Efficient Synthesis of Photoreactive 2-Propoxyaniline Derivatives as Artificial Sweeteners

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Abstract
5-Nitro-2-propoxyaniline is one of the strongest artificial sweeteners. However, little is known about the detailed relationship of the structure and biological activity between 5-nitro-2-propoxyaniline and its sweet receptor. Photoaffinity labeling is a useful method for revealing interactions of a small bioactive compound with molecules. Therefore, we synthesized photoreactive 2-propoxyaniline derivatives as useful tools for revealing the interactions by photoaffinity labeling.

Key words photoaffinity labeling, chemical biology, photophore, artificial sweetener, sweet receptor

Introduction:
5-Nitro-2-propoxyaniline (1, Figure 1), named P-4000, has a sweetness intensity that is approximately 4000-times greater than that of sucrose and is well known as one of the strongest artificial sweeteners.1 On the other hand, it was once used as an artificial sweetener, but its use has been banned because of its possible toxicity.2 It is known that sweet taste is recognized by a sweeter receptor binding with the sweet receptor, which is a heterodimeric receptor consisting of T1R2 and T1R3 subunits.3 However, the mechanism of sweetness and toxicity of 5-nitro-2-propoxyaniline has still not been elucidated. Elucidation of the interactions between artificial sweeteners and their sweet receptor has attracted much interest and many researchers have studied the interactions by using NMR spectroscopy4 and X-ray crystallography.5 There have been only a few studies using homology modeling to determine the mechanism of action of 5-nitro-2-propoxyaniline for the gustatory receptor.6 However, satisfactory results have not been obtained, the detailed mechanism of action of 5-nitro-2-propoxyaniline for the receptor has not been elucidated. Identification of the biological mechanism as well as that of the target protein is a crucial point in the field of chemical biology. Photoaffinity labeling is one of the most powerful chemical tools to reveal interactions of bioactive compounds with biomolecules instead of X-ray crystallography and the solution-state NMR method, which are difficult to apply to a membrane protein such as the gustatory receptor. It is suitable for the analysis of biological interactions based on the affinity of biological active compounds for biomolecules. Therefore we have reported that synthesis of several photoaffinity labeling reagent for gustatory receptor.7

Figure 1 Structure of 5-nitro-2-propoxyaniline (1) and 5-cyano-2-propoxyaniline (2). The nitro group of 5-nitro-2-propoxyaniline was converted to photoreactive groups in this study

To the best of our knowledge, synthesis of photoreactive-2-propoxyaniline derivatives for photoaffinity labeling has not been reported yet. According to a previous report8, even though the nitro group of 5-nitro-2-propoxyaniline was converted to a cyano group, there was almost no decrease in sweetness activity (2, Figure 1). Modification at the 5-position of 2-propoxyaniline might be useful for the introduction of photophores into the ligand skeleton. Therefore, we decided to synthesize 2-propoxyaniline-substituted photophores at the 5-position. Photophores, typically three types, arylazide, benzophenone and aryldiazirine, are used in photoaffinity labeling. To obtain good results using photoaffinity labeling,
selection of an appropriate photophore is important. In this paper, the synthesis of each photoreactive 2-propoxyaniline derivative with aryl azide, benzophenone and aryl diazirinyl also and the results of sweet-tasting effect assay for determining biological activities of photoreactive compounds are reported.

**Results and Discussion:**

The synthesis of 5-azide-2-propoxyaniline (6) started with commercially available 4-propoxy bromobenzene (3) to synthesize (6) efficiently with a few steps. Because an azide group often cannot tolerate strong acidic condition or reductive condition, we decided to install an azide group in the final step. First, compound (3) was subjected to electrophilic nitration with nitric acid (fuming) in acetic anhydride to obtain compound (4) without ipso nitration. Subsequently, since H$_2$-Pd/C reductive condition of the nitro group was simultaneously liable to reduce the bromo group, we chose commercially available 4-propoxy bromobenzene (3) to synthesize 5-bromo-2-propoxyaniline (5) in 78% yield. Finally, the bromo group in compound (5) was substituted with an azide group by sodium azide through Cu$^+$/catalyzed reaction to obtain compound (6). (Scheme 1)

![Scheme 1](image1)

We next tried to synthesize benzophenone derivative (10) from compound (4) as the common intermediate. Although the bromide of (4) was subjected to lithiation with n-BuLi followed by treatment with benzoylated reagents to produce a benzophenone moiety, the products were complicated. Consequently, we considered an alternative synthesis strategy for constructing compound (10), and it was prepared from commercially available N-(2-hydroxyphenyl)acetamide (7) according to similarly previous methods. Compound (7) was subjected to Williamson ether synthesis with 1-bromopropane to produce (8) in high yield. Subsequently, Friedel-Crafts benzylation between compound (8) and benzoyl chloride with AlCl$_3$ at room temperature for 3 h gave compound (9), and this was followed by deprotection of the acetyl group under an acidic condition to afford the benzophenone derivative (10) in 84% overall yield without cleaving the ether group by a three-step sequence. (Scheme 2)

![Scheme 2](image2)

For the (trifluoromethyl)phenyldiazirinyl moiety, compound (4) was not available for the starting material to install a trifluorocetyl group for the same reason in installing a benzophenone group. In addition, it was not possible to obtain a trifluorocetyl derivative from compound (7) or (8) by Friedel-Crafts acylation. Therefore, we selected alternative starting material (11), and it was subjected to demethylation by lithium chloride under a reflux condition to give (12), and this was followed by Williamson ether synthesis to produce (15). Compound (15) was able to be prepared in another way; commercially available 4-propoxybenzaldehyde (13) was treated with CF$_3$-TMS and worked up with 1 M HCl to obtain (14) in good yield. Compound (14) was oxidized with Dess-Martin periodinane under an acidic condition in excellent yield. (Scheme 3)

![Scheme 3](image3)

Nitrations of compound (15) with fuming HNO$_3$ in acetic anhydride at 0 $^\circ$C proceeded selectively (16). The trifluorocetyl moiety was converted to the (trifluoromethyl)diazirinyl moiety (20) using a general method. However, the diazirinyl moiety could not tolerate the condition in which the nitro group was reduced by Na$_2$S$_2$O$_4$, and we therefore previously had the compound (19) reduced without breaking the diazirinyl moiety and obtained (21) in moderate yield. Subsequently, the diazirinyl moiety was converted to diazirinyl moiety (22) with activated MnO$_2$ under a mild condition. (Scheme 4)

![Scheme 4](image4)

The activities of compound (6) and (22) were measured by a cell-based assay, which determines the changes of intracellular calcium ion levels in the human sweet taste receptor hT1R2-hT1R3-expressing HEK293T cells by the fluorescent calcium indicator fura-
2 acetoxyethyl ester] as described by Imada et al. Both the photoreactive 2-propoxaniline, (6) and (22) have enough affinity to the sweet group presumably. These results indicated that photoreactive 2-propoxaniline (6) and (22) have enough affinity with the sweet taste receptor to elucidate the binding site for the ligands in the sweet taste receptor.

Conclusion:
In summary, we have achieved for the first time a comprehensive synthesis of photoreactive (an arylazide, a benzophenone, and an aryl diazirine) 2-propoxanilines for investigation of the sweet taste activity as sucrose. On the other hand, compound (10) did not appreciably show the activity due to a bulky benzoyl group presumably. The reaction mixture was stirred for 1 d at 95 °C and the solution was removed. The residue was purified by silica column chromatography (CH2Cl2/n-hexane 1:1) to yield 6 (82.0 mg, 42%) as yellow oil.

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Supporting Information
YES (this text will be updated with links prior to publication)

Primary Data
NO (this text will be deleted prior to publication)

References and Notes
(11) Andersen, J.; Madsen, Ulf; Bjorkling, F.; Liang, X.; Synlett 2005, 14, 2209.
(12) (5-Azido-2-propoxaniline (6) Compound 5 (57.3 mg, 0.25 mmol), NaN3 (32.3 mg, 0.5 mmol), CuI (4.74 mg, 24.9 μmol). The reaction mixture was stirred for 1 d at 95 °C and the solution was removed. The residue was purified by silica column chromatography (CH2Cl2/n-hexane 1:1) to yield 6 (82.0 mg, 42%) as yellow oil.

1H NMR (75 MHz, CDCl3) δ = 7.81 - 7.68 (m, 2H), 7.62 - 7.38 (m, 3H), 7.27 (s, 1H), 7.19 (d, J = 8.4 Hz, 1H), 6.79 (d, J = 8.2 Hz, 1H), 4.04 (t, J = 6.4 Hz, 2H), 3.93 (b, 2H), 1.87 - 1.77 (m, 7J = 7.1 Hz, 2H), 1.04 (t, J = 7.4 Hz, 3H). 13C NMR (126 MHz, CDCl3) δ = 144.1, 137.7, 132.6, 112.3, 108.2, 70.2, 22.6, 10.6. HRRMS (ESI) m/z [M + H]+ calcd for C19H17N3O 343.1332, found 343.1329.

130, 129.8, 128.1, 127.7, 67.0, 109.9, 69.9, 22.4, 22.4. 10.4. HRRMS (ESI) m/z [M + H]+ calcd for C19H17N3O 343.1338, found 343.1341.

(22) 2-Propoxy-5-(3-(trifluoromethyl)-4H-1,2-diazin-3-yl)aniline (22) Diaziridine 21 (38.1 mg, 0.15 mmol) and activated MnO2 (excess) were suspended in ether (6 mL). The reaction mixture was stirred at room temperature for 1 h, then filtrated insoluble material. The filtrate was concentrated and the residue was purified by silica column chromatography (CH2Cl2/n-hexane 1:3) to yield 22 (35.5 mg, 94%) as yellow oil.

1H NMR (500 MHz, CDCl3) δ = 6.72 (d, J = 8.6 Hz, 1H), 6.55 (s, 1H), 6.46 (d, J = 8.6 Hz, 1H), 3.94 (t, J = 6.6 Hz, 2H), 3.90 (brs, 2H), 1.87 - 1.78 (m, 7J = 7.1 Hz, 2H), 1.04 (t, J = 7.4 Hz, 3H). 13C NMR (126 MHz, CDCl3) δ = 144.1, 137.7, 132.6, 112.3, 108.2, 70.2, 22.6, 10.6. HRRMS (ESI) m/z [M + H]+ calcd for C29H23BrN2O 507.1499, found 507.1492.

19F NMR (471 MHz,
CDCl₃ $\delta = -65.2$. HRMS (ESI) $m/z$ [M + H]$^+$ calcld for C₁₁H₁₃F₃N₃O260.1011, found 260.1010.

(23) **Cellular Responses with Cell-Based Assay**
The hT1R2-hT1R3 and G16-gust44 cell lines (approx 80,000 cells) were treated in 96-well black-wall plates with a calcium indicator dye (FLIPR Calcium 4) for 1 hour at 37 °C. Fluorescence changes by excitation at 485 nm, emission at 525 nm, were monitored at 2 seconds intervals. The photoreactive compounds (6, 10, 22) and sucrose (as positive control) were added at 20 seconds, and scanning was continued for an additional 4 minutes.