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Photoactive ligands probing the sweet taste receptor.

Design and synthesis of highly potent diazirinyl D-phenylalanine derivatives

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Abstract—Some D-Amino acids such as D-tryptophan and D-phenylalanine and are well known as naturally-occurring sweeteners. Photoreactive D-phenylalanine derivatives containing trifluoromethyldiazirinyl moiety at 3- or 4-position of phenylalanine, were designed as sweeteners for functional analysis with photoaffinity labeling. The trifluoromethyldiazirinyl D-phenylalanine derivatives were prepared effectively with chemo-enzymatic methods using L-amino acid oxidase and were found to have potent activity toward the human sweet taste receptor. [BMCL ABSTRACT] ©2000 Elsevier Science Ltd. All rights reserved.
study of the interactions of low molecular bioactive compounds with biomolecules. It is suitable for the analysis of biological interactions because it is based on the affinity of the bioactive compound for biomolecules. Selection of photophore for photoaffinity labeling is very critical to obtain better results, but there are no universal photophore selections. Various photophores, such as benzophenone, arylazide and 3-(trifluoromethyl)phenyldiazirine, are used for the elucidation of the ligand-receptor or substrate-enzyme interactions. In this study, we focused on synthesizing photoreactive D-phenylalanine derivatives, having trifluoromethyl diazirine at 3- or 4- position of phenylalanine benzene ring, based on our modeling work of the ligand-receptor complex, showing that the ligand-binding site has a space for binding the trifluoromethyl diazirine moiety on the phenyl ring of D-phenylalanine. Since preparing the carbene precursor (3-trifluoromethyl)phenyldiazirinyl three-membered ring requires somewhat complicated process, fewer applications have been reported in biomolecular studies than other photophores and neither does the synthesis of diazirinyl D-amino acid derivatives. A few cases of asymmetric synthesis of (3-trifluoromethyl)-diazirinyl L-phenylalanine derivatives are reported. However, D-selective asymmetric synthesis has not been reported. Although L-amino acid derivatives are prepared by enzymatic resolution of N-acyl derivatives using acylase, the residual N-acyl D-amino acid compounds were recovered with less effectiveness. L-amino acid oxidase is an enzyme for converting L-amino acid to α-keto acid but does not work on the D-amino acid compounds at all. Thus, the enzymatic resolution of D-amino acid from racemic mixture using L-amino acid oxidase. The D-phenylalanine derivatives were then subjected to calcium imaging assay using hT1R2-hT1R3 expressing cells.

A complex model of D-phenylalanine in the ATD of the hT1R2 has been constructed using the crystal structure of the glutamate bound closed form of the ATD of the metabotropic glutamate receptor type-1(mGluR1, PDB code:1EWK). D-Phenylalanine was docked into the binding site with a guide of the salt bond between the amino group of the ligand and Glu302 of the receptor, which is conserved and crucial in binding in mGluR1 and also suggested to be crucial for binding of some sweeteners such as aspartame by mutational experiments. The phenyl group bound a hydrophobic pocket which also binds a larger indole moiety of D-tryptophan. The docking of the designed diazirinyl D-phenylalanines at the same site suggested that the receptor accepts the diazirinyl moiety at the binding pocket (Figure 1). Thus, the photoaffinity labeling of the receptor with this photophore would validate the complex structure model.

The 4-diazirinyl benzyl bromide derivatives was reacted with N-(diphenylmethylene)glycine tert-butyl ester in the presence of CsOH and Bu4NBr as phase transfer catalyst to afford phenylalanine skeleton at room temperature, followed by deprotection with acidic conditions to afford racemic diazirinyl phenylalanine DL-6. The racemate was treated with L-amino acid oxidase in the neutral pH condition at 37°C to give the D-amino acid derivative (Figure 2).

**Figure 1.** A complex model of the phenylalanine derivative at the ligand-binding site of hT1R2. The residues at the binding site within 5Å from the ligand (ball-and-stick model) are shown by stick model and Connolly surface. Residue numbers are given by one letter code. The nitrogen, oxygen, fluorine and carbon atoms are colored by blue, red deep green and green, respectively. Hydrogen atoms are omitted for clarity.

**Scheme 1.** Synthesis of diazirinyl D-phenylalanine derivatives D-6 and D-7. i) CsOH, Bu4NBr, CH2Cl2, rt, 12 h, 60–68%. ii) TFA, rt, 2 h, 91–95%. iii) L-amino acid oxidase, pH7.0, 37°C, 12 h, 40–45%
The enzymatic product was monitored with chiral HPLC column (CHIROBIOTIC T, with 10% ethanol-water) at 350nm detection. Although L-4 was still detected within 2 hours, it was completely consumed after 12 hours. The keto acid derived from the L-form (Figure 3B, ~6 min), which is too unstable to isolate in pure form, was removed from the reaction mixture by acidification of the mixture, followed by washing with ethyl acetate. The desired diazirinyl D-amino acid derivative D-6 was then obtained as a powder after lyophilization in moderate yield (Figure 3C). The positional isomer, 3-diazirinyl D-phenylalanine derivative D-7, was also prepared starting from 3-diazirinyl benzyl bromide derivative 2 with the identical process in a moderate yield.

The activity of the diazirinyl phenylalanine derivatives D-6 and D-7 is shown in Figure 4. The sweetness activity of the D-amino acid derivatives was measured by using HEK293T cells transiently expressing hT1R2-hT1R3 and chimeric G-protein, Gα16-gust44, with Ca²⁺ imaging analysis as described by Nakajima et al. The cells, which responded to the ligands, showed red color in the pseudocolor images. The responses to the diazirinyl phenylalanine derivatives D-6 and D-7 were significantly reduced by addition of lactisole, an antagonist against hT1R2-hT1R3 (Fig. 4, A). Both the photoreactive D-amino acids, D-6 and D-7, exhibited higher sweetness activity than D-tryptophan and D-phenylalanine, and a similar activity as aspartame had at the same dose (1.25 mM). Since the trifluoromethyl-diazirinyl moiety may occupy the binding-site for the phenyl ring of D-tryptophane, the ligand-binding site would have a significantly large space for accepting hydrophobic moieties of ligands. These results indicate that the preparation of the diazirinyl D-phenylalanine derivatives through the enzymatic resolution with L-amino acid oxidase is effective and that these photoreactive compounds have enough affinity with the sweet taste receptor to elucidate the binding site for the ligands in the sweet taste receptor.
Acknowledgements

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References and Notes

22. The initial structural model of the active form of hT1R2 derived from the crystal structure of the closed form of the ATD of mGluR1 (IEW3) was energy-minimized with a molecular mechanics program, Discover 3 (Accelrys Inc, San Diego CA, USA), until the RMSD became less than 0.1 kcal/molÅ. D-Trp was then docked into the binding cleft assuming an electrostatic interaction between Glu302 and the amino group of the ligand. The initial complex structure model was energy-minimized and then optimized with molecular dynamics using Discover 3. The molecular dynamics calculation was performed for 0.2 ns, sampling the structure every 20ps. Each structure was energy-minimized as described above. The energetically most stable structure was selected as the complex structure model.
25. Typical procedure for enzymatic resolution; DL-6 was suspended in water (20 ml) and the suspension was adjusted to pH 7 with NH4OH and formic acid. L-amino acid oxidase (Sigma A-9378) was added to the suspension. The reaction mixture was incubated at 37 °C for 12 hours, then made acid with 1N formic acid and extracted with ethyl acetate. The aqueous layer was concentrated and the residue was subjected to chiral HPLC with Chirobiotic T (4.6 x 250 mm, 10% ethanol, 1 ml / min) at 350 nm, then lyophilized to afford colorless amorphous mass.
26. D-6 [α]D (c = 0.2, MeOH) +69.0, literature for L-6 [α]D (c = 0.115, MeOH) -70.0 [11]. 1H-NMR (500 MHz, CD3OD) δ 7.46 (d, 2H, J = 7.9 Hz), 7.27 (d, 2H, J = 7.9 Hz), 3.38 (dd, 1H, J = 8.2, 4.8 Hz), 3.10 (dd, 2H, J = 14.5, 8.2 Hz).
27. D-7 [α]D (c = 0.2, MeOH) +8.9, 1H-NMR (500 MHz, CD3OD) δ 7.37 (d, 1H, J = 8.2 Hz), 7.18 (d, 2H, J = 8.2 Hz), 7.05 (s, 1H), 3.67 (m, 1H), 2.92 (m, 1H).

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