d, $J=8.1$ Hz, 1H), 7.63 (dd, $J=1.2$ Hz, 7.8 Hz, 1H) ppm; $^{13}\text{C-NMR}$ δ 31.5, 49.9, 51.6, 108.2, 109.4, 119.1, 121.7, 124.0, 126.9, 127.1, 127.4, 127.5, 128.0, 128.3, 128.6, 129.3, 129.6, 131.7, 133.7, 136.4, 137.0, 137.6, 140.8, 171.0 ppm; HRES-MS m/z calculated for $[\text{M}+\text{H}]^+ \text{C}_{30}\text{H}_{25}\text{BrN}_2\text{O} = 531.1048$, found 531.1053.

PLANT GROWTH PROMOTING ACTIVITIES

Methods

The methods of Vargas et al. [12] and Fulbright et al. [13] were employed. Solutions of the synthesised compounds or IAA in 1.7, 0.17, 0.017 and 0.0017 ppm concentrations were prepared in H_2O -MeOH (H_2O : MeOH = 99.95: 0.05). Rice (*Oryza sativa*) seeds were surface disinfected by 70% ethanol for 1 min., followed by 1% sodium hypochlorite for 10 min. They were then washed five times with sterile distilled water. The sterilised seeds were immersed in sterile distilled water overnight. Sterilised Petri dishes (9.0-cm diameter), each containing 20 seeds, were used for germination experiments. Each dish contained two sheets of filter paper which were moistened with 4.0 mL of water or a solution of a test compound. The Petri dishes were placed under artificial light for 24 hr at 30°. The shoot growth and root growth were determined on day 5. Each experiment was done in triplicate.

Results and Discussion

Plant growth regulator activities of the selected compounds (**3a-b**, **4a**, **4c**, **5a-b** and **5d**) are shown in Table 1 and Figures 1-2 in comparison to the commercial plant growth regulator (IAA). Compounds **3b** and **5b** exhibit higher activities than IAA on both shoot and root growth in the concentration range of 1.7-0.017 ppm, while compounds **3b**, **5b** and **5d** exhibit better activities than IAA on root growth in the same range of concentration. Maximum shoot growth was observed in the presence of **4a** at the concentration of 1.7 ppm and maximum root growth was observed in the presence of **5b** at the same concentration.

From Table 1, it can be seen that the methyl ester group and a number of bromine atoms on the benzene ring have no effect on the growth promoting activities. Compounds **3a** and **3b** show slight difference in activities on both root and shoot while the substituents on the nitrogens of acetamide and indole affect the activities. Compound **4a**, which has no *N*-substituents, shows better growth promoting activities at low concentration than compound **4c**, which carries a benzyl group at the amide nitrogen. However, compound **4c** can stimulate the root growth at high concentration (1.7 ppm). The benzyl substituent on the indole nitrogen (**5d**) shows fluctuation in activities compared to compound **4c**. The methyl substituent on the acetamide nitrogen (**5a**) imparts better growth promoting activities on both shoot and root than the benzyl substituent (**5b**) in the concentration range of 1.7-0.17 ppm while the reverse is the case in the concentration range of 0.017-0.0017 ppm.

Table 1. Effect of 3-indolylacetamide derivatives on the shoot growth and root growth of *O. sativa* seedlings

Compound	% Germination	1.7 ppm		0.17 ppm		0.017 ppm		0.0017 ppm	
		SL	RL	SL	RL	SL	RL	SL	RL
H ₂ O	100	3.51±0.57	1.69±0.99	3.51±0.57	1.69±0.99	3.51±0.57	1.69±0.99	3.51±0.57	1.69±0.99
IAA	100	4.09±0.95	6.03±1.69	3.87±0.79	3.07±1.75	2.80±0.69	2.45±0.75	4.14±0.53	3.64±1.89
3a	100	4.27±0.48	6.84±2.72	3.24±0.81	2.52±1.14	4.12±1.15	2.17±1.07	3.67±0.40	3.98±1.29
3b	100	4.19±0.48	6.42±2.29	4.20±0.65	3.73±1.22	3.70±0.71	3.40±1.66	4.07±0.61	3.55±1.03
4a	100	4.38±0.53	4.63±2.17	3.77±0.57	4.04±1.48	3.90±0.75	3.52±1.62	3.93±0.70	4.0±1.45
4c	100	3.64±0.71	6.89±1.15	3.64±0.71	2.60±1.55	3.78±0.74	3.12±0.96	3.59±0.60	2.97±1.24
5a	100	4.12±1.15	5.49±2.19	3.52±0.71	2.69±1.17	4.28±0.48	3.66±1.32	3.85±0.66	3.25±1.11
5b	100	4.16±0.48	7.15±2.32	4.10±0.61	3.82±1.24	4.16±0.48	2.70±1.64	3.86±0.97	3.20±1.68
5d	100	4.07±0.61	6.71±1.84	3.95±0.50	3.79±2.04	4.04±0.95	2.61±1.60	3.49±0.94	2.71±1.59

Note: SL = shoot length in cm; RL = root length in cm

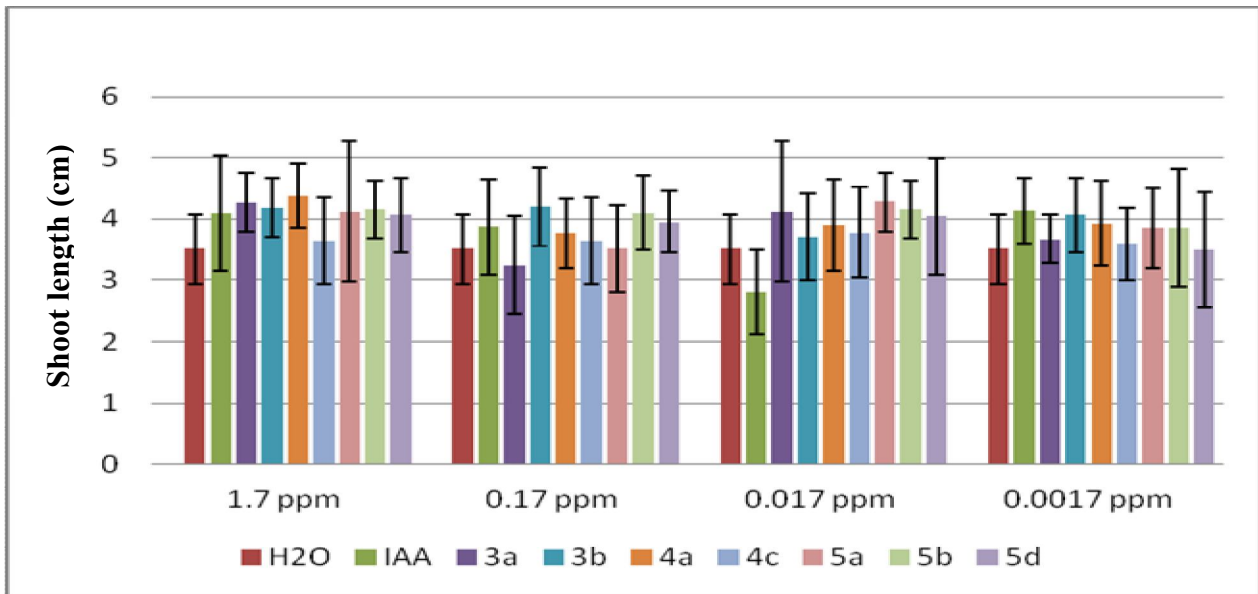


Figure 1. Comparative effects of IAA and 3-indolylacetamide derivatives on shoot growth of rice seedling

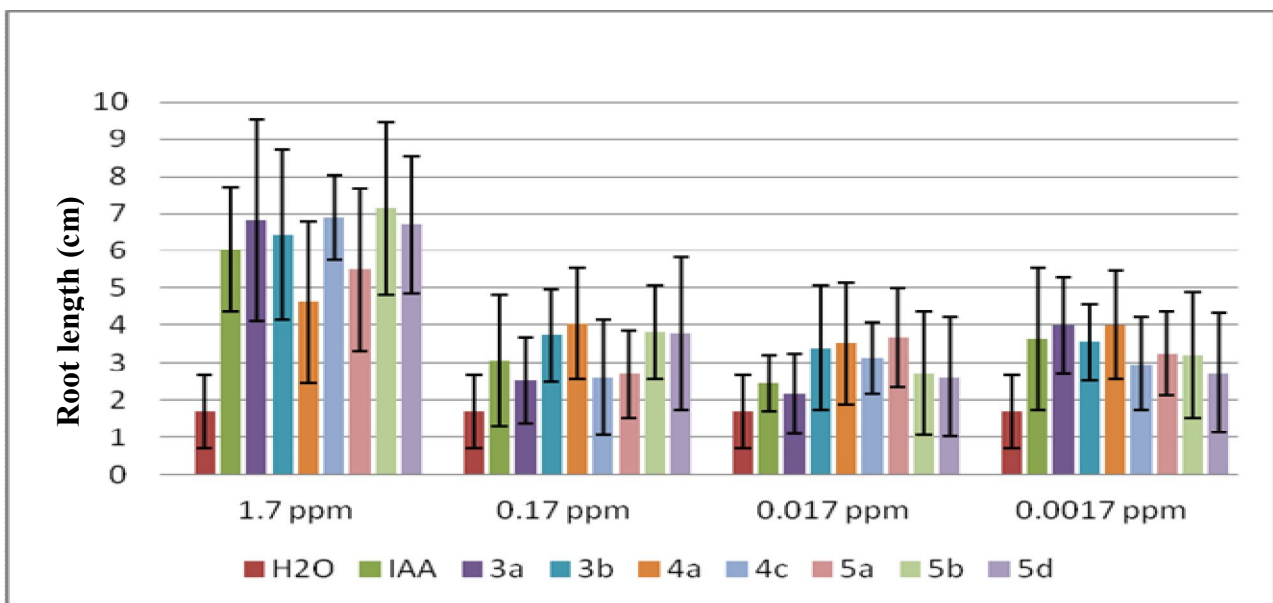


Figure 2. Comparative effects of IAA and 3-indolylacetamide derivatives on root growth of rice seedling

CONCLUSIONS

Although the plant growth regulator activities of some of the synthesised 3-indolylacetamide derivatives are higher than those of IAA in the concentration range of 1.7-0.017 ppm, the overall activities of the derivatives are considered comparable to those of IAA.

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REFERENCES

1. K. V. Thimann and J. B. Koepfli, "Identity of the growth-promoting and root-forming substances of plants", *Nature*, **1935**, 135, 101-102.
2. B. E. Haissig, T. D. Davis, "A historical evaluation of adventitious rooting research to 1993", in "Biology of Adventitious Root Formation" (Ed. T. D. Davis and B. E. Haissig), Plenum Press, New York, **1994**, pp.275-331.
3. H. T. Hartmann, D. E. Kestor, F. T. Davies and R. L. Geneve, "Plant Propagation: Principles and Practices", 6th Edn., Prentice Hall, Englewood Cliffs (N.J.), **1996**, p.770.
4. D. W. Armstrong, Y. S. Liu, L. He, K. H. Ekborg-Ott, C. L. Barnes and C. F. Hammer, "Potent enantioselective auxin: Indole-3-succinic acid", *J. Agric. Food Chem.*, **2002**, 50, 473-476.
5. M. Šoškić, B. Klaić, V. Magnus and A. Sabljčić, "Quantitative structure-activity relationships for *N*-(indol-3-ylacetyl)amino acids used as sources of auxin in plant tissue culture", *Plant Growth Reg.*, **1995**, 16, 141-152.
6. S. Jiang, J. Gao and L. Han, "Synthesis and biological activity of *N*-acyl-*O*-Indolylalkyl ethanalamines", *Biosci. Biotechnol. Biochem.*, **2011**, 75, 768-770.
7. L. M. Srivastava, "Plant Growth and Development: Hormones and Environment", Academic Press, Oxford, **2002**.
8. C. E. Minarik, D. Ready, A. G. Norman, H. E. Thomson and J. Fred Owings, Jr., "New growth-regulating compounds II. Substituted benzoic acids", *Bot. Gazette*, **1951**, 113, 135-147.
9. A. I. Vogel, A. R. Tatchell, B. S. Furnis, A. J. Hanaford and P. N. G. Smith, "Vogel's Textbook of Practical Organic Chemistry", 5th Edn., Longman Scientific and Technical, Essex, **1989**.
10. R. F. Borch, M. D. Bernstein and H. D. Durst, "Cyanohydridoborate anion as a selective reducing agent", *J. Amer. Chem. Soc.*, **1971**, 93, 2897-2904.
11. J. G. Avila-Zárraga, A. Lujan-Montelongo, A. Covarrubias-Zúniga and M. Romero- Ortega, "New Heck coupling strategies for the synthesis of paullone and dimethyl paullone" *Tetrahedron Lett.*, **2006**, 47, 7987-7989.
12. L. K. Vargas, B. B. Lisboa, G. Schlindwein, C. E. Granada, A. Giongo, A. Beneduzi and L. M. P. Passaglia, "Occurrence of plant growth-promoting traits in clover-modulating rhizobia strains isolated from different soils in Rio Grande do Sul State", *Rev. Bras. Ci. Solo*, **2009**, 33, 1227-1235.
13. T. E. Fulbright, K. S. Flenniken and G. L. Waggerman, "Methods of enhancing germination of Anacua seeds", *J. Range Manage.*, **1986**, 39, 450-453.