# T1R HETERO-OLIGOMERIC TASTE RECEPTORS, CELL LINES THAT EXPRESS SAID RECEPTORS, AND TASTE COMPOUNDS

## Cross Reference to Related Applications

This application claims priority to U.S. Provisional Application Serial No 60/494,071 filed on August 6, 2003, and U.S. Provisional Application Serial No 60/552,064 filed March 9, 2004, both of which are incorporated by reference in their entirety.

## Background of the Invention

Field of the Invention

The present invention in part relates to the discovery that the T1R receptors assemble to form functional taste receptors. Particularly, it has been discovered that co-expression of T1R1 and T1R3 results in a taste receptor that responds to umami taste stimuli, including monosodium glutamate. Also, it has been discovered that co-expression of the T1R2 and T1R3 receptors results in a taste receptor that responds to sweet taste stimuli including naturally occurring and artificial sweeteners.

Also, the present invention relates to the use of hetero-oligomeric taste receptors comprising T1R1/T1R3 and T1R2/T1R3 in assays to identify compounds that respectively respond to umami taste stimuli and sweet taste stimuli.

The invention also relates to chimeras and truncated versions of T1R1, T1R2, and T1R3, as well as chimeras of T1R1/T1R3 and T1R2/T1R3 receptors comprising human, rat, or human and rat subunits.

Further, the invention relates to the construction of cell lines that stably or transiently co-express a combination of T1R1 and T1R3; or T1R2 and T1R3, including truncated or chimeric versions of these subunits as well as chimeric receptors comprising wild-type or chimeric subunits; under constitutive or inducible conditions.

The use of these cell lines in cell-based assays to identify umami and sweet taste modulatory compounds is also provided, particularly high throughput screening assays that detect receptor activity by the use of fluorometric imaging.

The invention also relates to compounds that bind to T1R1/T1R3, T1R2/T1R3 receptors, as well as T1R1, T1R2, and T1R3 chimeric and truncated subunits and chimeric receptors.

Description of the Related Art

The taste system provides sensory information about the chemical composition of the external world. Mammals are believed to have at least five basic taste modalities: sweet, bitter, sour, salty, and umami. *See, e.g.*, Kawamura *et al.*, *Introduction to Umami: A Basic Taste* (1987); Kinnamon *et al.*, *Ann. Rev. Physiol.*, 54:715-31 (1992); Lindemann, *Physiol. Rev.*, 76:718-66 (1996); Stewart *et al.*, *Am. J. Physiol.*, 272:1-26(1997). Each taste modality is thought to be mediated by a distinct protein receptor or receptors that are expressed in taste receptor cells found on the surface of the tongue (Lindemann, Physol. Rev. 76:718-716 (1996)). The taste receptors that recognize bitter, sweet, and umami taste stimuli belong to the G-protein-coupled receptor (GPCR) superfamily (Hoon *et al.*, *Cell* 96:451 (1999); Adler *et al.*, *Cell* 100:693 (2000)). (Other taste modalities are believed to be mediated by ion channels.)

G protein-coupled receptors mediate many other physiological functions, such as endocrine function, exocrine function, heart rate, lipolysis, and carbohydrate metabolism. The biochemical analysis and molecular cloning of a number of such receptors has revealed many basic principles regarding the function of these receptors. For example, United States Patent No. 5,691,188 describes how upon a ligand binding to a GPCR, the receptor undergoes a conformational change leading to activation of a heterotrimeric G protein by promoting the displacement of bound GDP by GTP on the surface of the Gα subunit and subsequent dissociation of the Gα subunit from the Gβ and Gγ subunits. The free Gα subunits and Gβγ complexes activate downstream elements of a variety of signal transduction pathways.

The T1R receptors were previously hypothesized to function as sweet taste receptors (Hoon et al., *Cell* 96:541-51 (1999); Kitagawa et al., *Biochem Biophys Res. Commun.* 283:236-42 (2001); Max et al., *Nat. Genet.* 28:58-63 (2001); Montmayeur et al., *Nat. Neurosci.* 4: 412-8 (2001); Sainz et al., *J. Neurochem.* 77: 896-903 (2001)), and Nelson et al. (2001) and Li et al (2002) have recently demonstrated that rat and human, respectively, T1R2 and T1R3 act in combination to recognize sweet taste stimuli.

However, there remains in the art a need for new and improved flavoring agents. For example, one of the five known basic tastes is the "savory" or "umami"

flavor of monosodium glutamate ("MSG"). MSG is known to produce adverse reactions in some people, but very little progress has been made in identifying artificial substitutes for MSG. It is known that a few naturally occurring materials can increase or enhance the effectiveness of MSG as a savory flavoring agent, so that less MSG would be needed for a given flavoring application. For example the naturally occurring nucleotide compounds inosine monophosphate (IMP) or guanosine monophosphate (GMP) are known to have a multiplier effect on the savory taste of MSG, but IMP and GMP are very difficult and expensive to isolate and purify from natural sources, or synthesize, and hence have only limited practical application to most commercial needs in food or medicinal compositions. Less expensive compounds that would provide the flavor of MSG itself, or enhance the effectiveness of any MSG that is present could be of very high value. Similarly, discovery of compounds that are either new "High Intensity" sweeteners (*i.e.* they are many times sweeter than sucrose) would be of value.

What is needed in the art is the identification and characterization of taste receptors which function as sweet and umami receptors, assays for identifying compounds that modulate (enhance or block) sweet and umami taste, and the compounds that specifically bind to these receptors.

## Summary of the Invention

The present invention provides chimeric receptors comprising various combinations of human and rat TIRs, such as a chimeric T1R2/T1R3 receptor comprising a human T1R2 subunit and a rat T1R3 subunit; a chimeric T1R2/T1R3 receptor comprising a rat T1R2 subunit and a human T1R3 subunit; a chimeric T1R2 receptor subunit comprising a human extracellular domain, a rat transmembrane domain and a rat intracellular domain; and a chimeric T1R3 receptor subunit comprising a rat extracellular domain, a human transmembrane domain and a human intracellular domain.

The present invention also provides compounds that specifically bind to T1R1, T1R2, T1R3, T1R1/T1R3 and T1R2/T1R3, or isolated subunits, fragments, chimeras or truncated versions thereof as disclosed herein.

The present invention relates to the discovery that different combinations of T1Rs, when co-expressed, produce functional taste receptors that respond to taste

stimuli. Particularly, the present invention relates to the discovery that co-expression of T1R2 and T1R3 results in a hetero-oligomeric taste receptor that responds to sweet taste stimuli. Also, the present invention relates to the discovery that the co-expression of T1R1 and T1R3 results in a hetero-oligomeric taste receptor that responds to umami taste stimuli such as monosodium glutamate.

The present invention also relates to cell lines that co-express T1R1 and T1R3, including human or rat, or T1R2 and T1R3, including human or rat. In preferred embodiments these cell lines will express elevated amounts of the receptors, either constitutively or inducibly. These cell lines include cells that transiently or stably express T1R1 and T1R3 or T1R2 and T1R3.

Also, the present invention provides assays, preferably high throughput screening assays, that utilize the T1R2/T1R3 taste receptor, or the T1R1/T1R3 receptor, preferably high throughput cell-based assays, to identify compounds that modulate sweet or umami taste. The invention also provides assays that include taste tests to confirm that these compounds modulate sweet or umami taste.

The invention also relates to compounds that bind to the N-terminal extracellular domain of T1R2, compounds that bind to the cysteine-rich domain of T1R2, compounds that bind to the Transmembrane Domain of T1R2, compounds that bind to the Transmembrane Domain of T1R3, compounds that bind to the Transmembrane Domain of T1R2 of a truncated receptor h2TM/h3TM, and compounds that bind to the Transmembrane Domain of T1R3 of a truncated receptor h2TM/h3TM, for example.

## Brief Description of the Figures

Figure 1 contains a sequence alignment of human and rat T1Rs, human calcium-sensing receptor and rat metabotropic glutamate receptor.

Figure 2 contains RT-PCR amplification experimental results which show that hT1R2 and hT1R3 are expressed in taste tissue.

Figure 3a – 3b contain functional data (intracellular calcium responses) elicited by different sweet taste stimuli in HEK cells stably expressing $G_{\alpha 15}$ that are transiently transfected with human T1R2, T1R3 and T1R2/T1R3 at various concentrations of sweet taste stimuli (Figure 3a); human T1R2/T1R3 dose responses for several sweet taste stimuli (Figure 3b); human T1R2/T1R3 responses to sucrose in

the presence of gurmarin, and endogenous β2-adrenergic receptor responses to isoproterenol in the presence of gurmarin. Figure 3c contains the normalized response to different sweeteners.

Figure 4 contains intracellular calcium responses in HEK cells stably expressing Gα15, transiently transfected with hT1R2/hT1R3, rT1R2/rT1R3, hT1R2/rT1R3 and rT1R2/hT1R3 in response to 350 mM sucrose, 25 mM tryptophan, 15 mM aspartame, and 0.05 % monellin.

Figure 5 contains the results of a fluorescence plate reactor based assay wherein HEK cells stably expressing Gα15 were transiently transfected with hT1R2 and hT1R3 or hT1R3 alone and contacted with the calcium dye Fluo-4 and a sweet taste stimulus (12.5 mM cyclamate).

Figure 6 contains normalized dose-response curves which show that hT1R2 and hT1R3 function in combination as the human sweet receptor based on their dose-specific interaction with various sweet stimuli (trp, cyclamate, sucrose, neotame, asparame, saccharin and Acek).

Figure 7 contains structural information relating to mGluR1 and T1R1 showing the key ligand binding residues are observed in these molecules.

Figure 8a-8c contains functional data showing HEK cells which stably express Gα15 that are transiently transfected with T1R1/T1R3 respond to glutamate in an intracellular calcium-based assay. Figure 8a shows that intracellular calcium increases in response to increasing glutamate concentration; Figure 8b shows intracellular calcium responds to IMP (2 mM), glutamate (0.5 mM) and 0.2 mM IMP; and Figure 8c shows human T1R1/T1R3 responses for glutamate in the presence and absence of 0.2 mM IMP.

Figures 9a-9b respectively contain the results of an immunofluorescence staining assay using Myc-tagged hT1R2 and a FACS experiment showing that the incorporation of the PDZIP peptide (SEQ ID No: 1) enhanced the expression of a T1R (hT1R2) on the plasma membrane.

Figure 10a through 10b contain calcium imaging data demonstrating that h1TR2/hT1R3 respond to different sweet stimuli.

Figure 11 shows the responses of cell lines which stably express hT1R1/hT1R3 by automated fluorescence imaging to umami taste stimuli.

Figure 12 shows the responses of a cell line which stably expresses hT1R2/hT1R3 by automated fluorescence imaging to sweet taste stimuli.

Figure 13 shows dose-response curves determined using automated fluorescence imaging for a cell line that inducibly expresses the human T1R1/T1R3 taste receptor for L-glutamate in the presence and absence of 0.2mM IMP.

Figures 14 and 15 show the response of a cell line that inducibly expresses the human T1R1/T1R3 taste receptor (I-17 clone) to a panel of L-amino acids. In Figure 14 different C-amino acids at 10mM were tested in the presence and absence of 1 mM IMP. In Figure 15 dose-responses for active amino acids were determined in the presence of 0.2mM IMP.

Figure 16 shows that lactisole inhibits the receptor activities of human T1R2/T1R3 and human T1R1/T1R3.

Figure 17 shows schematics of human-rat T1R chimeras. The chimeras are constructed by fusing the human or rat extracellular domains to the rat or human transmembrane domains respectively, as shown in h2-r2, r2-h2, h3-r3 and r3-h3.

Figure 18 shows neohesperidin dihydrochalcone (NHDC) enhances the activities of T1R1/T1R3 umami taste receptor. [Neohesperidin dihydrochalcone] = 5 μM. The glutamate dose response curve is left-shifted by 2.3 fold (left panel), and the glutamate/IMP dose response is left-shifted by 2.1 fold.

Figure 19 shows that control sweeteners do not affect the activities of T1R1/T1R3 umami taste receptor [Steviocide] = 0.5 mM. [Saccharin] = 1 mM. Glutamate dose response is shown in the left panel, and glutamate/IMP dose response is shown in the right panel.

Figure 20 shows NHDC maps to the transmembrane domain of human T1R3.

Figure 21 shows mapping of a compound to the human T1R2 transmembrane domain.

Figures 22a-d show sweeteners which map to different domains/subunits of the human sweet receptor. Figure 22a shows responses of human and rat sweet receptors to sucrose (200 mM), aspartame (10 mM), neotame (0.1 mM), cyclamate (10 mM), and sucrose (200 mM) in the presence of lactisole (1 mM) (Suc/Lac). HEK-293T cells were transiently transfected with human or rat T1R2, T1R3, and a $G_{\alpha 15}$ chimera $G_{\alpha 15/il}$, and assayed for intracellular calcium increases in response to sweeteners. Figure 22b shows aspartame and neotame were mapped to N- terminal extracellular domain of human

T1R2. Combinations of T1R chimeras were transiently transfected into HEK-293T cells with $G_{\alpha 15/il}$, and assayed for responses to sweeteners at the concentrations listed in 23a. The presence or absence of response is what is important. Figure 22c shows cyclamate was mapped to the C-terminal transmembrane domain of human T1R3. Figure 22d shows lactisole was mapped to the transmembrane domain of human T1R3. Different combinations of T1R chimeras were transiently transfected into HEK-293T cells with G $G_{\alpha 15/il}$, and assayed for responses to sucrose (200 mM) and AceK (10 mM) in the absence or presence of lactisole (1 mM). The activities in B, C and D represent the mean ± SE of number of responding cells for four imaged field of ~1,000 confluent cells.

Figures 23a-d show mutations in T1R2 or T1R3 selectively affect the activity of different sweeteners. Figure 23a shows sequence alignment of the N-terminal ligand binding domain of rat mGluR5 with human and rodent T1R2s. The 8 critical amino acids involved in ligand-binding in mGluR5 are labeled with *, three of the 8 amino acids are conserved in T1R2 and underlined. Figure 23b shows two point mutations in the human T1R2 N-terminal extracellular domain that abolish response to aspartame and neotame without affecting cyclamate. Stable cell lines of hT1R2/hT1R3 (WT), hT1R2 S144A/hT1R3 (S144A) and hT1R2 E302A/hT1R3 (E302A) were generated as describe in the Examples. The dose-responses of these stable lines were determined on FLIPR for sucrose, aspartame, neotame and cyclamate. The activities represent the mean ± SE of fold increases in fluorescence intensities for four recorded wells. Figure 23c shows sequence alignment of human and rodent T1R3 transmembrane domains. The three extracellular loops are underlined and labeled EL1, 2, or 3, according to their order in the protein sequences. Figure 23d shows mutations in the extracellular loop of hT1R3 that abolish response to cyclamate without affecting aspartame. Each of the three extracellular loops of hT1R3 were replaced with rat protein sequence separately, and the resulting hT1R3 mutants were transiently transfected into HEK-293T cells together with $G_{\alpha 15/il}$, and assayed for responses to sucrose (200mM), aspartame (10 mM) and cyclamate (10 mM). The activities represent the mean ± SE of number of responding cells for four imaged field of ~1,000 confluent cells.

Figures 24a-b show human T1R2 is required for $G_{\alpha 15}$-coupling. Figure 24a shows responses of human, rat and chimeric sweet receptors to sucrose (200 mM) and AceK (10 mM). Stable $G_{\alpha 15}$ cells were transiently transfected with human, rat or

chimeric T1Rs, and assayed for intracellular calcium increases in response to sweeteners. Figure 24b shows $G_{\alpha 15}$–coupling is mediated by human T1R2. The activities represent the mean ± SE of number of responding cells for four imaged field of ~1,000 confluent cells.

Figures 25a-f show the effect of lactisole and cyclamate on the human T1R1/T1R3 umami receptor. Figure 25a shows the response of human T1R1/T1R3 stable cell line to L-glutamate (5 mM) and L- glutamate/IMP (1/0.2 mM) in the absence and presence of lactisole (5 mM). Figure 25b shows the lactisole dose-dependent inhibition curves were determined for L-glutamate (Glu), and L- glutamate with 0.2 mM IMP (Glu/IMP), each at two different concentrations. The IC50s are 0.19 ± 0.02 mM and 0.21 ± 0.01 mM for L-glutamate at 8 and 80 mM; 0.35 ± 0.03 mM and 0.82 ± 0.06 mM for L-glutamate with IMP at 0.8 and 8 mM respectively. Figure 25c shows the dose responses for L-glutamate, with or without 0.2 mM IMP, were determined in the presence of different concentrations of lactisole. In the presence of 0, 25, or 50 μM lactisole, the EC50s are 9.9 ± 1.5 mM, 7.9 ± 0.5 mM, and 7.0 ± 0.3 mM for L-glutamate; in the presence of 0, 100, or 200 μM lactisole, the $EC_{50}$s are 0.53 ± 0.04 mM, 0.71 ± 0.10 mM, and 0.84 ± 0.10 mM for L-glutamate with IMP. Values represent the mean ± SE for four independent responses. Figure 25d shows the detection thresholds for sweet, umami, and salty taste stimuli were determined in the presence or absence of lactisole. The inhibition effect of lactisole is shown as fold increases in detection thresholds. "Detection thresholds" are defined as the lower limit of detectable tastants. The detection threshold values were averaged over four trials for three subjects. Figure 25e shows the responses of human T1R1/T1R3 stable cell line to threshold level of L-glutamate (4 mM) and endogenous M2 receptor agonist carbachol were assayed on FLIPR in the absence and presence of various concentrations of cyclamate. Figure 25f shows the dose-responses of the human T1R1/T1R3 stable cell line were determined on FLIPR for L-glutamate with or without 0.2 mM IMP in the absence and presence of cyclamate (8 mM). The activities in B, C, E and F represent the mean ± SE of fold increases in fluorescence intensities for four recorded wells. The dose– responses in B, C, E and F were reproduced at least 6 times independently.

Figure 26 shows a working model for the sweet and umami taste receptor structure-function relationships. Filled arrows indicate direct activation, open arrows indicate enhancement, and bar heads indicate inhibition.

Figure 27a shows all 16 combinations of T1Rs and chimeras that were tested for responses to sweeteners and lactisole. rT1R2/T1R3H-R, rT1R2/hT1R3, and T1R2H-R/T1R3R-H show a significant response to cyclamate and they can be inhibited by lactisole. T1R chimeras were transiently transfected into HEK-293T cells with $G_{\alpha 15/il}$. The activities represent the mean ± SE of number of responding cells for four imaged field of ~1,000 confluent cells, each unit on the Y axis represents 50 responding cells. Abbreviations: Suc (sucrose 100mM); Suc/Lac (sucrose 100mM, lactisole 1 mM); AceK (acesulfame K 10 mM); AceK/Lac (acesulfame K 10 mM, lactisole 1 mM); ATM (aspartame 10mM); NTM (neotame 10 mM); Cyc (cyclamate 10 mM). Figure 27b shows the lactisole dose-dependent inhibition curves of the human sweet receptor were determined for sucrose (Suc), saccharin (Sac), and D-tryptophan (D-Trp), each at two different concentrations. The IC50s are 19.6 ± 0.1 μM and 64.6 ± 0.3 μM for sucrose at 50 mM and 120 mM; 22.6 ± 0.1 μM and 103 ± 7 μM for saccharin at 0.1 and 2 mM; 19.9 ± 0.2 μM and 168 ± 9 μM for D-tryptophan respectively. Figure 27c shows the dose responses of human sweet receptor for sucrose, D-Trp and saccharin were determined with different concentrations of lactisole. In the presence of 0, 10, or 20 μM lactisole, the $EC_{50}$s are 19.4 ± 0.9 mM, 24.7 ± 1.0 mM, and 31.3 ± 0.3 mM for sucrose; 0.37 ± 0.02 mM, 0.60 ± 0.03 mM, 0.94 ± 0.08 mM for D-Trp; 42 ± 3 μM, 67 ± 6 μM, 118 ± 2 μM for saccharin. Values represent the mean ± SE for four independent responses. The dose-responses in B and C were determined at least 6 times independently, and generated similar results as shown here.

## Detailed Description of the Invention

The inventions provides compounds that specifically bind to the wild-type and chimeric sweet and umami taste receptors disclosed herein. Further provided are compounds that specifically bind to the wild-type, chimeric or truncated T1R2 or T1R3 subunits of the sweet and umami receptors.

Binding to the T1R2/T1R3 sweet receptor defines a large genus of molecules. The receptor responds to every sweetener tested, including carbohydrate sugars, amino acids and derivatives, sweet proteins, and synthetic sweeteners. In the meantime, the receptor exhibits stereo-selectivity for certain sweeteners, for example, it responds to D-tryptophan but not L-tryptophan, which is in correlation with taste physiology data.

Thus, the compounds of the invention specifically bind chimeric receptors. Examples include, but are not limited to, a chimeric T1R2/T1R3 receptor comprising a human T1R2 subunit and a rat T1R3 subunit; a chimeric T1R2/T1R3 receptor comprising a rat T1R2 subunit and a human T1R3 subunit; a chimeric T1R2 receptor subunit comprising a human extracellular domain, a rat transmembrane domain and a rat intracellular domain; and a chimeric T1R3 receptor subunit comprising a rat extracellular domain, a human transmembrane domain and a human intracellular domain. The invention provides functional taste receptors, preferably human taste receptors, that are produced by co-expression of a combination of different T1Rs, preferably T1R1/T1R3 or T1R2/T1R3, and the corresponding isolated nucleic acid sequences or fragments, chimeras, or variants thereof that upon co-expression result in a functional taste receptor, i.e., a sweet taste receptor (T1R2/T1R3) or umami taste receptor (T1R1/T1R3).

T1Rs, a family of class C G protein-coupled receptors (GPCRs), are selectively expressed in the taste tissue (Hoon, M.A., et al., Cell, 1999. 96(4): p. 541-51, Bachmanov, A.A., et al., Chem Senses, 2001. 26(7): p. 925-33, Montmayeur, J.P., et al., Nat Neurosci, 2001. 4(5): p. 492-8, Max, M., et al., Nat Genet, 2001. 28(1): p. 58-63, Kitagawa, M., et al., Biochem Biophys Res Commun, 2001. 283(1): p. 236-42 and Nelson, G., et al., Cell, 2001. 106(3): p. 381-90.) Functional expression of T1Rs in HEK293 cells revealed that different combinations of T1Rs respond to sweet and umami taste stimuli (Nelson, G., et al., Cell, 2001. 106(3): p. 381-90, Li, X., et al., Proc Natl Acad Sci U S A, 2002. 99(7): p. 4692-6.) T1R2 and T1R3, when co-expressed in 293 cells, recognize diverse natural and synthetic sweeteners [For the reason mentioned above re "diverse", please consider whether we need this section for enablement. If not, I'd delete. We can discuss], while T1R1 and T1R3 recognize umami taste stimulus L-glutamate, and this response is enhanced by 5'-ribonucleotides, a hallmark of umami taste. Knockout data confirmed that T1Rs indeed mediate mouse sweet and umami tastes (Damak, S., et al., Science, 2003 301(5634): p. 850-3, Zhao, G.Q., et al., Cell 2003 Oct 31;115(3):255-66).

The class C GPCRs possess a large N-terminal extracellular domain, often referred to as the Venus flytrap domain (VFD) (Pin, J.P., Pharmacol Ther, 2003 98(3): p. 325-54), and are known to function as either homodimers, in the cases of metabotropic glutamate receptors (mGluRs) and calcium- sensing receptor (CaR), or

heterodimers, in the case of γ-aminobutyric acid type B receptor ($GABA_BR$). The functional expression data shows a heterodimer mechanism for T1Rs: both T1R1 and T1R2 need to be coexpressed with T1R3 to be functional, which is supported by the overlapping expression patterns of T1Rs in rodent tongue.

It is established herein that T1R family members act in combination with other T1R family members to function as sweet and umami taste receptors. As disclosed in further detail infra in the experimental examples, it has been demonstrated that heterologous cells which co-express hT1R2 and hT1R3 are selectively activated by sweet taste stimuli in a manner that mirrors human sweet taste.

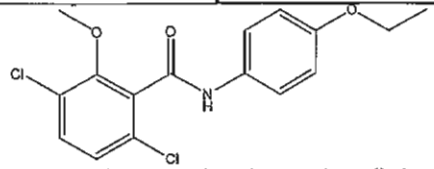
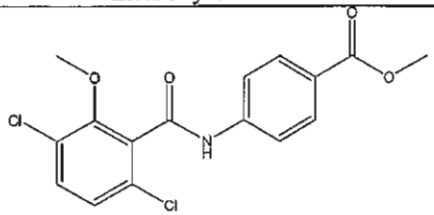
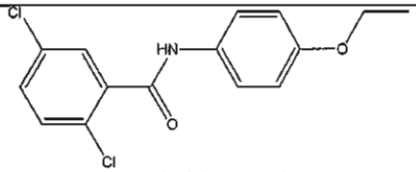
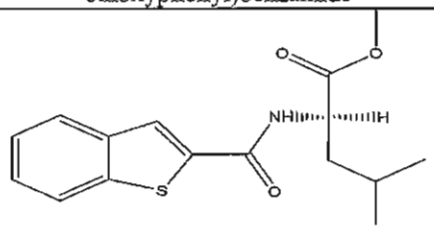
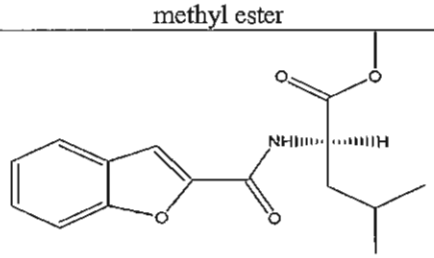
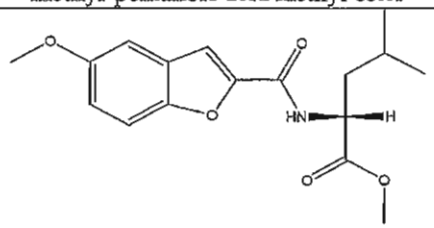
For example, HEK-293-Gα15 cells that co-express hT1R2 and hT1R3 specifically respond to cyclamate, sucrose, aspartame, and saccharin, and the dose responses for these compounds correlate with the psychophysical taste detection thresholds.

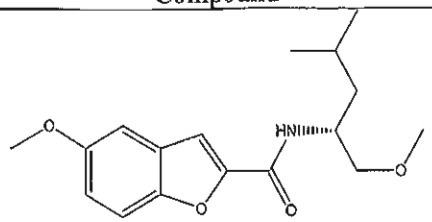
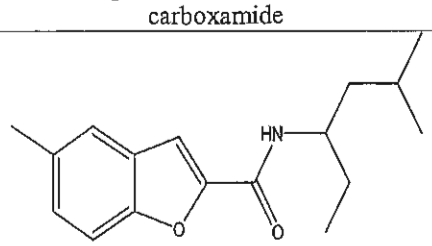
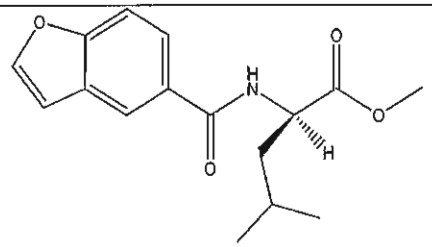
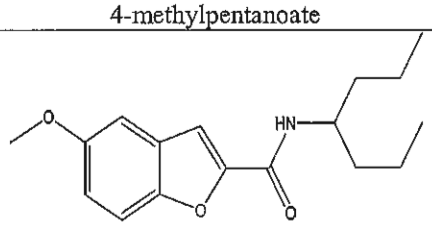
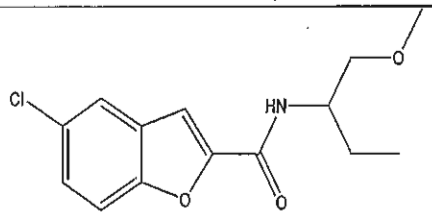
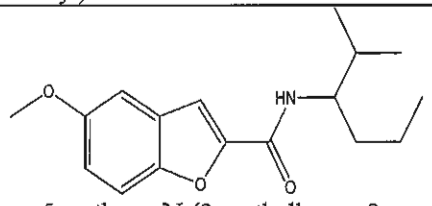
Also, as supported by data in the experimental examples, it has been shown that cells which co-express hT1R1 and hT1R3 are selectively activated by glutamate (monosodium glutamate) and 5'-ribonucleotides in a manner that mirrors human umami taste. For example, HEK-293-Gα15 cells that co-express hT1R1 and hT1R3 specifically respond to glutamate and the dose response for this umami-tasting compound correlates with its psychophysical taste detection threshold. Moreover, 5'-ribonucleotides such as IMP enhance the glutamate response of the T1R1/T1R3 receptor, a synergism characteristic of umami taste.

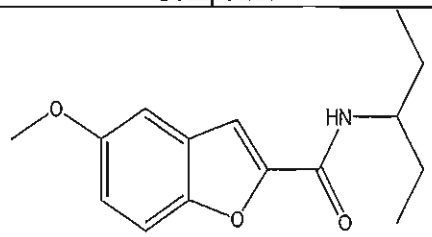
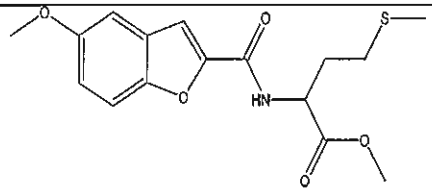
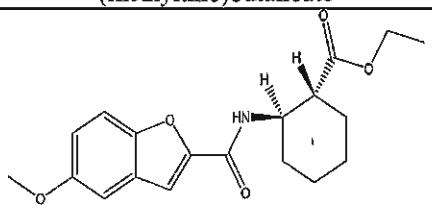
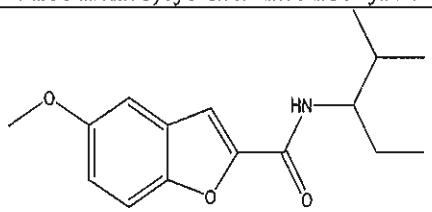
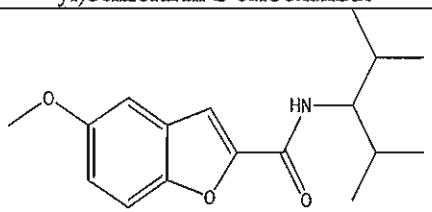
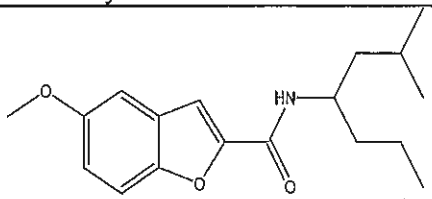
Further, as shown by experimental data in the examples it has been shown that cells which stably and inducibly co-express T1R1/T1R3 selectively respond to the umami taste stimuli L-glutamate and L-aspartate and only weakly respond to other L-amino acids, and at much higher concentrations, providing further evidence that the T1R1/T1R3 receptor can be used in assays to identify compounds that modulate (enhance or block) umami taste stimuli.

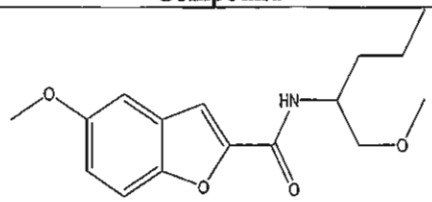
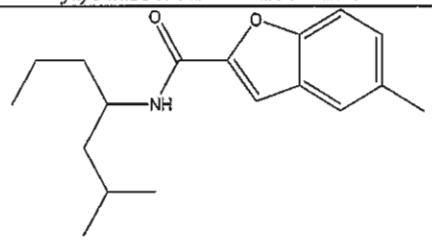
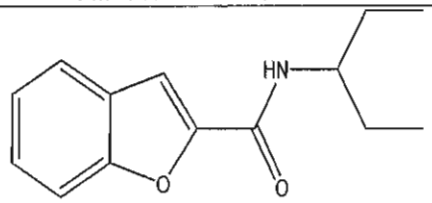
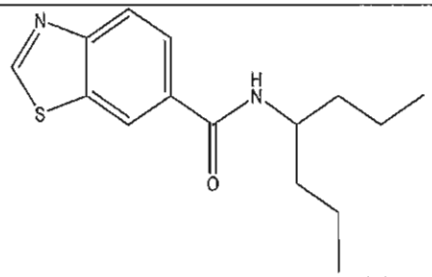
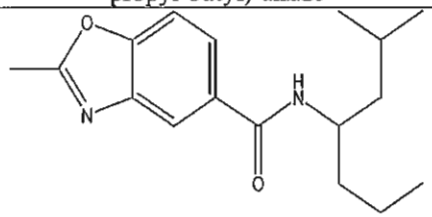
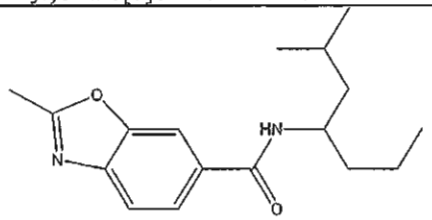
Examples of compounds that specifically bind to the sweet receptor and modulate sweet taste can be found in Table 5.

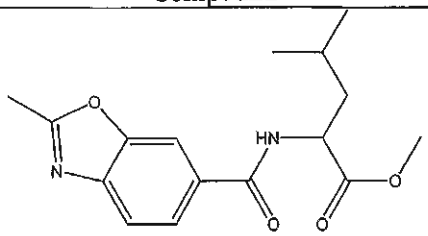
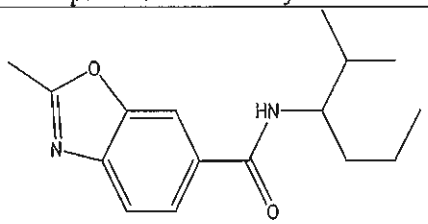
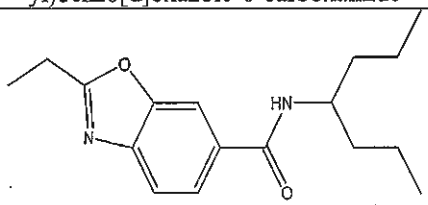
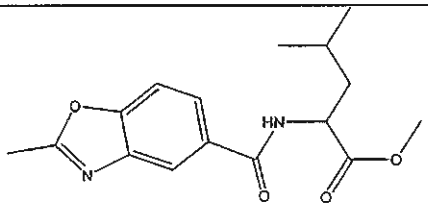
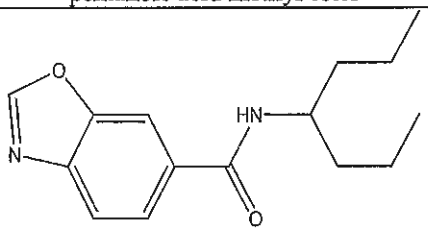
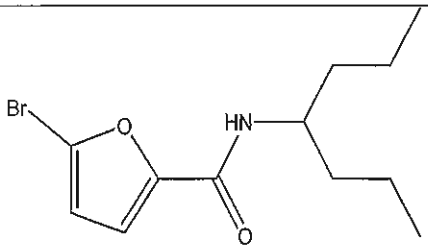
Tables 1-4 provide examples of compounds that specifically bind to the umami receptor and modulate umami taste.

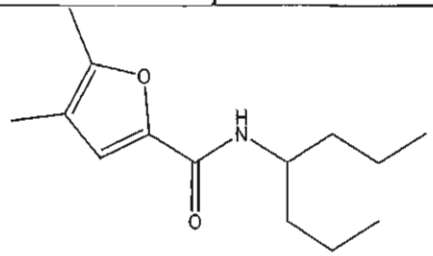
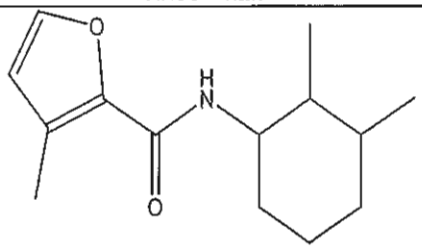
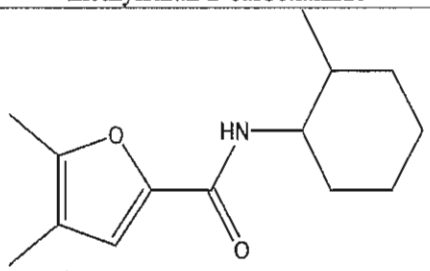
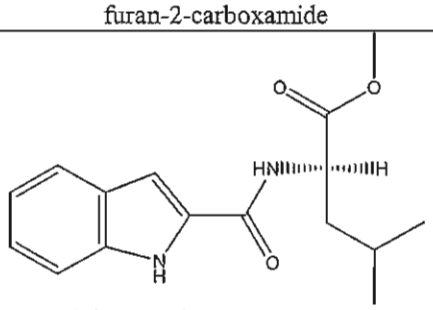
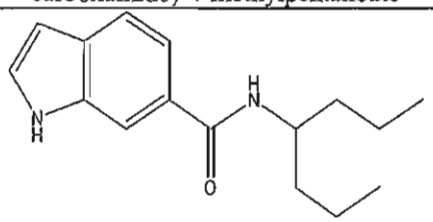
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A1 |  3,6-Dichloro-N-(4-ethoxy-phenyl)-2-methoxy-benzamide | 0.22 | 2.74 | 1 |
| A2 |  4-(3,6-Dichloro-2-methoxy-benzoylamino)-benzoic acid methyl ester | 0.93 | 6.98 | 0.01 |
| A3 c |  2,5-dichloro-N-(4-ethoxyphenyl)benzamide | 1.08 | 6.14 | 0.03 |
| A4 |  2-[(Benzo[b]thiophene-2-carbonyl)-amino]-4-methyl-pentanoic acid methyl ester | 0.4 | | |
| A5 |  2-[(Benzofuran-2-carbonyl)-amino]-4-methyl-pentanoic acid methyl ester | 0.31 | | |
| A6 |  2-[(5-Methoxy-benzofuran-2-carbonyl)-amino]-4-methyl-pentanoic acid methyl ester | 0.32 | 2.86 | 1 |

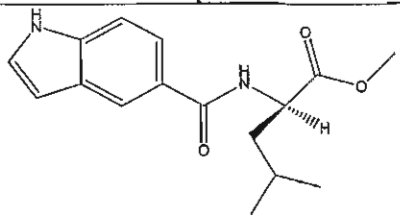
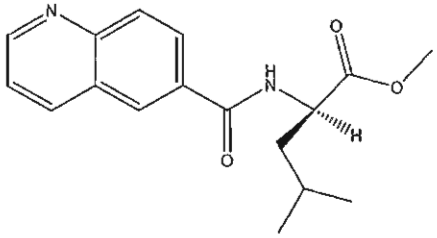
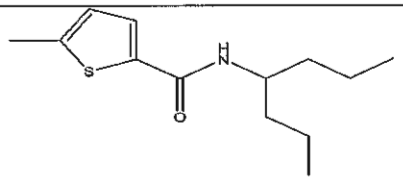
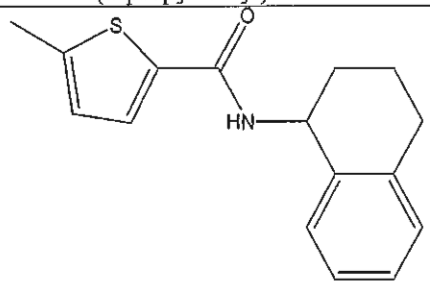
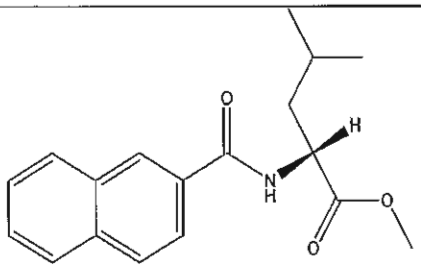
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A7 |  (R)-5-methoxy-N-(1-methoxy-4-methylpentan-2-yl)benzofuran-2-carboxamide | 0.46 | | |
| A8 |  5-methyl-N-(5-methylhexan-3-yl) benzofuran-2-carboxamide | 0.5 | | |
| A9 |  2-[(Benzofuran-5-carbonyl)-amino]-4-methyl-pentanoic acid methyl ester(R)-methyl 2-(benzofuran-5-carboxamido)-4-methylpentanoate | 0.71 | | |
| A10 |  N-(heptan-4-yl)-5-methoxybenzofuran-2-carboxamide | 0.91 | 4.51 | 1 |
| A11 |  5-chloro-N-(1-methoxybutan-2-yl)benzofuran-2-carboxamide | 1.05 | 6.5 | 0.3 |
| A12 |  5-methoxy-N-(2-methylhexan-3-yl)benzofuran-2-carboxamide | 1.13 | | |

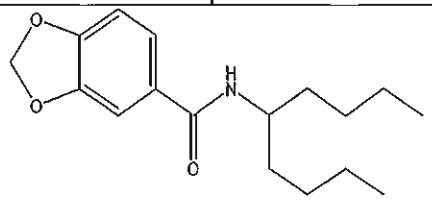
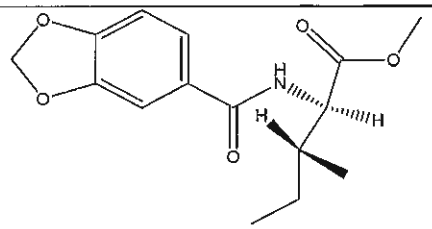
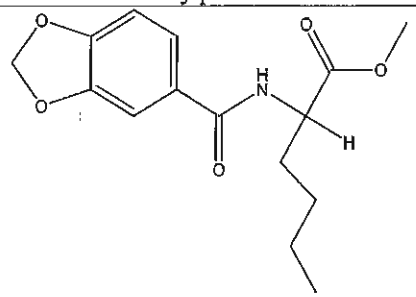
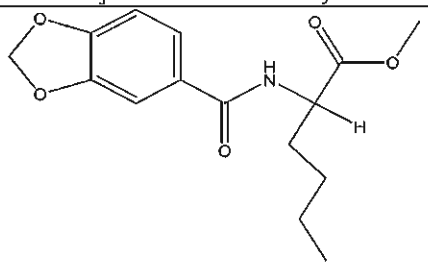
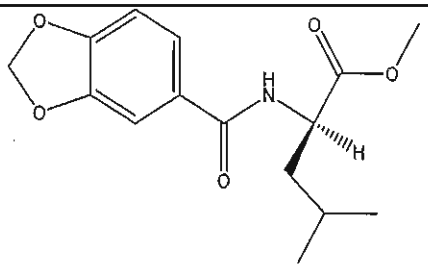
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A13 |  5-methoxy-N-(pentan-3-yl)benzofuran-2-carboxamide | 1.14 | 4.46 | 1 |
| A14 |  2-[(5-Methoxy-benzofuran-2-carbonyl)-amino]-4-methylsulfanyl-butyric acid methyl ester methyl 2-(5-methoxybenzofuran-2-carboxamido)-4-(methylthio)butanoate | 1.14 | | |
| A15 |  (1R,2R)-ethyl 2-(5-methoxybenzofuran-2-carboxamido)cyclohexanecarboxylate | 1.14 | | |
| A16 |  5-methoxy-N-(2-methylpentan-3-yl)benzofuran-2-carboxamide | 1.18 | | |
| A17 |  N-(2,4-dimethylpentan-3-yl)-5-methoxybenzofuran-2-carboxamide | 1.2 | | |
| A18 |  5-methoxy-N-(2-methylheptan-4-yl)benzofuran-2-carboxamide | 1.27 | | |

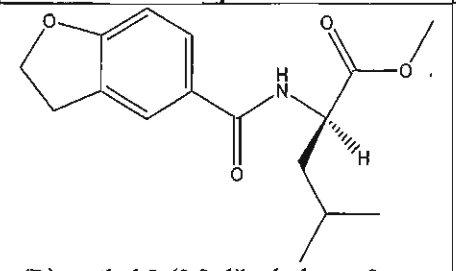
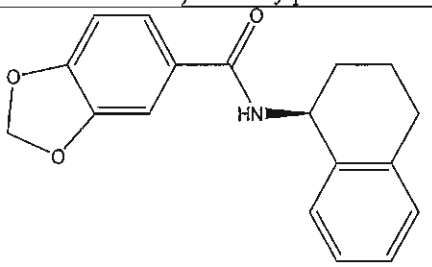
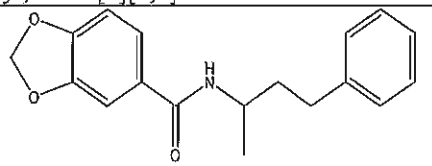
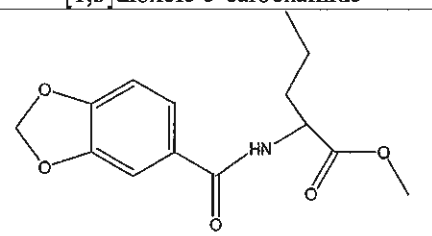
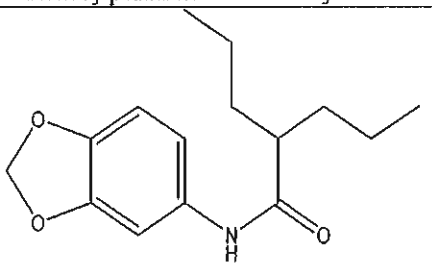
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A19 |  5-methoxy-N-(1-methoxypentan-2-yl)benzofuran-2-carboxamide | 1.3 | | |
| A20 |  5-methyl-N-(2-methylheptan-4-yl) benzofuran-2-carboxamide | 1.32 | | |
| A21 |  N-(pentan-3-yl)benzofuran-2-carboxamide | 1.52 | 3.74 | 1 |
| A22 |  Benzothiazole-6-carboxylic acid (1-propyl-butyl)-amide | 1.58 | | |
| A23 |  2-methyl-N-(2-methylheptan-4-yl)benzo[d]oxazole-5-carboxamide | 0.38 | | |
| A24 |  2-methyl-N-(2-methylheptan-4-yl)benzo[d]oxazole-6-carboxamide | 1.12 | | |

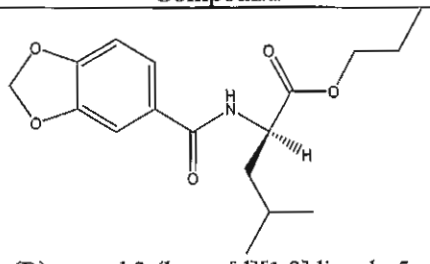
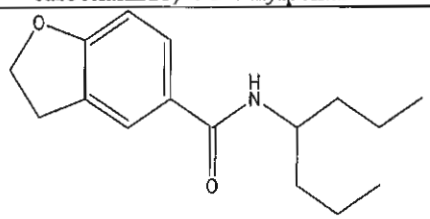
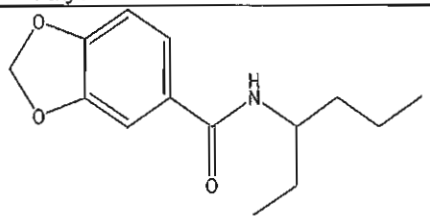
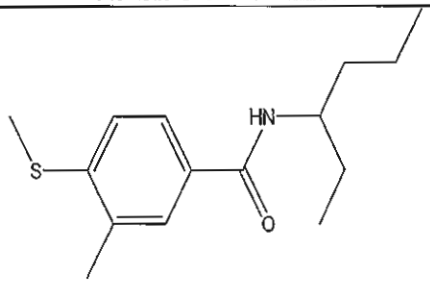
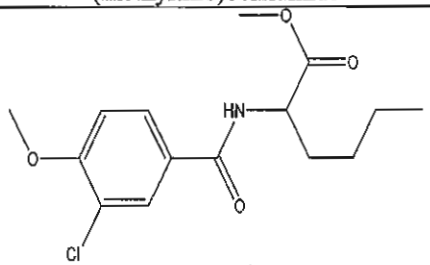
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A25 |  (R)-4-Methyl-2-[(2-methyl-benzooxazole-6-carbonyl)-amino]-pentanoic acid methyl ester | 1.48 | | |
| A26 |  2-methyl-N-(2-methylhexan-3-yl)benzo[d]oxazole-6-carboxamide | 1.6 | | |
| A27 |  2-ethyl-N-(heptan-4-yl)benzo[d] oxazole-6-carboxamide | 1.61 | | |
| A28 |  (R)- 4-Methyl-2-[(2-methyl-benzooxazole-5-carbonyl)-amino]-pentanoic acid methyl ester | 1.69 | | |
| A29 |  N-(heptan-4-yl)benzo[d] oxazole-6-carboxamide | 1.91 | | |
| A30 |  5-bromo-N-(heptan-4-yl)furan-2-carboxamide | 0.49 | 12.6 | 1 |

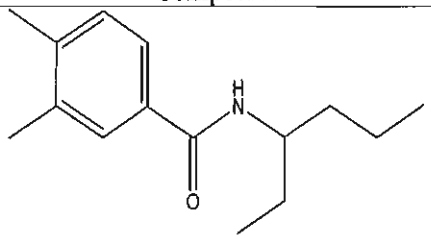
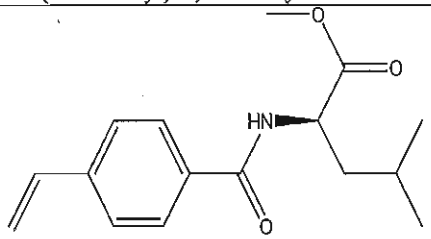
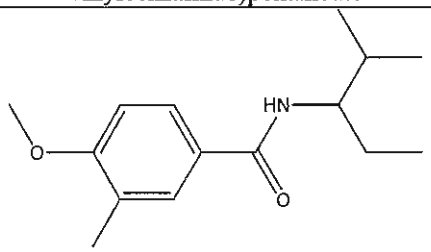
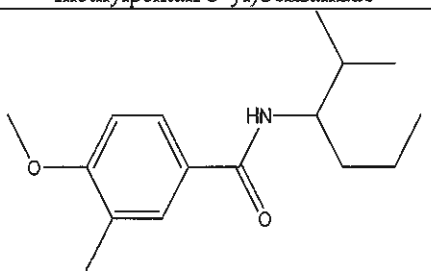
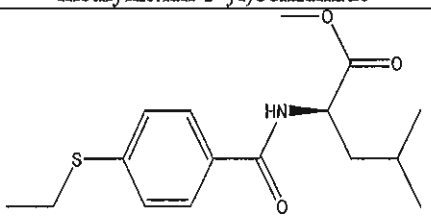
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A31 |  N-(heptan-4-yl)-4,5-dimethylfuran-2-carboxamide | 0.62 | 10.04 | 1 |
| A32 |  N-(2,3-dimethylcyclohexyl)-3-methylfuran-2-carboxamide | 1.15 | | |
| A33 |  4,5-dimethyl-N-(2-methylcyclohexyl) furan-2-carboxamide | 1.33 | | |
| A34 |  (R)-methyl 2-(1H-indole-2-carboxamido)-4-methylpentanoate | 0.53 | | |
| A35 |  N-(heptan-4-yl)-1H-indole-6-carboxamide | 0.82 | 8.81 | 1 |

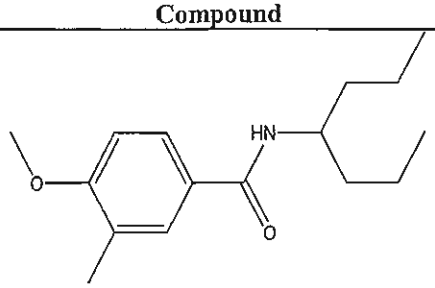
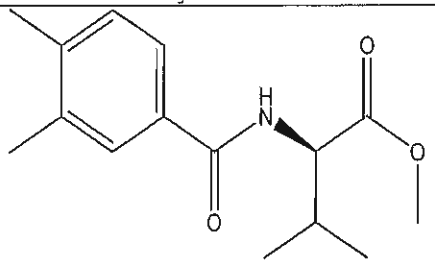
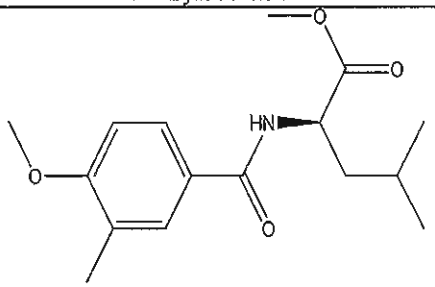
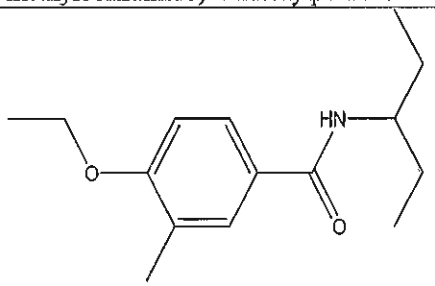
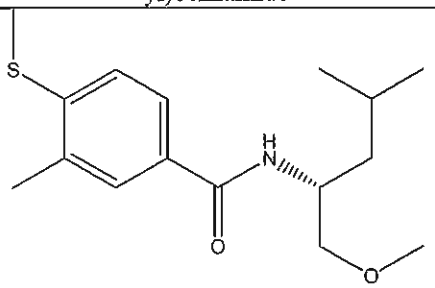
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A36 |  (R)-methyl 2-(1H-indole-5-carboxamido)-4-methylpentanoate | 1.01 | | |
| A37 |  (R)-methyl 4-methyl-2-(quinoline-6-carboxamido)pentanoate | 1.5 | | |
| A38 |  5-Methyl-thiophene-2-carboxylic acid (1-propyl-butyl)-amide | 1.22 | 6.54 | 1 |
| A39 |  5-Methyl-thiophene-2-carboxylic acid (1,2,3,4-tetrahydro-naphthalen-1-yl)-amide | 1.31 | 2.3 | 1 |
| A40 |  (R)-methyl 2-(2-naphthamido)-4-methylpentanoate | 0.37 | | |

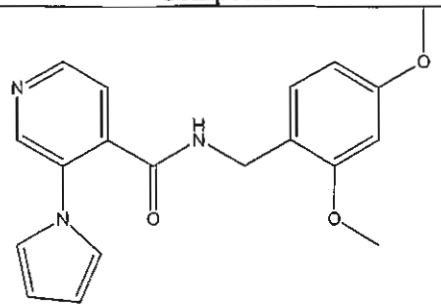
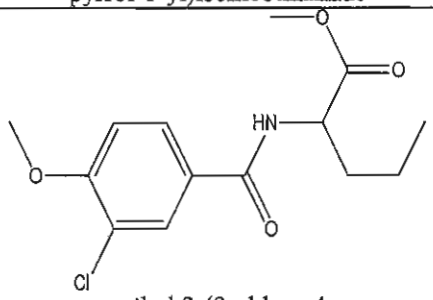
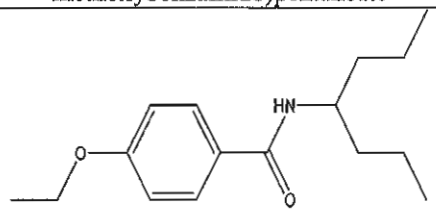
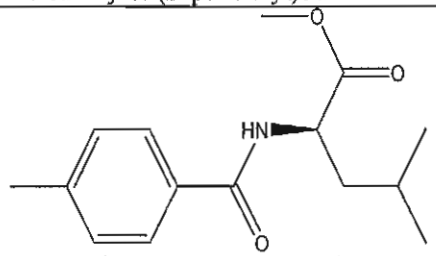
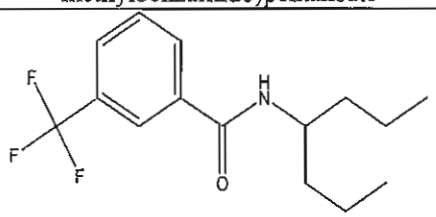
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A41 |  N-(nonan-5-yl)benzo[d][1,3]dioxole-5-carboxamide | 0.7 | 2.14 | 3 |
| A42 |  (2R,3R)-methyl 2-(benzo[d][1,3]dioxole-5-carboxamido)-3-methylpentanoate | 0.35 | | |
| A43 |  2-[(Benzo[1,3]dioxole-5-carbonyl)-amino]-hexanoic acid methyl ester | 0.49 | | |
| A44 |  (R)-2-[(Benzo[1,3]dioxole-5-carbonyl)-amino]-hexanoic acid methyl ester | 0.61 | | |
| A45 |  (R)-ethyl 2-(benzo[d][1,3]dioxole-5-carboxamido)-4-methylpentanoate | 0.88 | | |

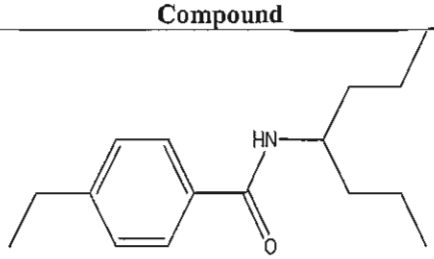
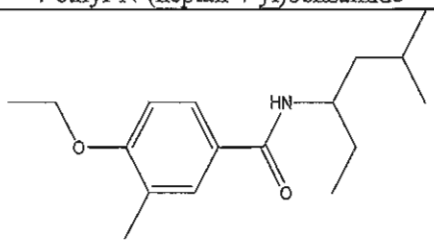
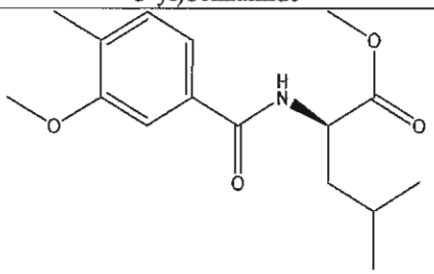
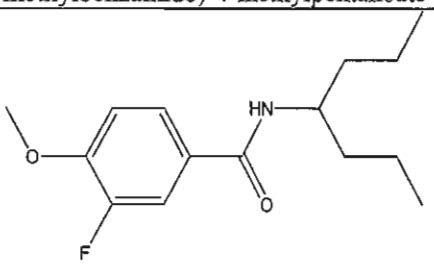
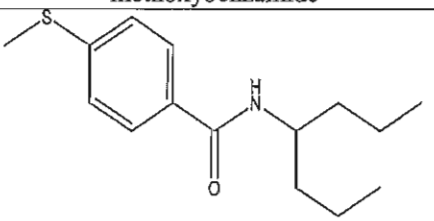
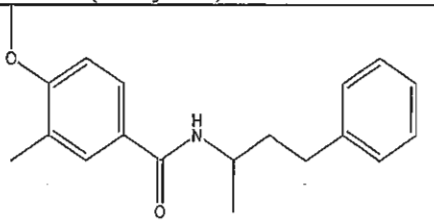
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A46 |  (R)-methyl 2-(2,3-dihydrobenzofuran-5-carboxamido)-4-methylpentanoate | 1.32 | | |
| A47 |  (S)-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzo[d][1,3]dioxole-5-carboxamide | 1.33 | 6.42 | 0.1 |
| A48 |  N-(4-phenylbutan-2-yl)benzo[d][1,3]dioxole-5-carboxamide | 1.51 | 9.27 | 1 |
| A49 |  2-[(Benzo[1,3]dioxole-5-carbonyl)-amino]-pentanoic acid methyl ester | 1.54 | 9.53 | 1 |
| A50 |  N-(benzo[d][1,3]dioxol-5-yl)-2-propylpentanamide | 1.57 | | |

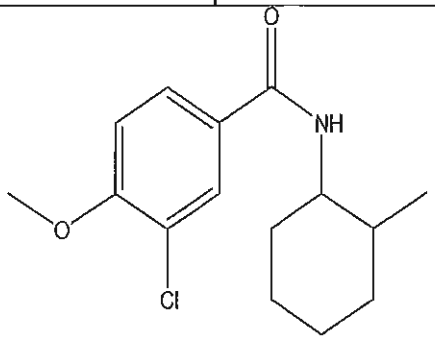
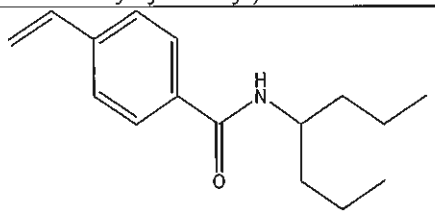
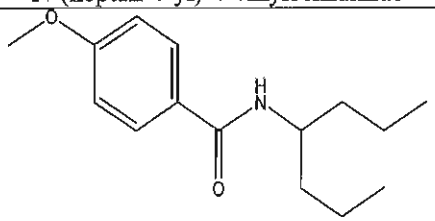
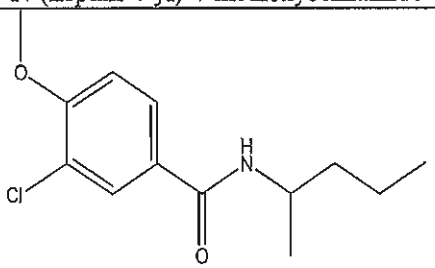
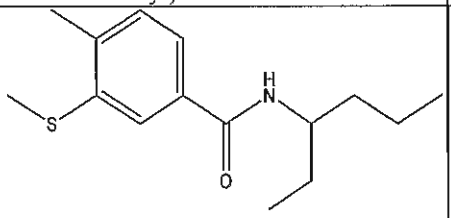
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A51 |  (R)-propyl 2-(benzo[d][1,3]dioxole-5-carboxamido)-4-methylpentanoate | 1.58 | | |
| A52 |  N-(heptan-4-yl)-2,3-dihydrobenzofuran-5-carboxamide | 1.65 | | |
| A53 |  N-(hexan-3-yl)benzo[d][1,3] dioxole-5-carboxamide | 1.83 | | |
| A54 |  N-(hexan-3-yl)-3-methyl-4-(methylthio)benzamide | 0.12 | | |
| A55 |  methyl 2-(3-chloro-4-methoxybenzamido)hexanoate | 0.12 | | |

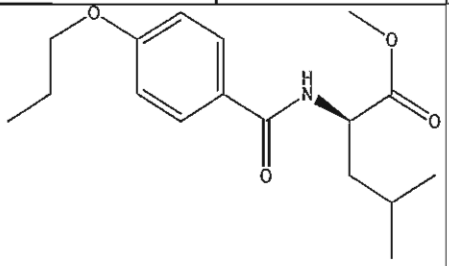
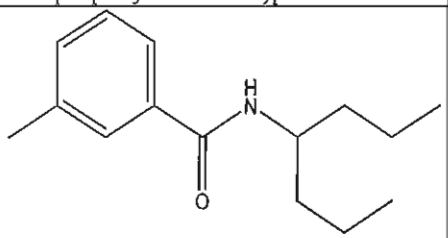
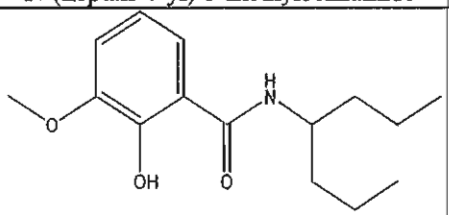
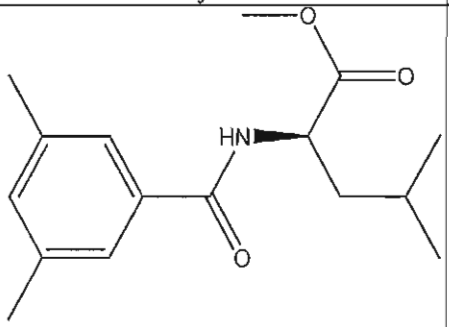
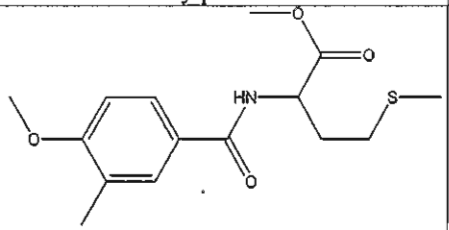
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A56 |  N-(hexan-3-yl)-3,4-imethylbenzamide | 0.14 | | |
| A57 |  (R)-methyl 4-methyl-2-(4-vinylbenzamido)pentanoate | 0.18 | | |
| A58 |  4-methoxy-3-methyl-N-(2-methylpentan-3-yl)benzamide | 0.2 | | |
| A59 |  4-methoxy-3-methyl-N-(2-methylhexan-3-yl)benzamide | 0.2 | | |
| A60 |  (R)-methyl 2-(4-(ethylthio)benzamido)-4-methylpentanoate | 0.2 | | |

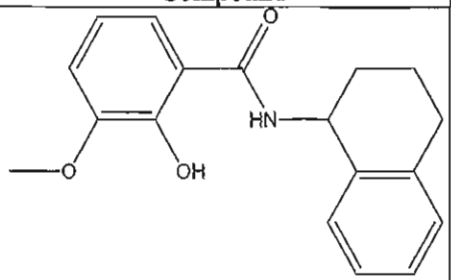
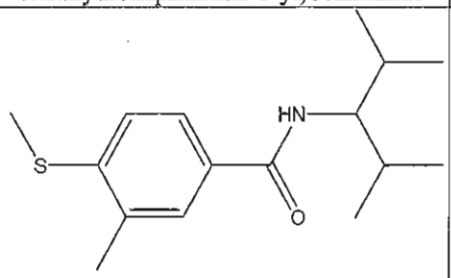
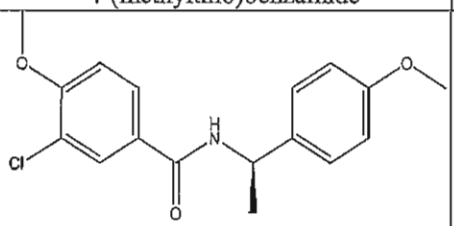
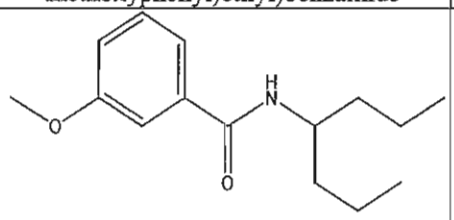
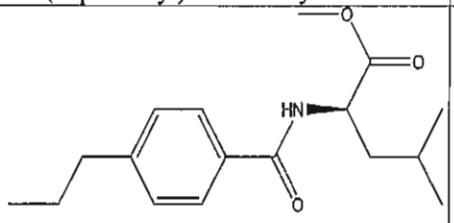
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A61 |  N-(heptan-4-yl)-4-methoxy-3-methylbenzamide | 0.22 | | |
| A62 |  (R)-methyl 2-(3,4-dimethylbenzamido)-3-methylbutanoate | 0.25 | | |
| A63 |  (R)-methyl 2-(4-methoxy-3-methylbenzamido)-4-methylpentanoate | 0.25 | | |
| A64 |  4-ethoxy-3-methyl-N-(pentan-3-yl)benzamide | 0.26 | | |
| A65 |  (R)-N-(1-methoxy-4-methylpentan-2-yl)-3-methyl-4-(methylthio)benzamide | 0.29 | | |

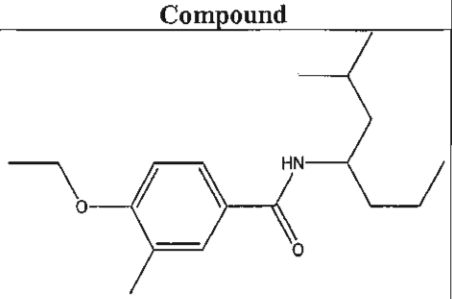
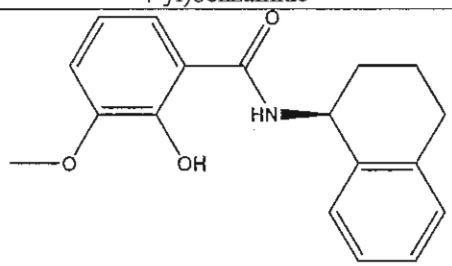
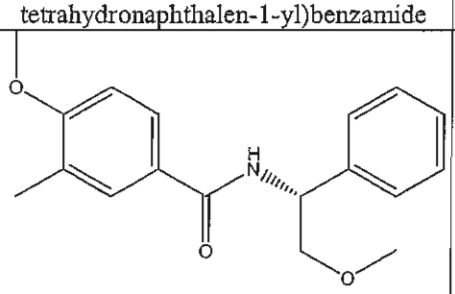
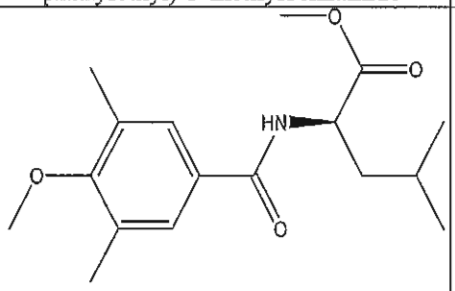
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A66 |  N-(2,4-dimethoxybenzyl)-3-(1H-pyrrol-1-yl)isonicotinamide | 0.29 | | |
| A67 |  methyl 2-(3-chloro-4-methoxybenzamido)pentanoate | 0.29 | 10.75 | 1 |
| A68 |  4-ethoxy-N-(heptan-4-yl)benzamide | 0.32 | 2.62 | 0.3 |
| A69 |  (R)-methyl 4-methyl-2-(4-methylbenzamido)pentanoate | 0.32 | | |
| A70 |  N-(heptan-4-yl)-3-(trifluoromethyl)benzamide | 0.33 | | |

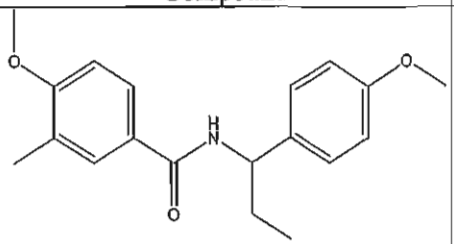
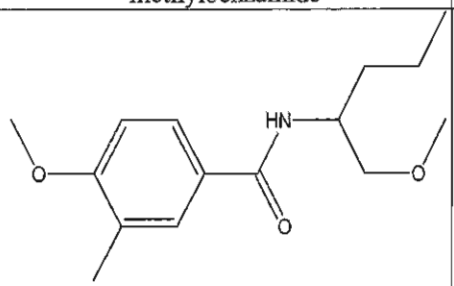
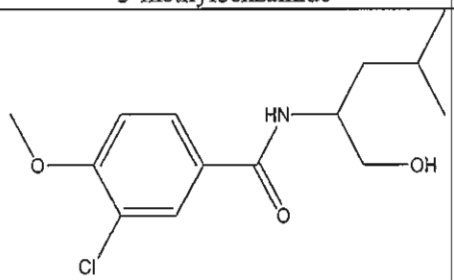
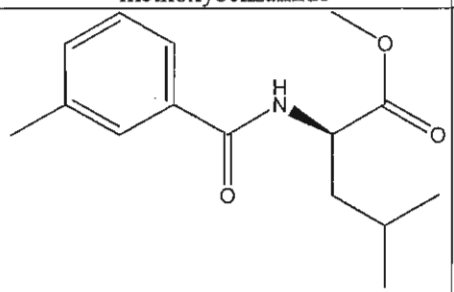
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A71 |  4-ethyl-N-(heptan-4-yl)benzamide | 0.34 | | |
| A72 |  4-ethoxy-3-methyl-N-(5-methylhexan-3-yl)benzamide | 0.34 | | |
| A73 |  (R)-methyl 2-(3-methoxy-4-methylbenzamido)-4-methylpentanoate | 0.34 | | |
| A74 |  3-fluoro-N-(heptan-4-yl)-4-methoxybenzamide | 0.35 | 4.98 | 0.3 |
| A75 |  N-(heptan-4-yl)-4-(methylthio)benzamide | 0.39 | | |
| A76 |  4-methoxy-3-methyl-N-(4-phenylbutan-2-yl)benzamide | 0.4 | | |

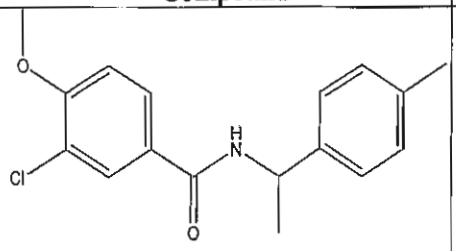
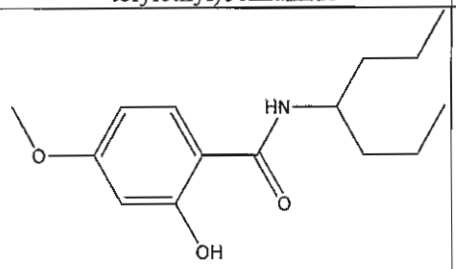
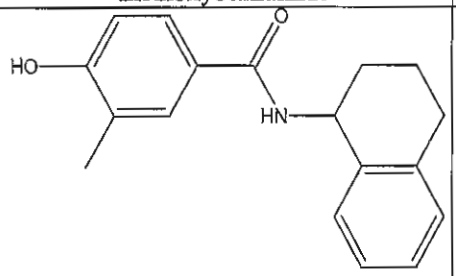
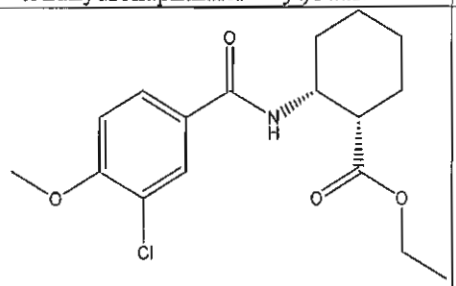
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A77 |  3-chloro-4-methoxy-N-(2-methylcyclohexyl)benzamide | 0.44 | | |
| A78 |  c N-(heptan-4-yl)-4-vinylbenzamide | 0.46 | 10.22 | 0.3 |
| A79 |  N-(heptan-4-yl)-4-methoxybenzamide | 0.46 | | |
| A80 |  3-chloro-4-methoxy-N-(pentan-2-yl)benzamide | 0.47 | 5.12 | 0.1 |
| A81 |  N-(hexan-3-yl)-4-methyl-3-(methylthio)benzamide | 0.5 | | |

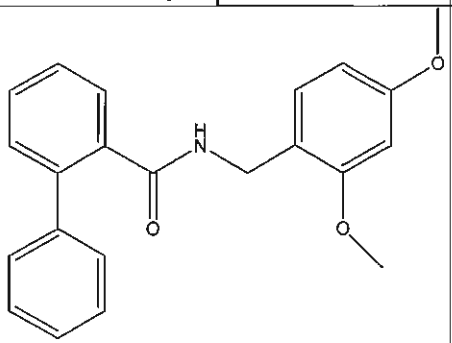
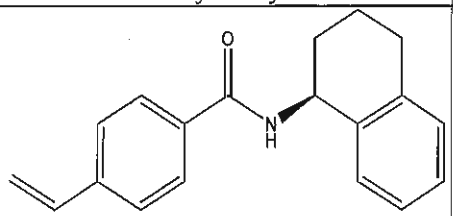
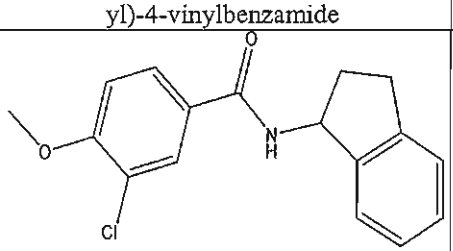
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A82 |  (R)-methyl 4-methyl-2-(4-propoxybenzamido)pentanoate | 0.51 | | |
| A83 |  N-(heptan-4-yl)-3-methylbenzamide | 0.52 | | |
| A84 |  N-(heptan-4-yl)-2-hydroxy-3-methoxybenzamide | 0.53 | | |
| A85 |  (R)-methyl 2-(3,5-dimethylbenzamido)-4-methylpentanoate | 0.53 | | |
| A86 |  methyl 2-(4-methoxy-3-methylbenzamido)-4-(methylthio)butanoate | 0.53 | | |

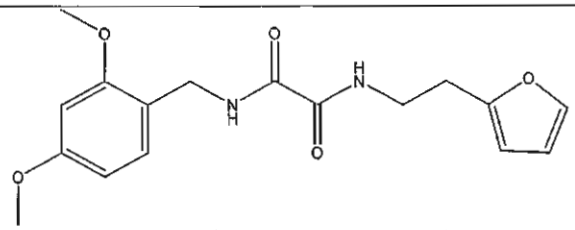
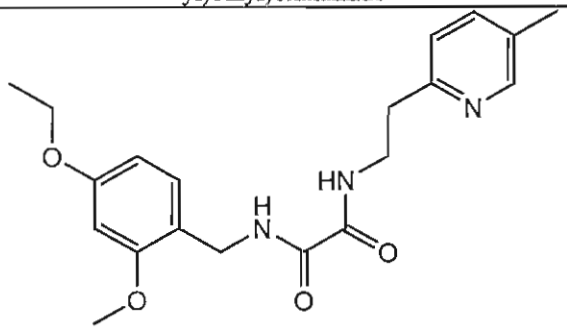
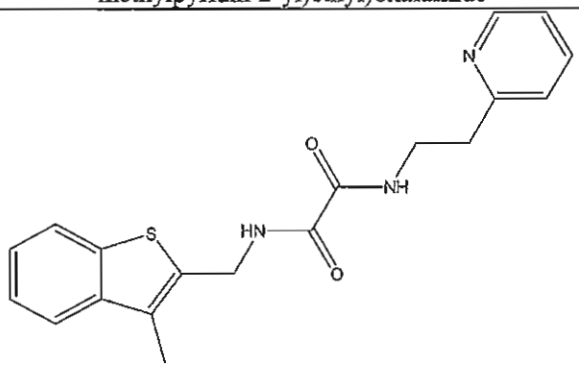
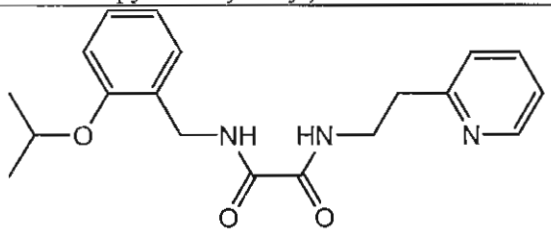
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| A87 |  2-hydroxy-3-methoxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 0.54 | 3.8 | 1 |
| A88 |  N-(2,4-dimethylpentan-3-yl)-3-methyl-4-(methylthio)benzamide | 0.55 | | |
| A89 |  (R)-3-chloro-4-methoxy-N-(1-(4-methoxyphenyl)ethyl)benzamide | 0.6 | 2.85 | 1 |
| A90 |  N-(heptan-4-yl)-3-methoxybenzamide | 0.61 | | |
| A91 |  (R)-methyl 4-methyl-2-(4-propylbenzamido)pentanoate | 0.62 | | |

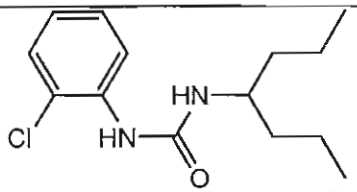
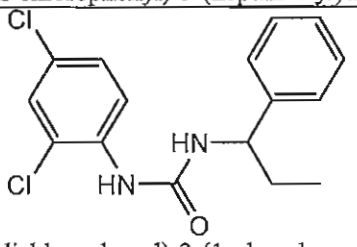
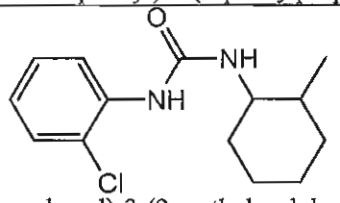
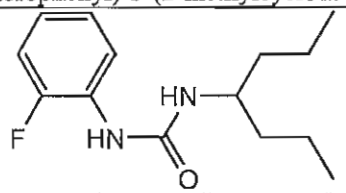
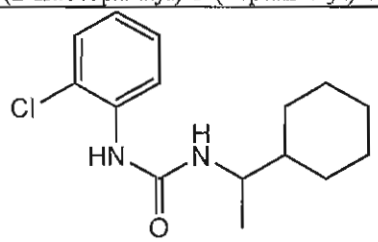
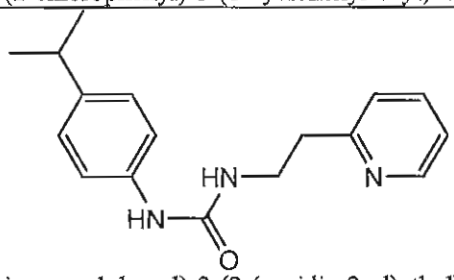
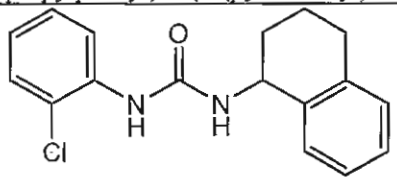
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A92 |  4-ethoxy-3-methyl-N-(2-methylheptan-4-yl)benzamide | 0.65 | | |
| A93 |  (S)-2-hydroxy-3-methoxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 0.7 | 5.7 | 1 |
| A94 |  (R)-4-methoxy-N-(2-methoxy-1-phenylethyl)-3-methylbenzamide | 0.72 | | |
| A95 |  (R)-methyl 2-(4-methoxy-3,5-dimethylbenzamido)-4-methylpentanoate | 0.74 | | |

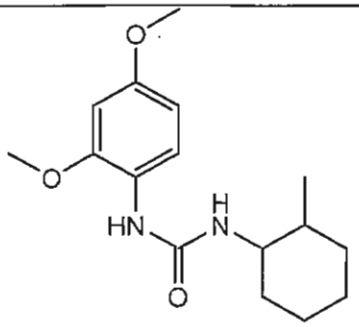
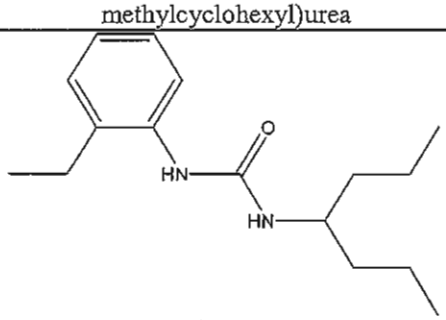
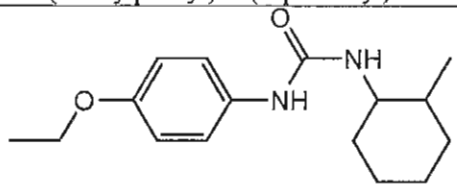
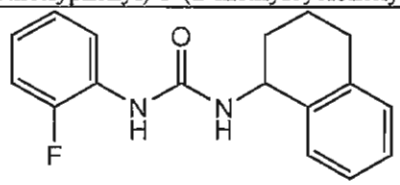
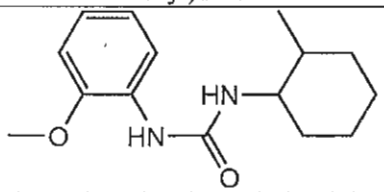
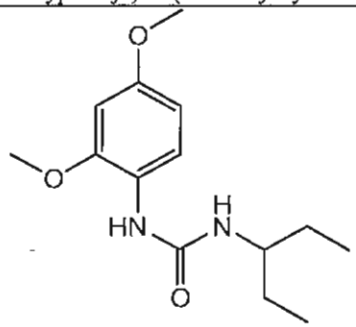
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A96 |  4-methoxy-N-(1-(4-methoxyphenyl)propyl)-3-methylbenzamide | 0.76 | | |
| A97 |  4-methoxy-N-(1-methoxypentan-2-yl)-3-methylbenzamide | 0.85 | | |
| A98 |  3-chloro-N-(1-hydroxy-4-methylpentan-2-yl)-4-methoxybenzamide | 0.88 | | |
| A99 |  (R)-methyl 4-methyl-2-(3-methylbenzamido)pentanoate | 0.89 | | |

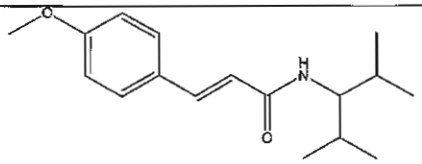
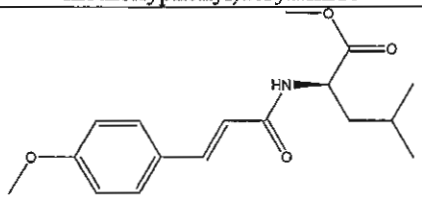
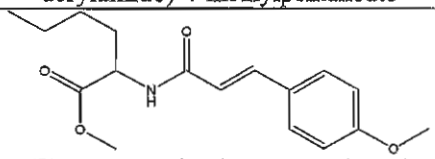
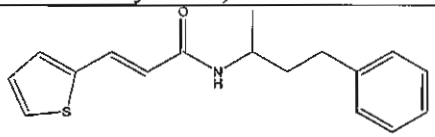
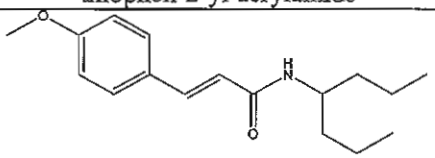
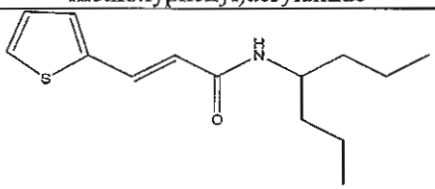
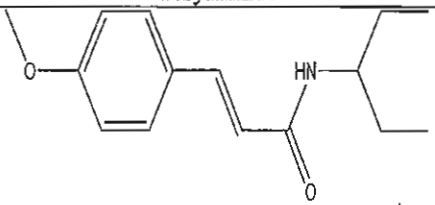
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A100 |  3-chloro-4-methoxy-N-(1-p-tolylethyl)benzamide | 1.1 | | |
| A101 |  N-(heptan-4-yl)-2-hydroxy-4-methoxybenzamide | 1.16 | 7.62 | 1 |
| A102 |  4-hydroxy-3-methyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.32 | 9.49 | 1 |
| A103 |  (1S,2R)-ethyl 2-(3-chloro-4-methoxybenzamido) cyclohexanecarboxylate | 1.36 | | |

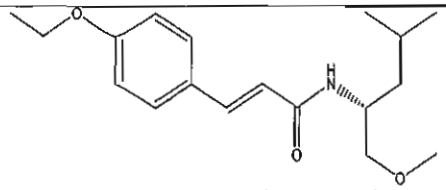
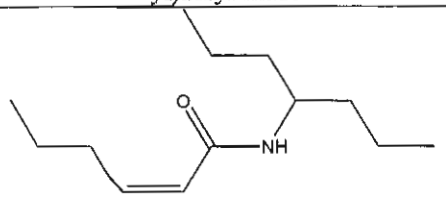
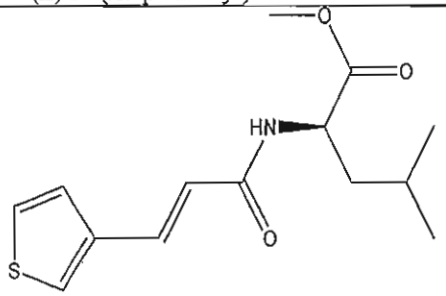
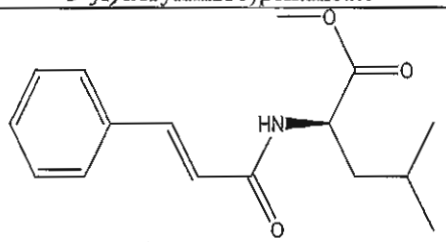
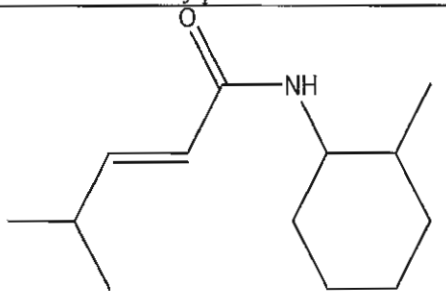
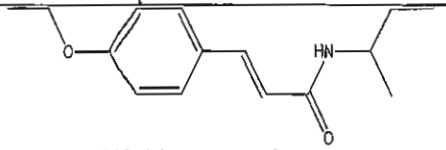
| Table 1 - Umami Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| A104 |  Biphenyl-2-carboxylic acid 2,4-dimethoxy-benzylamide | 1.37 | | |
| A105 |  (S)-N-(1,2,3,4-tetrahydronaphthalen-1-yl)-4-vinylbenzamide | 1.38 | 2.79 | 1 |
| A106 |  3-chloro-N-(2,3-dihydro-1H-inden-1-yl)-4-methoxybenzamide | 1.39 | 4.01 | 0.3 |

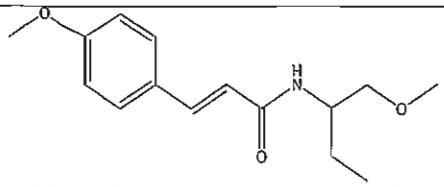
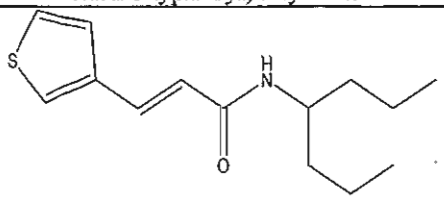
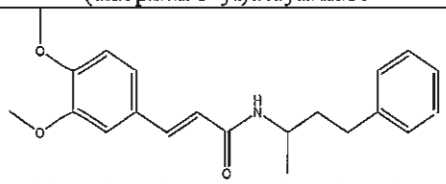
| Table 2 - Umami Oxalamides | | | |
|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** |
| B1 |  N1-(2,4-dimethoxybenzyl)-N2-(2-(furan-2-yl)ethyl)oxalamide | 0.18 | |
| B2 |  N1-(4-ethoxy-2-methoxybenzyl)-N2-(2-(5-methylpyridin-2-yl)ethyl)oxalamide | 0.19 | |
| B3 |  N-(3-Methyl-benzo[b]thiophen-2-ylmethyl)-N'-(2-pyridin-2-yl-ethyl)-oxalamide | 0.81 | |
| B4 |  N1-(2-isopropoxybenzyl)-N2-(2-(pyridin-2-yl)ethyl)oxalamide | 1.22 | |

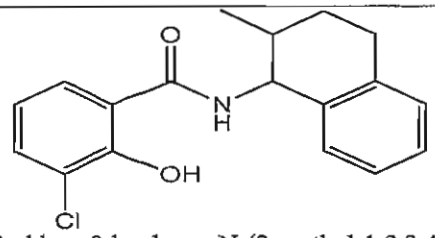
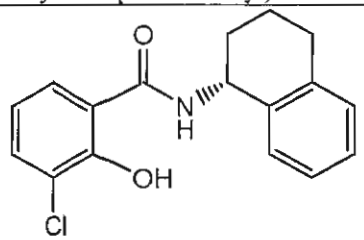
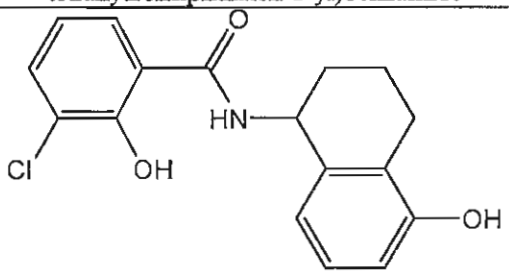
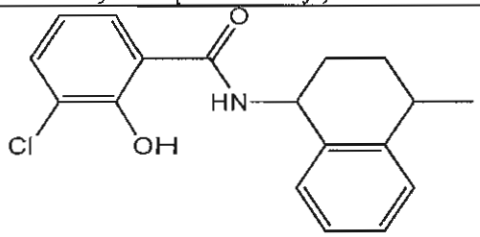
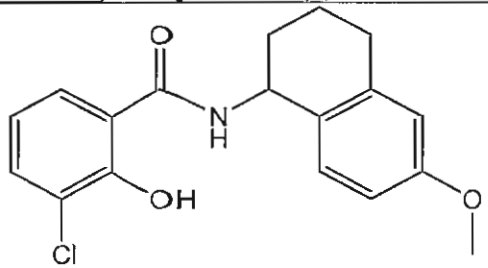
| Table 3 - Umami Ureas | | | | |
|---|---|---|---|---|
| **Compound No.** | **IUPAC Name** | **Umami $EC_{50}$ uM** | **Ec50 ratio (vs. MSG)** | **Con. (uM)** |
| C1 |  1-(2-chlorophenyl)-3-(heptan-4-yl)urea | 0.37 | 4.95 | 1 |
| C2 |  1-(2,4-dichlorophenyl)-3-(1-phenylpropyl)urea | 0.49 | 4.52 | 1 |
| C3 |  1-(2-chlorophenyl)-3-(2-methylcyclohexyl)urea | 0.52 | 3.24 | 3 |
| C4 |  1-(2-fluorophenyl)-3-(heptan-4-yl)urea | 0.79 | 12.15 | 3 |
| C5 |  1-(2-chlorophenyl)-3-(1-cyclohexylethyl)urea | 0.84 | 9.08 | 1 |
| C6 |  1-(4-isopropylphenyl)-3-(2-(pyridin-2-yl)ethyl)urea | 0.98 | | |
| C7 |  1-(2-chlorophenyl)-3-(1,2,3,4-tetrahydronaphthalen-1-yl)urea | 0.99 | 3.68 | 1 |

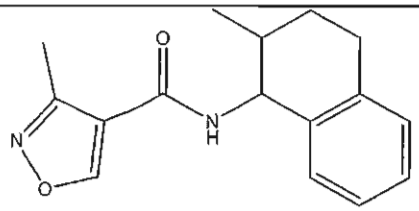
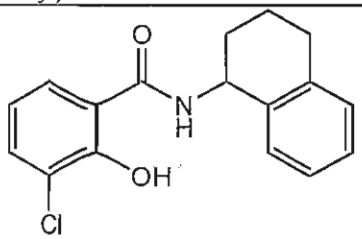
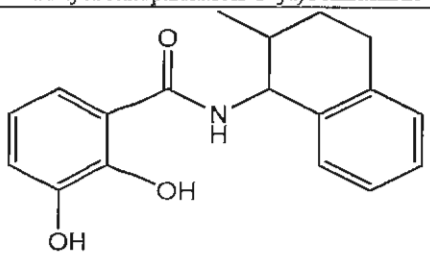
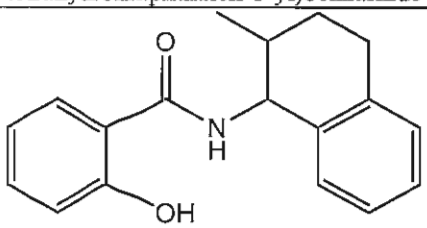
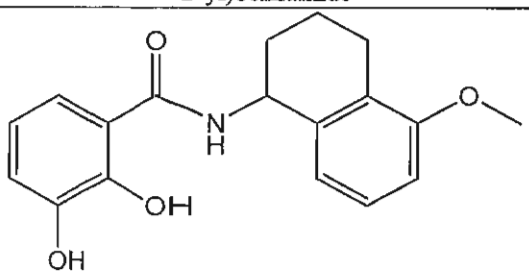
| Table 3 - Umami Ureas | | | | |
|---|---|---|---|---|
| **Compound No.** | **IUPAC Name** | **Umami $EC_{50}$ uM** | **Ec50 ratio (vs. MSG)** | **Con. (uM)** |
| C8 |  1-(2,4-dimethoxyphenyl)-3-(2-methylcyclohexyl)urea | 1.41 | 2.62 | 0.3 |
| C9 |  1-(2-ethylphenyl)-3-(heptan-4-yl)urea | 1.42 | | |
| C10 |  1-(4-ethoxyphenyl)-3-(2-methylcyclohexyl)urea | 1.51 | 2.1 | 0.3 |
| C11 |  1-(2-fluorophenyl)-3-(1,2,3,4-tetrahydronaphthalen-1-yl)urea | 1.65 | 4.49 | 1 |
| C12 |  1-(2-methoxyphenyl)-3-(2-methylcyclohexyl)urea | 1.67 | | |
| C13 |  1-(2,4-dimethoxyphenyl)-3-(pentan-3-yl)urea | 1.72 | 11.87 | 1 |

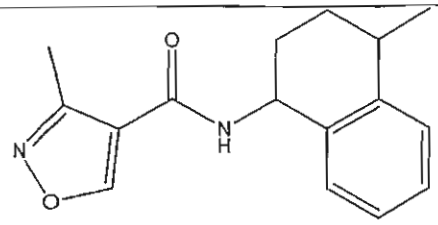
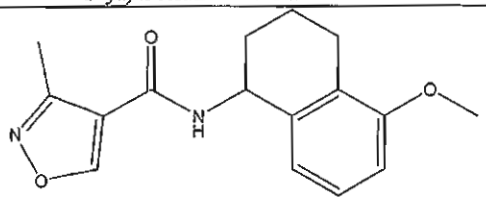
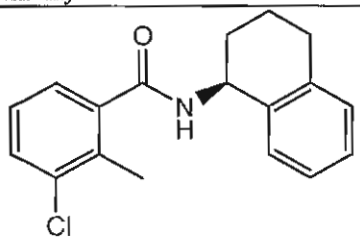
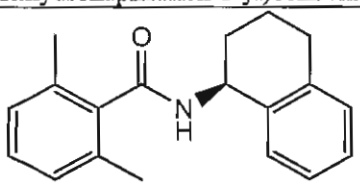
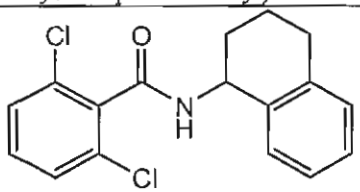
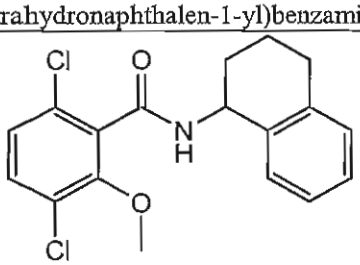
| Table 4 - Umami Acrylamides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Umami $EC_{50}$ (uM) | $Ec_{50}$ ratio (vs. MSG) | @ (uM) |
| D1 |  (E)-N-(2,4-dimethylpentan-3-yl)-3-(4-methoxyphenyl)acrylamide | 0.29 | 3.46 | 1 |
| D2 |  (R,E)-methyl 2-(3-(4-methoxyphenyl) acrylamido)-4-methylpentanoate | 0.32 | | |
| D3 |  (E)-methyl 2-(3-(4-methoxyphenyl) acrylamido)hexanoate | 0.63 | | |
| D4 |  N-(1-Methyl-3-phenyl-propyl)-3-thiophen-2-yl-acrylamide | 0.69 | 9.73 | 1 |
| D5 |  (E)-N-(heptan-4-yl)-3-(4-methoxyphenyl)acrylamide | 0.72 | 3.48 | 0.3 |
| D6 |  N-(1-Propyl-butyl)-3-thiophen-2-yl-acrylamide | 0.75 | 6.3 | 1 |
| D7 |  (E)-3-(4-methoxyphenyl)-N-(pentan-3-yl)acrylamide | 0.82 | 9.62 | 1 |

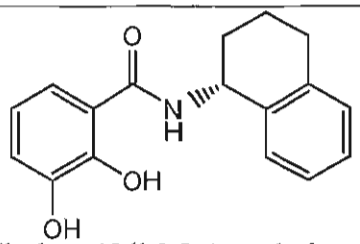
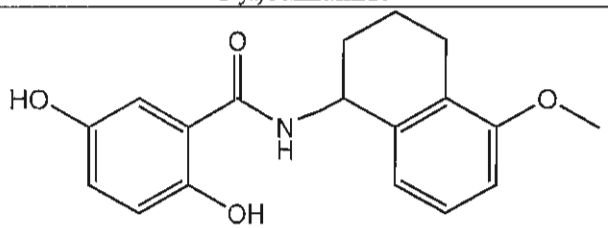
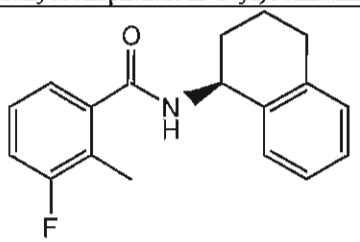
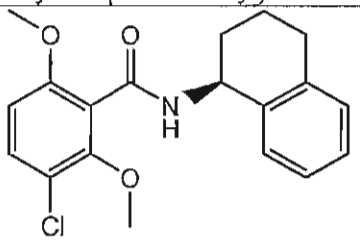
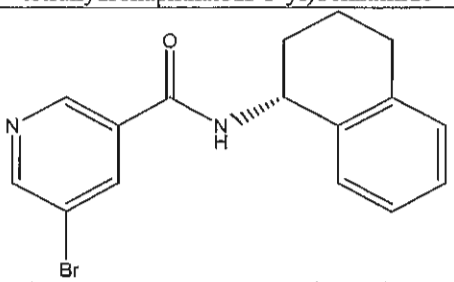
| Table 4 - Umami Acrylamides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| D8 |  (R,E)-3-(4-ethoxyphenyl)-N-(1-methoxy-4-methylpentan-2-yl)acrylamide | 0.94 | | |
| D9 |  (Z)-N-(heptan-4-yl)hex-2-enamide | 0.98 | | |
| D10 |  (R,E)-methyl 4-methyl-2-(3-(thiophen-3-yl)acrylamido)pentanoate | 1.09 | | |
| D11 |  (R)-methyl 2-cinnamamido-4-methylpentanoate | 1.17 | | |
| D12 |  (E)-4-methyl-N-(2-methylcyclohexyl) pent-2-enamide | 1.28 | | |
| D13 |  (E)-N-sec-butyl-3-(4-ethoxyphenyl)acrylamide | 1.31 | 2.7 | 0.3 |

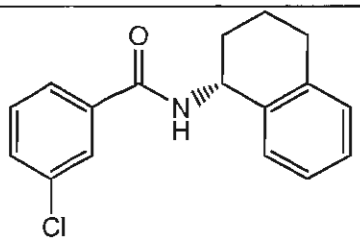
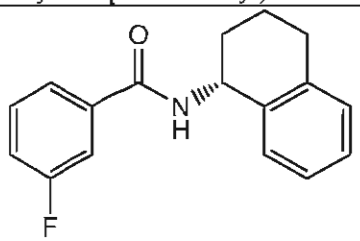
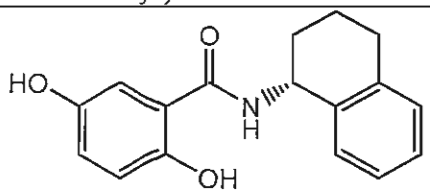
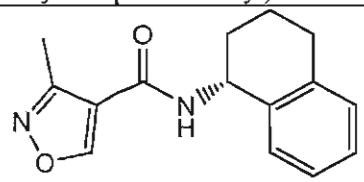
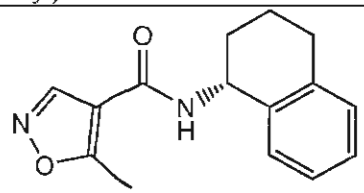
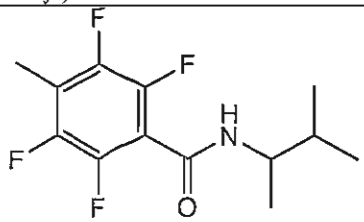
| Table 4 - Umami Acrylamides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Umami $EC_{50}$ (uM)** | **$Ec_{50}$ ratio (vs. MSG)** | **@ (uM)** |
| D14 |  (E)-N-(1-methoxybutan-2-yl)-3-(4-methoxyphenyl)acrylamide | 1.43 | 8.48 | 1 |
| D15 |  (E)-N-(heptan-4-yl)-3-(thiophen-3-yl)acrylamide | 1.54 | 2.22 | 0.3 |
| D16 |  (E)-3-(3,4-dimethoxyphenyl)-N-(4-phenylbutan-2-yl)acrylamide | 1.56 | 3.13 | 1 |

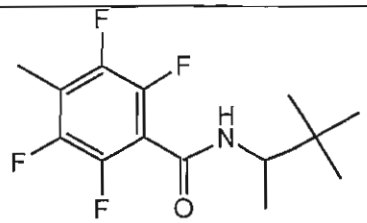
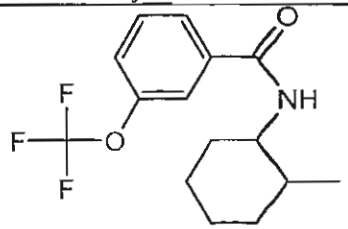
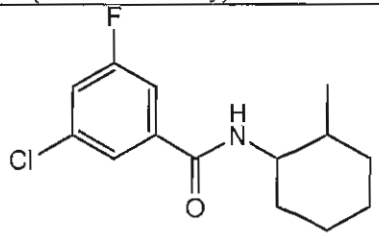
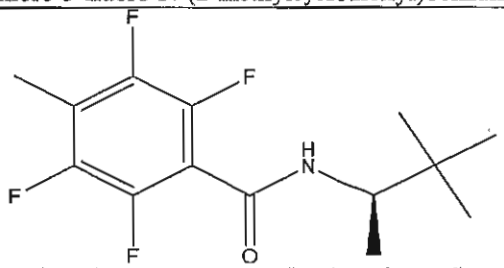
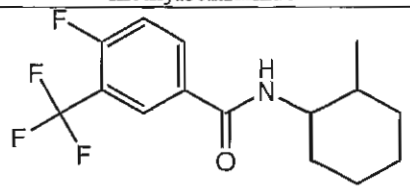
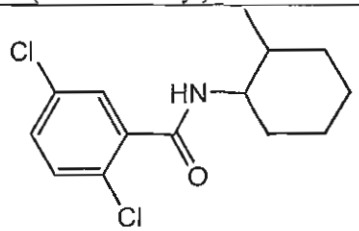
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Sweet $EC_{50}$ uM | Umami $EC_{50}$ uM | Umami $EC_{50}$ ratio |
| E1 |  3-chloro-2-hydroxy-N-(2-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 0.19 | | |
| E2 |  (R)-3-chloro-2-hydroxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 0.65 | | |
| E3 |  3-chloro-2-hydroxy-N-(5-hydroxy-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.03 | | |
| E4 |  3-chloro-2-hydroxy-N-(4-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.61 | | |
| E5 |  3-chloro-2-hydroxy-N-(6-methoxy-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.61 | | |

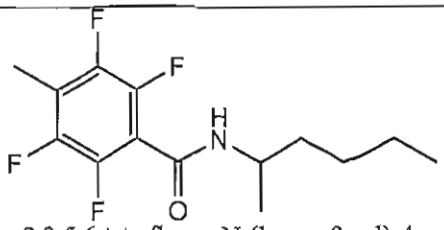
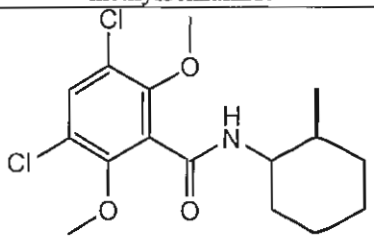
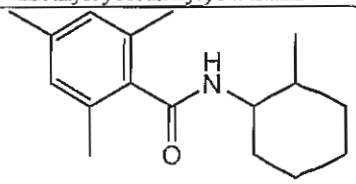
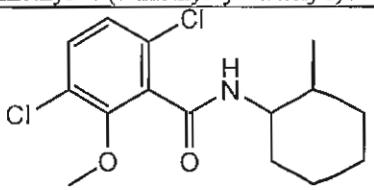
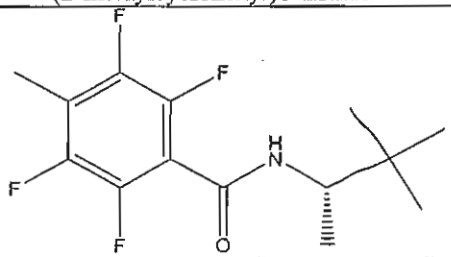
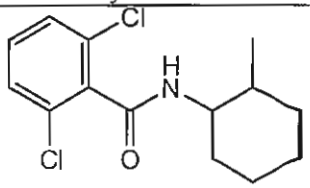
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E6 |  3-methyl-N-(2-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)isoxazole-4-carboxamide | 1.48 | | |
| E7 |  3-chloro-2-hydroxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.81 | | 4.04 |
| E8 |  2,3-dihydroxy-N-(2-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 1.98 | | |
| E9 |  2-hydroxy-N-(2-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 2.36 | | |
| E10 |  2,3-dihydroxy-N-(5-methoxy-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 2.44 | | |

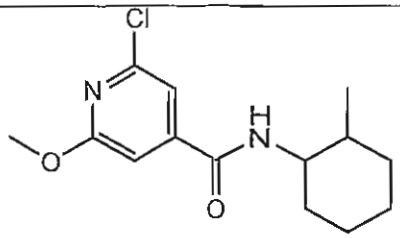
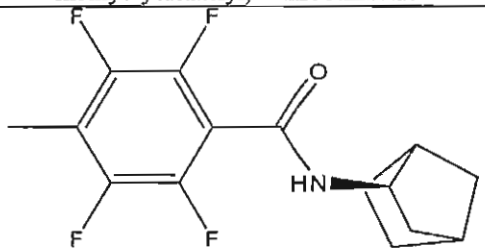
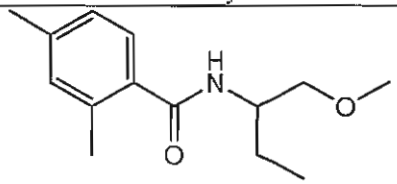
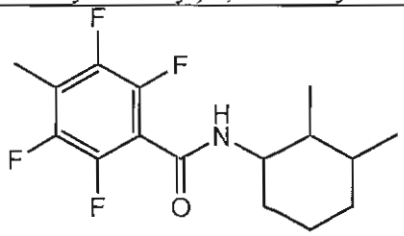
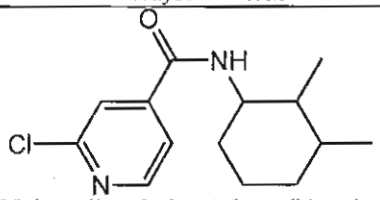
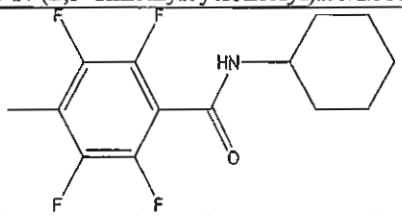
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Sweet $EC_{50}$ uM | Umami $EC_{50}$ uM | Umami $EC_{50}$ ratio |
| E11 |  3-methyl-N-(4-methyl-1,2,3,4-tetrahydronaphthalen-1-yl)isoxazole-4-carboxamide | 2.46 | | |
| E12 |  N-(5-methoxy-1,2,3,4-tetrahydronaphthalen-1-yl)-3-methylisoxazole-4-carboxamide | 2.85 | | |
| E13 |  (S)-3-chloro-2-methyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 2.91 | | |
| E14 |  (S)-2,6-dimethyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 2.91 | | |
| E15 |  2,6-dichloro-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 3.02 | | |
| E16 |  3,6-dichloro-2-methoxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 3.04 | | |

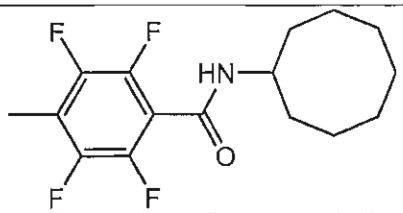
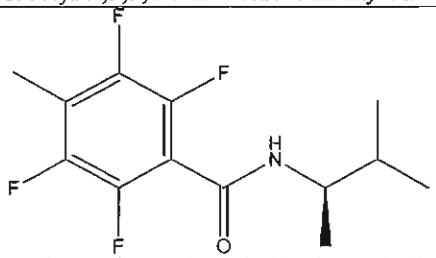
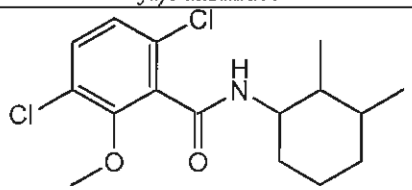
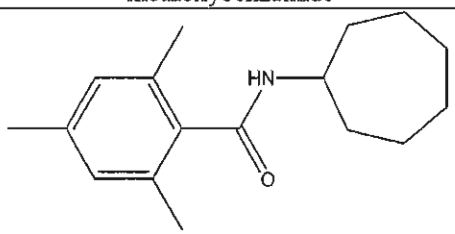
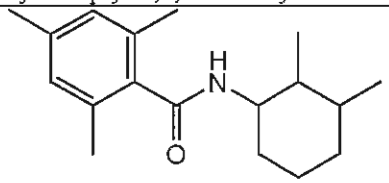
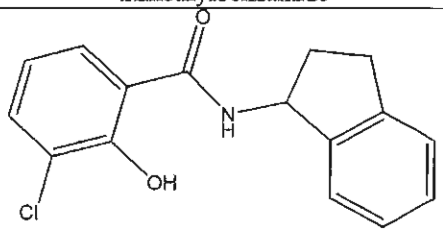
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E17 |  (R)-2,3-dihydroxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 3.13 | | |
| E18 |  2,5-dihydroxy-N-(5-methoxy-1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 3.38 | | |
| E19 |  (S)-3-fluoro-2-methyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 3.57 | | |
| E20 |  (S)-3-chloro-2,6-dimethoxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 4.13 | | |
| E21 |  (R)-5-bromo-N-(1,2,3,4-tetrahydronaphthalen-1-yl)nicotinamide | 4.19 | | |

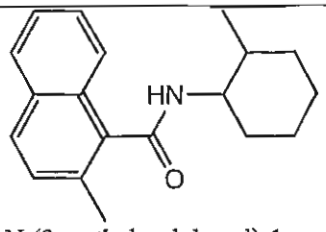
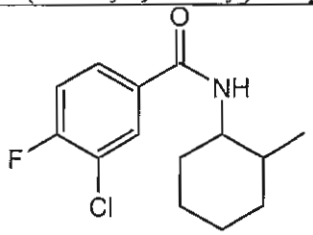
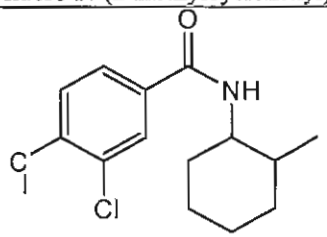
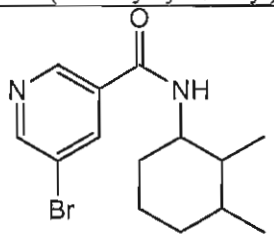
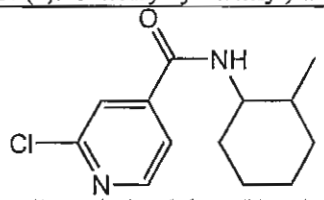
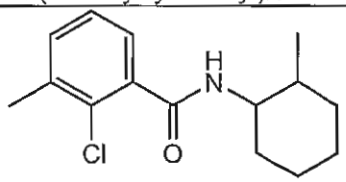
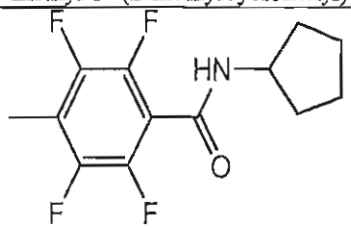
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E22 |  (R)-3-chloro-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 4.52 | | |
| E23 |  (R)-3-fluoro-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 4.86 | | |
| E24 |  (R)-2,5-dihydroxy-N-(1,2,3,4-tetrahydronaphthalen-1-yl)benzamide | 6.04 | | |
| E25 |  (R)-3-methyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)isoxazole-4-carboxamide | 7.79 | | |
| E26 |  (R)-5-methyl-N-(1,2,3,4-tetrahydronaphthalen-1-yl)isoxazole-4-carboxamide | 8.09 | | |
| E27 |  2,3,5,6-tetrafluoro-4-methyl-N-(3-methylbutan-2-yl)benzamide | 0.14 | | |

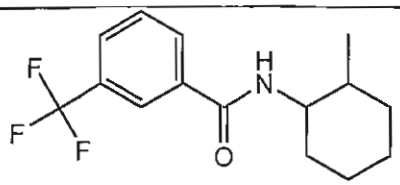
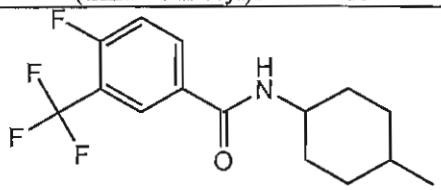
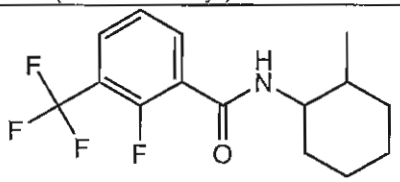
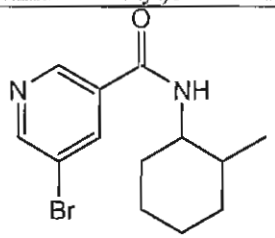
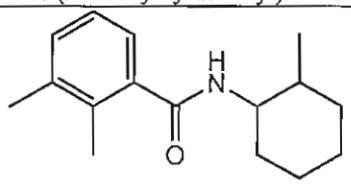
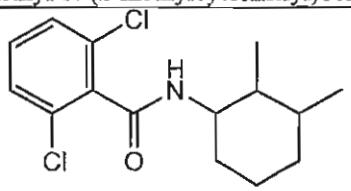
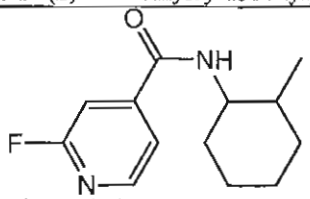
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Sweet $EC_{50}$ uM | Umami $EC_{50}$ uM | Umami $EC_{50}$ ratio |
| E28 |  N-(3,3-dimethylbutan-2-yl)-2,3,5,6-tetrafluoro-4-methylbenzamide | 0.21 | | |
| E29 |  N-(2-methylcyclohexyl)-3-(trifluoromethoxy)benzamide | 0.42 | | |
| E30 |  3-chloro-5-fluoro-N-(2-methylcyclohexyl)benzamide | 0.45 | | |
| E31 |  (R)-N-(3,3-dimethylbutan-2-yl)-2,3,5,6-tetrafluoro-4-methylbenzamide | 0.49 | | |
| E32 |  4-fluoro-N-(2-methylcyclohexyl)-3-(trifluoromethyl)benzamide | 0.51 | | |
| E33 |  2,5-dichloro-N-(2-methylcyclohexyl)benzamide | 0.63 | | |

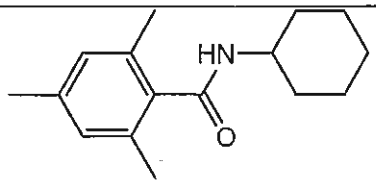
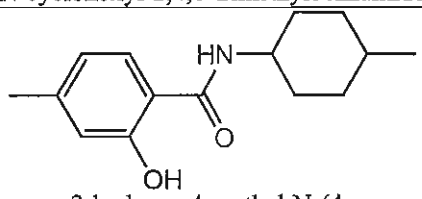
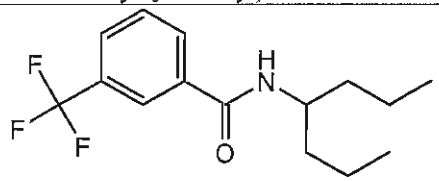
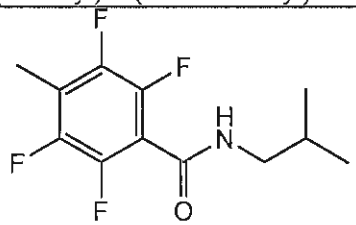
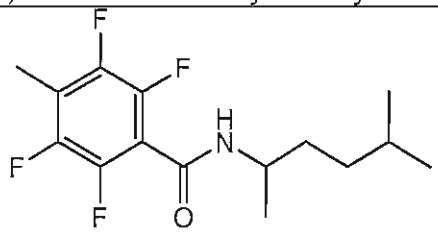
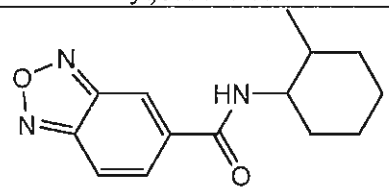
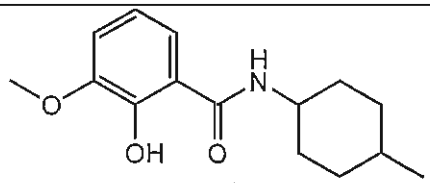
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E34 |  2,3,5,6-tetrafluoro-N-(hexan-2-yl)-4-methylbenzamide | 0.71 | | |
| E35 |  3,5-dichloro-2,6-dimethoxy-N-(2-methylcyclohexyl)benzamide | 0.71 | | |
| E36 |  2,4,6-trimethyl-N-(2-methylcyclohexyl)benzamide | 0.72 | | |
| E37 |  3,6-dichloro-2-methoxy-N-(2-methylcyclohexyl)benzamide | 0.77 | | |
| E38 |  (S)-N-(3,3-dimethylbutan-2-yl)-2,3,5,6-tetrafluoro-4-methylbenzamide | 0.9 | | |
| E39 |  2,6-dichloro-N-(2-methylcyclohexyl)benzamide | 0.91 | | |

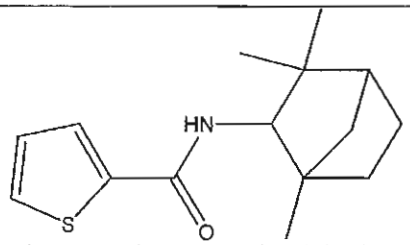
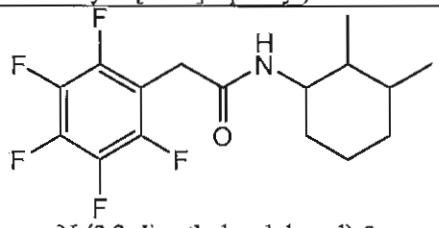
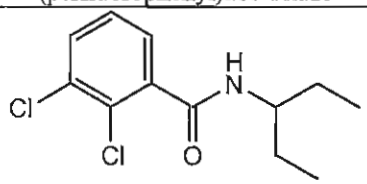
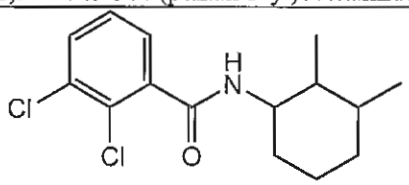
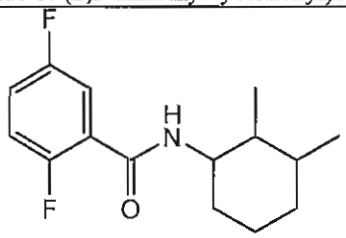
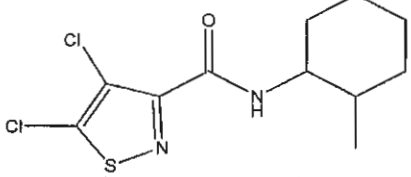
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| Compound No. | Compound | Sweet $EC_{50}$ uM | Umami $EC_{50}$ uM | Umami $EC_{50}$ ratio |
| E40 |  2-chloro-6-methoxy-N-(2-methylcyclohexyl)isonicotinamide | 0.95 | | 9.77 |
| E41 |  N-((2R)-bicyclo[2.2.1]heptan-2-yl)-2,3,5,6-tetrafluoro-4-methylbenzamide | 1.02 | | |
| E42 |  N-(1-methoxybutan-2-yl)-2,4-dimethylbenzamide | 1.06 | | |
| E43 |  N-(2,3-dimethylcyclohexyl)-2,3,5,6-tetrafluoro-4-methylbenzamide | 1.08 | | |
| E44 |  2-chloro-N-(2,3-dimethylcyclohexyl)isonicotinamide | 1.08 | | |
| E45 |  N-cyclohexyl-2,3,5,6-tetrafluoro-4-methylbenzamide | 1.13 | | |

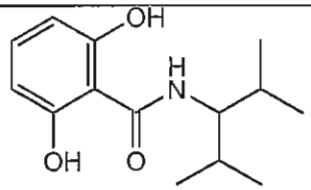
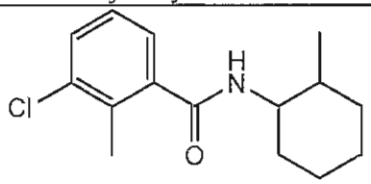
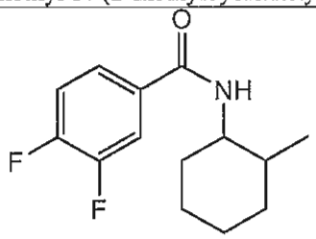
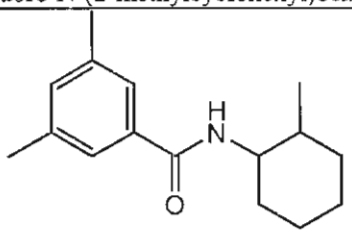
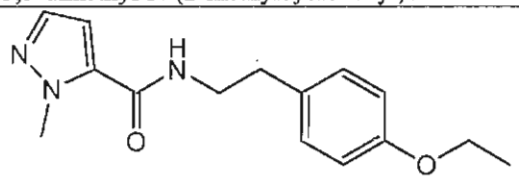
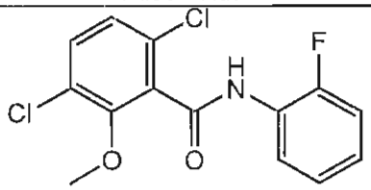
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E46 |  N-cyclooctyl-2,3,5,6-tetrafluoro-4-methylbenzamide | 1.25 | | |
| E47 |  (R)-2,3,5,6-tetrafluoro-4-methyl-N-(3-methylbutan-2-yl)benzamide | 1.25 | | |
| E48 |  3,6-dichloro-N-(2,3-dimethylcyclohexyl)-2-methoxybenzamide | 1.29 | | |
| E49 |  N-cycloheptyl-2,4,6-trimethylbenzamide | 1.39 | | |
| E50 |  N-(2,3-dimethylcyclohexyl)-2,4,6-trimethylbenzamide | 1.41 | | |
| E51 |  3-chloro-N-(2,3-dihydro-1H-inden-1-yl)-2-hydroxybenzamide | 1.49 | | |

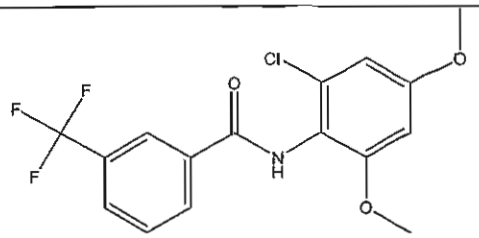
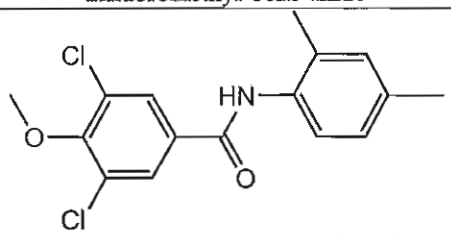
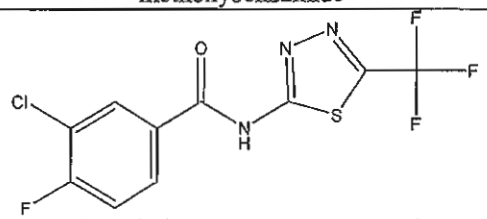
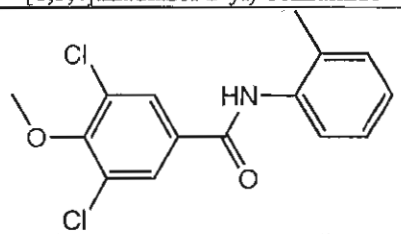
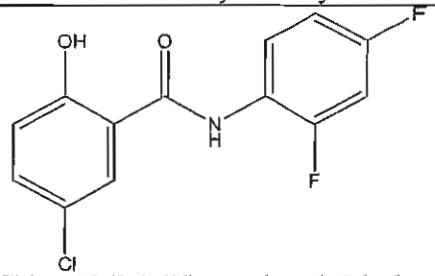
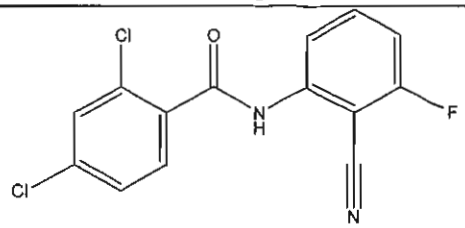
| Table 5 - Sweet Enhancer Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E52 |  2-methyl-N-(2-methylcyclohexyl)-1-naphthamide | 1.52 | | |
| E53 |  3-chloro-4-fluoro-N-(2-methylcyclohexyl)benzamide | 1.7 | | |
| E54 |  3,4-dichloro-N-(2-methylcyclohexyl)benzamide | 1.83 | | 10.66 |
| E55 |  5-bromo-N-(2,3-dimethylcyclohexyl)nicotinamide | 1.89 | | |
| E56 |  2-chloro-N-(2-methylcyclohexyl)isonicotinamide | 1.92 | | 2.08 |
| E57 |  2-chloro-3-methyl-N-(2-methylcyclohexyl)benzamide | 1.95 | | |
| E58 |  N-cyclopentyl-2,3,5,6-tetrafluoro-4-methylbenzamide | 2.23 | | |

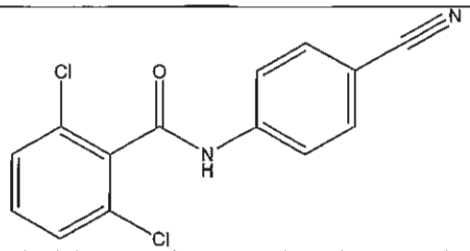
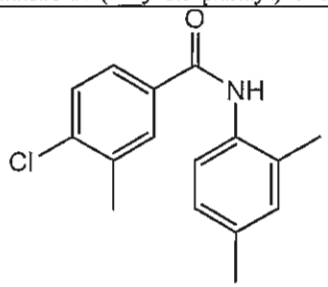
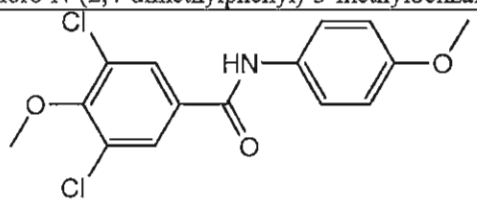
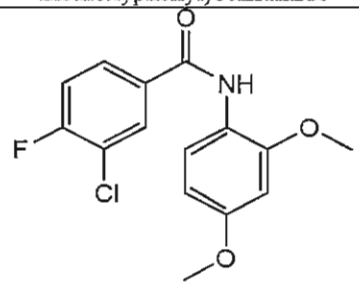
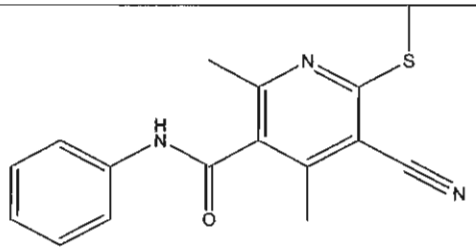
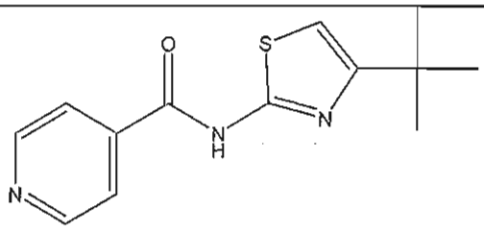
| Table 5 - Sweet Enhancer Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E59 |  N-(2-methylcyclohexyl)-3-(trifluoromethyl)benzamide | 2.34 | | 2.07 |
| E60 |  4-fluoro-N-(4-methylcyclohexyl)-3-(trifluoromethyl)benzamide | 2.37 | | |
| E61 |  2-fluoro-N-(2-methylcyclohexyl)-3-(trifluoromethyl)benzamide | 2.4 | | |
| E62 |  5-bromo-N-(2-methylcyclohexyl)nicotinamide | 2.42 | | |
| E63 |  2,3-dimethyl-N-(2-methylcyclohexyl)benzamide | 2.6 | | |
| E64 |  2,6-dichloro-N-(2,3-dimethylcyclohexyl)benzamide | 2.77 | | |
| E65 |  2-fluoro-N-(2-methylcyclohexyl)isonicotinamide | 2.83 | | |

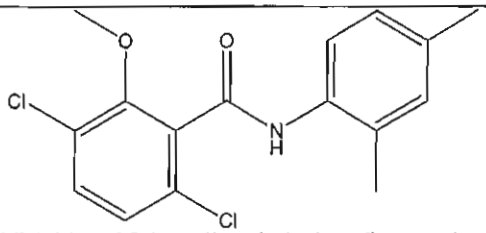
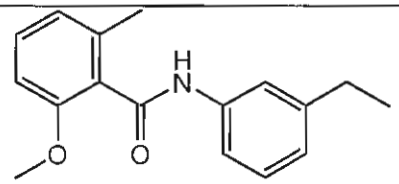
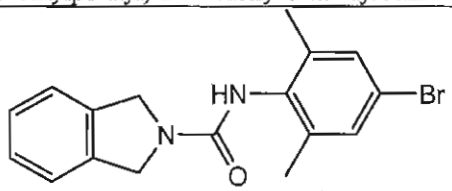
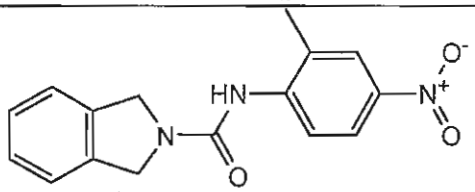
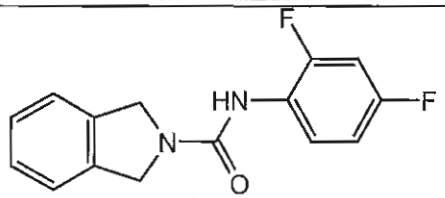
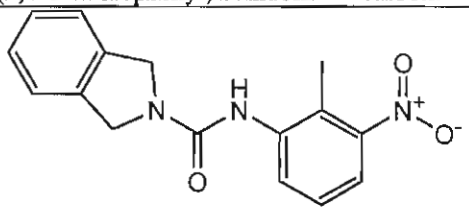
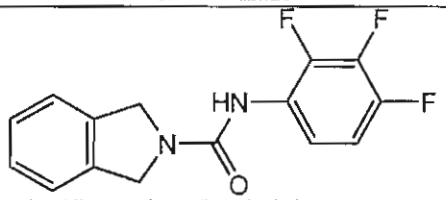
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E66 |  N-cyclohexyl-2,4,6-trimethylbenzamide | 2.86 | | |
| E67 |  2-hydroxy-4-methyl-N-(4-methylcyclohexyl)benzamide | 2.98 | | |
| E68 |  N-(heptan-4-yl)-3-(trifluoromethyl)benzamide | 3.03 | 0.33 | |
| E69 |  2,3,5,6-tetrafluoro-N-isobutyl-4-methylbenzamide | 3.19 | | |
| E70 |  2,3,5,6-tetrafluoro-4-methyl-N-(5-methylhexan-2-yl)benzamide | 3.2 | | |
| E71 |  N-(2-methylcyclohexyl)benzo[c][1,2,5]oxadiazole-5-carboxamide | 3.33 | | |
| E72 |  2-hydroxy-3-methoxy-N-(4-methylcyclohexyl)benzamide | 3.35 | | |

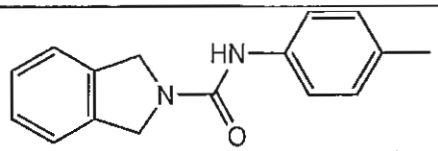
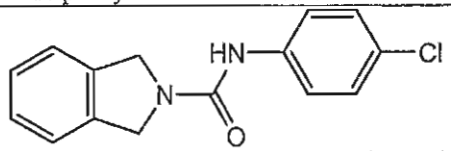
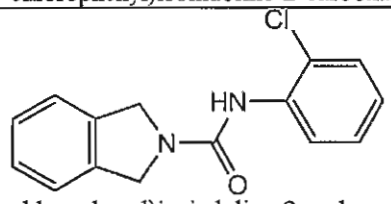
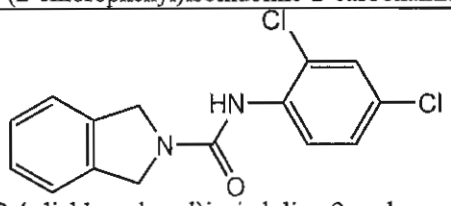
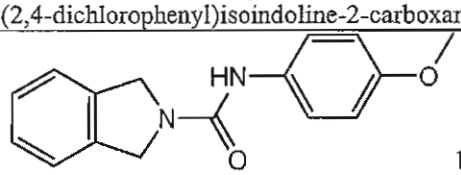
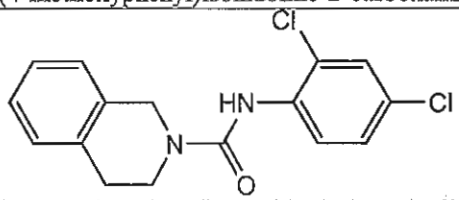
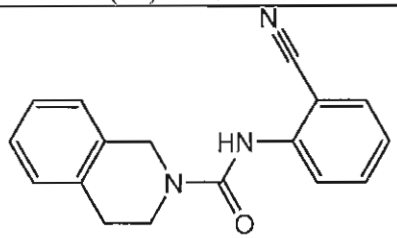
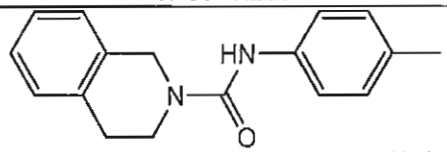
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E73 |  Thiophene-2-carboxylic acid (1,3,3-trimethyl-bicyclo[2.2.1]hept-2-yl)-amide | 3.36 | | |
| E74 |  N-(2,3-dimethylcyclohexyl)-2-(perfluorophenyl)acetamide | 3.62 | | |
| E75 |  2,3-dichloro-N-(pentan-3-yl)benzamide | 3.78 | | |
| E76 |  2,3-dichloro-N-(2,3-dimethylcyclohexyl)benzamide | 3.99 | | |
| E77 |  N-(2,3-dimethylcyclohexyl)-2,5-difluorobenzamide | 4.11 | | |
| E78 |  4,5-Dichloro-isothiazole-3-carboxylic acid (2-methyl-cyclohexyl)-amide | 4.24 | 8.51 | |

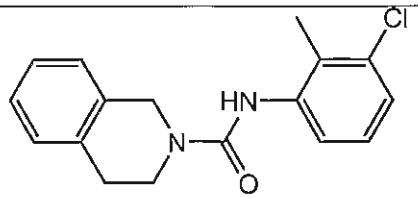
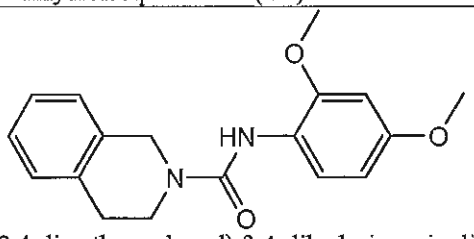
| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E79 |  N-(2,4-dimethylpentan-3-yl)-2,6-dihydroxybenzamide | 4.28 | | |
| E80 |  3-chloro-2-methyl-N-(2-methylcyclohexyl)benzamide | 4.29 | | |
| E81 |  3,4-difluoro-N-(2-methylcyclohexyl)benzamide | 4.37 | | 6.98 |
| E82 |  3,5-dimethyl-N-(2-methylcyclohexyl)benzamide | 4.48 | | |
| E83 |  N-(4-ethoxyphenethyl)-1-methyl-1H-pyrazole-5-carboxamide | 4.68 | | |
| E84 |  3,6-dichloro-N-(2-fluorophenyl)-2-methoxybenzamide | 0.83 | | 16.51 |

| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E85 |  N-(2-Chloro-4,6-dimethoxy-phenyl)-3-trifluoromethyl-benzamide | 1.42 | | |
| E86 |  3,5-dichloro-N-(2,4-dimethylphenyl)-4-methoxybenzamide | 1.48 | | |
| E87 |  3-Chloro-4-fluoro-N-(5-trifluoromethyl-[1,3,4]thiadiazol-2-yl)-benzamide | 1.55 | | |
| E88 |  3,5-dichloro-4-methoxy-N-o-tolylbenzamide | 1.84 | | |
| E89 |  5-Chloro-N-(2,4-difluoro-phenyl)-2-hydroxy-benzamide | 2.56 | | |
| E90 |  2,4-Dichloro-N-(2-cyano-3-fluoro-phenyl)-benzamide | 2.71 | | |

| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E91 |  2,6-Dichloro-N-(4-cyano-phenyl)-benzamide | 2.74 | | |
| E92 |  4-chloro-N-(2,4-dimethylphenyl)-3-methylbenzamide | 2.74 | | |
| E93 |  3,5-dichloro-4-methoxy-N-(4-methoxyphenyl)benzamide | 3.24 | | |
| E94 |  3-chloro-N-(2,4-dimethoxyphenyl)-4-fluorobenzamide | 3.56 | | |
| E95 |  5-Cyano-2,4-dimethyl-6-methylsulfanyl-N-phenyl-nicotinamide | 3.58 | | |
| E96 |  N-(4-tert-Butyl-thiazol-2-yl)-isonicotinamide | 3.73 | | |

| Table 5 - Sweet Enhancer Amides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E97 |  3,6-Dichloro-N-(2,4-dimethyl-phenyl)-2-methoxy-benzamide | 4.25 | | |
| E98 |  N-(3-ethylphenyl)-2-methoxy-6-methylbenzamide | 4.63 | | |
| E99 |  N-(4-bromo-2,6-dimethylphenyl)isoindoline-2-carboxamide | 0.93 | | |
| E100 |  N-(2-methyl-4-nitrophenyl)isoindoline-2-carboxamide | 1.3 | | |
| E101 |  N-(2,4-difluorophenyl)isoindoline-2-carboxamide | 1.37 | | |
| E102 |  N-(2-methyl-3-nitrophenyl)isoindoline-2-carboxamide | 2.01 | | |
| E103 |  N-(2,3,4-trifluorophenyl)isoindoline-2-carboxamide | 2.58 | | |

| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E104 |  N-p-tolylisoindoline-2-carboxamide | 3.05 | | |
| E105 |  N-(4-chlorophenyl)isoindoline-2-carboxamide | 3.4 | | |
| E106 |  N-(2-chlorophenyl)isoindoline-2-carboxamide | 3.85 | | |
| E107 |  N-(2,4-dichlorophenyl)isoindoline-2-carboxamide | 4.15 | | |
| E108 |  N-(4-methoxyphenyl)isoindoline-2-carboxamide | 4.99 | | |
| E109 |  N-(2,4-dichlorophenyl)-3,4-dihydroisoquinoline-2(1H)-carboxamide | 2.34 | | |
| E110 |  N-(2-cyanophenyl)-3,4-dihydroisoquinoline-2(1H)-carboxamide | 2.5 | | |
| E111 |  N-p-tolyl-3,4-dihydroisoquinoline-2(1H)-carboxamide | 4.27 | | |

| Table 5 - Sweet EnhancerAmides | | | | |
|---|---|---|---|---|
| **Compound No.** | **Compound** | **Sweet $EC_{50}$ uM** | **Umami $EC_{50}$ uM** | **Umami $EC_{50}$ ratio** |
| E112 | <br>N-(3-chloro-2-methylphenyl)-3,4-dihydroisoquinoline-2(1H)-carboxamide | 4.33 | | |
| E113 | <br>N-(2,4-dimethoxyphenyl)-3,4-dihydroisoquinoline-2(1H)-carboxamide | 4.44 | | |

Also, as supported by experimental data in the examples, it has been shown that cell lines which co-express T1R1/T1R3 or T1R2/T1R3 respectively respond to umami or sweet taste stimuli and a quantitative dose-responsive manner which further supports a conclusion that specific binding to the T1R1/T1R3 and T1R2/T1R3 receptor can be used to define receptor agonists and antagonists, e.g., MSG substitutes, umami blockers, novel artificial and natural sweeteners, and sweet blockers.

Also, as supported by data in experimental examples, it has been shown that the sweet taste blocker lactisole inhibits both the T1R2/T1R3 sweet receptor and the T1R1/T1R3 umami taste receptor. Compounds are provided herein that enhance, mimic, modulate or block sweet or umami taste. The fact that lactisole inhibits both the T1R1/T1R3 and T1R2/T1R3 receptors suggests that these receptors may share a common subunit which is bound by lactisole and potentially other taste modulators. Therefore, this shows that some compounds which enhance, mimic, modulate or block sweet taste can have a similar effect on umami taste or vice versa.

Further, as supported by data in experimental examples, it has been demonstrated that cell lines which stably co-express T1Rs, i.e. T1R1/T1R3 or T1R2/T1R3, when assayed by automated fluorescence imaging very effectively respond to various sweet and umami taste stimuli, i.e. at magnitudes substantially greater than transiently transfected cells. Thus, these cell lines are especially well suited for use in high throughput screening assays for identifying compounds that modulate, block, mimic or enhance sweet or umami taste. However, the invention also encompasses assays that utilize cells that transiently express a T1R or combination thereof.

Moreover, while the application contains data demonstrating that some T1Rs act in combination, particularly T1R1/T1R3 and T1R2/T1R3, and that such receptor combinations may be used in assays, preferably high throughput assays, it should be noted that the subject invention also encompasses assays that utilize T1R1, T1R2 and T1R3 alone or in combination with other proteins, e.g., other GPCRs.

There are differences in human and rodent sweet taste in terms of the ligand specificity, G protein coupling efficiency, as well as sensitivity to inhibitors. The species differences in T1R ligand specificity can be utilized to demonstrate that the sweet taste receptor indeed functions as a heteromeric complex, and that there is more than one ligand binding site on the receptor. Furthermore, a functional link between

the sweet and umami receptors mediated by T1R3 has been shown (Example 16).

Both human and rat sweet receptors can efficiently couple to a chimeric Gα15 with the C-terminal tail sequence from $G_{\alpha il}$ ($G_{\alpha 15/il}$). For example, human but not rat T1R2/T1R3 selectively responds to a group of sweeteners, including aspartame, neotame, and cyclamate. This is consistent with taste physiology data. These differences in agonist specificity can be utilized to map their binding sites on the receptor. A chimeric T1R can be generated between human and rat genes, with a junction immediately before the transmembrane domain. Each T1R chimera therefore consists of two halves, the N-terminal extracellular domain, and the C-terminal transmembrane and intracellular domain, from different species. For example, a chimeric T1R2, termed T1R2-R, has a sequence from the N-terminus of human T1R2 fused to rat T1R2 C-terminal sequence. Responses to these chimeras can then be tested (Figure 22).

Novel compounds and novel flavor, tastants, and sweet enhancers were discovered in the chemistry series of amide derivatives. The amide compounds also comprise certain sub-classes of amide derivatives or classes of derivatives related to amides, such as for example ureas, urethanes, oxalamides, acrylamides, and the like. These compounds, when used together with sucrose or alone, increase a response in vitro and concomitant increase in sweet perception in human tasting. These compounds enhance other natural and synthetic sweet tastants. Examples of these compounds are listed in Table 5.

In one embodiment, the invention provides novel compounds, flavorants, tastants, flavor enhancers, taste enhancers, flavor modifying compounds, and/or compositions containing them.

In a more specific embodiment, the invention provides novel sweet flavorants, sweet tastants, sweet taste enhancers, and sweet taste modifiers and compositions containing them.

More particularly, in another embodiment, the invention is directed to compounds that modulate, induce, enhance, or inhibit natural or synthetic sweet tastants, *e.g.*, naturally occurring and synthetic sweeteners.

In another embodiment, the invention provides compositions, preferably compositions suitable for human or animal consumption, containing at least one compound of the invention. These compositions include foods, beverages and

medicinals, and food additives which when added to foods, beverages or medicinals modulate the flavor or taste thereof, particularly by enhancing the sweet taste thereof.

Another embodiment of the invention is directed to use of a compound of the invention to modulate the sweet taste of a desired food, beverage or medicinal, which composition may comprise one or more other compounds that elicit a sweet taste. These compounds, when they were used together with naturally occurring and synthetic sweeteners, not only increased a response *in vitro* but also intensified the sweet and other flavor or taste perceptions in human tasting. These specific compounds, when they were used together with sweet tastants, such as naturally occurring and synthetic sweeteners, not only increased the T1R2/T1R3 response *in vitro* but also intensified the sweet taste and other flavor or taste perceptions in human tasting.

Novel compounds and novel flavor, tastant, and umami enhancers and tastants such as amides, ureas, amino-amides, amido-amides, and β-lactams are also disclosed herein. These compounds, when used together with MSG or alone, increase a response *in vitro* and the umami perception in human tasting. These compounds also enhance other natural and synthetic umami tastants. Examples of these compounds are listed in Tables 1-4.

In one embodiment, the invention provides novel compounds, flavorants, tastants, flavor enhancers, taste enhancers, flavor modifying compounds, and/or compositions containing them.

In a more specific embodiment, the invention provides novel umami flavorants, umami tastants, umami taste enhancers, and umami taste modifiers and compositions containing them.

More particularly, in another embodiment, the invention is directed to compounds that modulate (induce, enhance or inhibit) natural or synthetic umami tastants, *e.g.*, monosodium glutamate (MSG).

In another embodiment, the invention provides compositions, preferably compositions suitable for human or animal consumption, containing at least one compound of the invention. These compositions include foods, beverages and medicinals, and food additives which when added to foods, beverages or medicinals modulate the flavor or taste thereof, particularly by enhancing the umami taste thereof.

Another embodiment of the invention is directed to use of a compound of the invention to modulate the umami taste of a desired food, beverage or medicinal, which

composition may comprise one or more other compounds that elicit a umami taste, *e.g.*, MSG. These compounds, when they were used together with MSG, not only increased a response *in vitro* but also intensified the umami and other flavor or taste perceptions in human tasting. These specific compounds, when they were used together with umami tastants, such as MSG, not only increased the T1R1/T1R3 response *in vitro* but also intensified the umami taste and other flavor or taste perceptions in human tasting. Some of the compounds, when they were tasted alone, elicited human perception of umami.

Compounds defined by specific binding to specific receptors using the present T1R assays can be used to modulate the taste of foods and beverages. Suitable assays described in further detail infra include by way of example whole-cell assays and biochemical assays, including direct-binding assays using one of a combination of different T1R receptors, chimeras or fragments thereof, especially fragments containing N-terminal ligand-binding domains. Examples of assays appropriate for use in the invention are described in greater detail infra and are known in the GPCR field.

Assays can be designed that quantitate the binding of different compounds or mixtures of compounds to T1R taste receptors or T1R taste receptor combinations or T1R receptors expressed in combination with other heterologous (non-T1R) proteins, e.g. other GPCRs, or that quantitate the activation of cells that express T1R taste receptors. This can be effected by stably or transiently expressing taste receptors in heterologous cells such as HEK-293, CHO and COS cells. Thus, this physico-chemical characteristic of the compounds is used to define a genus of compound that share this characteristic.

The assays will preferably use cells that also express (preferably stably) a G protein such as Gα15 or Gα16 or other promiscuous G proteins or G protein variants, or an endogenous G protein. In addition, $G_\beta$ and $G_\gamma$ proteins may also be expressed therein.

The effect of a compound on sweet or umami taste using cells or compositions that express or contain the above-identified receptors or receptor combinations may be determined by various means including the use of calcium-sensitive dyes, voltage-sensitive dyes, cAMP assays, direct binding assays using fluorescently labeled ligands

or radioactive ligands such as $^{3}$H-glutamate, or transcriptional assays (using a suitable reporter such as luciferase or beta-lactamase).

Assays that may be utilized with one or more T1Rs according to the invention include by way of example, assays that utilize a genetic selection for living cells; assays that utilize whole cells or membrane fragments or purified T1R proteins; assays that utilize second messengers such as cAMP and IP3, assays that detect the translocation of arrestin to the cell surface, assays that detect the loss of receptor expression on the cell surface (internalization) by tested ligands, direct ligand-binding assays, competitive-binding assays with inhibitors, assays using in vitro translated protein, assays that detect conformational changes upon the binding of a ligand (e.g., as evidenced by proteolysis, fluorescence, or NMR), behavioral assays that utilize transgenic non-human animals that express a T1R or T1R combination, such as flies, worms, or mice, assays that utilize cells infected with recombinant viruses that contain T1R genes.

Also within the scope of the invention are structure-based analyses wherein the X-ray crystal structure of a T1R or T1R fragment (or combination of T1Rs, or a combination of a T1R with another protein) is determined and utilized to predict by molecular modeling techniques compounds that will bind to and/or enhance, mimic, block or modulate the particular T1R receptor or receptor combination. More particularly, the invention embraces the determination of the crystal structure of T1R1/T1R3 (preferably hT1R1/hT1R3) and/or T1R2/T1R3 (preferably hT1R2/hT1R3) and the use of such crystal structures in structure-based design methods to identify molecules that modulate T1R receptor activity.

The invention especially includes biochemical assays conducted using cells, e.g., mammalian, yeast, insect or other heterologous cells that express one or more full length T1R receptors or fragments, preferably N-terminal domains of T1R1, T1R2 and/or T1R3. The effect of a compound in such assays can be determined using competitive binding assays, e.g., using radioactive glutamate or IMP, fluorescence (e.g., fluorescence polarization, FRET), or GTP$\gamma$ $^{35}$S binding assays. As noted, in a preferred embodiment, such assays will utilize cell lines that stably co-express T1R1/T1R3 or T1R2/T1R3 and a suitable G protein, such as $G_{\alpha 15}$. Other appropriate G proteins include the chimeric and variant G proteins disclosed in U.S. Application Serial No. 09/984,292 and 60/243,770, incorporated by reference in their entirety herein.

Still further, altered receptors can be constructed and expressed having improved properties, e.g., enhanced surface expression or G-protein coupling. These T1R variants can be incorporated into cell-based and biochemical assays.

It is envisioned that the present discoveries relating to human T1Rs will extend to other species, e.g., rodents, pigs, monkeys, dogs and cats, and perhaps even non-mammals such as fish. In this regard, several fish T1R fragments are identified infra in Example 1. Therefore, the subject invention has application in screening for compounds for use in animal feed formulations.

The invention further includes that utilize different allelic variants of various T1Rs and combinations thereof, thereby enabling the identification of compounds that elicit specific taste sensation in individuals that express those allelic variants or compounds that elicit specific taste sensations in all individuals. Such compounds can be used to make foods more generally palatable.

T1R encoding nucleic acids also provide valuable probes for the identification of taste cells, as the nucleic acids are specifically expressed in taste cells. For example, probes for T1R polypeptides and proteins can be used to identify taste cells present in foliate, circumvallate, and fungiform papillae, as well as taste cells present in the geschmackstreifen, oral cavity, gastrointestinal epithelium, and epiglottis. In particular, methods of detecting T1Rs can be used to identify taste cells sensitive to sweet and/or umami taste stimuli or other taste stimuli representing other taste modalities. For example, cells stably or transiently expressing T1R2 and/or T1R3 would be predicted from the work herein to be responsive to sweet taste stimuli. Similarly, cells expressing T1R1 and/or T1R3 would be predicted to be responsive to umami taste stimuli. The nucleic acids encoding the T1R proteins and polypeptides of the invention can be isolated from a variety of sources, genetically engineered, amplified, synthesized, and/or expressed recombinantly according to the methods disclosed in WO 00/035374, which is herein incorporated by reference in its entirety. A listing of T1Rs that may be expressed according to the invention are provided in the Examples. However, it should be emphasized that the invention embraces the expression and use of other specific T1Rs or fragments, variants, or chimeras constructed based on such T1R sequences, and particularly T1Rs of other species.

As disclosed, an important aspect of the invention is the plurality of methods of screening for modulators, *e.g.*, activators, inhibitors, stimulators, enhancers, agonists,

and antagonists, of these taste-cell-specific GPCRs. Such modulators of taste transduction are useful for the modulation of taste signaling pathways. These methods of screening can be used to identify high affinity agonists and antagonists of taste cell activity. These modulatory compounds can then be used in the food industry to customize taste, *e.g.*, to modulate the sweet and/or umami tastes of foods.

This invention rectifies the previous lack of understanding relating to sweet and umami taste as it identifies specific T1Rs and T1R receptor combinations that mediate sweet and umami taste sensation. Therefore, in general, this application relates to the inventors' discoveries relating to the T1R class of taste-specific G-protein-coupled receptors and their specific function in taste perception and the relationship of these discoveries to a better understanding of the molecular basis of taste.

The molecular basis of sweet taste and umami taste – the savor of monosodium glutamate – is enigmatic. Recently, a three-member class of taste-specific G-protein-coupled receptors, termed T1Rs, was identified. Overlapping T1R expression patterns and the demonstration that the structurally related $GABA_B$ receptor is heterodimeric suggest that the T1Rs function as heterodimeric taste receptors. In the examples infra, the present inventors describe the functional co-expression of human T1R1, T1R2, and T1R3 in heterologous cells; cells co-expressing T1R1 and T1R3 are activated by umami taste stimuli; cells co-expressing T1R2 and T1R3 are activated by sweet taste stimuli. T1R1/T1R3 and T1R2/T1R3 activity correlated with psychophysical detection thresholds. In addition, the 5'-ribonucleotide IMP was found to enhance the T1R1/T1R3 response to glutamate, a synergism characteristic of umami taste. These findings demonstrate that specific T1Rs and particularly different combinations of the T1Rs function as sweet and umami taste receptors.

Human perception of bitter, sweet, and umami is thought to be mediated by G-protein-coupled receptors (Lindemann, B., *Physiol. Res.* 76:718-66 (1996)). Recently, evaluation of the human genome revealed the T2R class of bitter taste receptors (Adler et al., *Cell* 100:613-702 (2000); Chandrasgekar et al., *Cell* 100:703-11 (2000); Matsunami et al., *Nature* 404: 601-604 (2000)) but the receptors for sweet and umami taste have not been identified. Recently, another class of candidate taste receptors, the T1Rs, was identified. The T1Rs were first identified by large-scale sequencing of a subtracted cDNA library derived from rat taste tissue, which identified T1R1, and subsequently by T1R1-based degenerate PCR, which led to the identification of T1R2

(Hoon et al., *Cell* 96:541-551 (1999)). Recently, the present inventors and others identified a third and possibly final member of the T1R family, T1R3, in the human genome databank (Kitagawa et al., *Biochem Biophys. Res Commun.* 283(1): 236-42 (2001); Max et al., *Nat. Genet.* 28(1): 58-63 (2001); Sainz et al., *J. Neurochem.* 77(3): 896-903 (2001); Montmayeur et al., *Nat. Neurosci.* 4, 492-8. (2001)). Tellingly, mouse T1R3 maps to a genomic interval containing *Sac*, a locus that influences sweet taste in the mouse (Fuller et al., *J. Hered.* 65:33-6 (1974); Li et al., *Mamm. Genome* 12:13-16 (2001)). Therefore, T1R3 was predicted to function as a sweet taste receptor. Recent high-resolution genetic mapping studies have strengthened the connection between mouse T1R3 and *Sac* (Fuller T.C., *J. Hered.* 65(1): 33-36 (1974); Li et al., *Mammal. Genome* 12(1): 13-16 (2001)).

Interestingly, all C-family receptors that have been functionally expressed thus far – metabotropic glutamate receptors, the $GABA_B$ receptor, the calcium-sensing receptor (Conigrave, A. D., Quinn, S. J. & Brown, E. M., Proc Natl Acad Sci *USA* 97, 4814-9. (2000)), and a fish olfactory receptor (Speca, D. J. et al., *Neuron* 23, 487-98. (1999)) – have been shown to be activated by amino acids. This common feature raises the possibility that the T1Rs recognize amino acids, and that the T1Rs may be involved in the detection of glutamate in addition to sweet-tasting amino acids. Alternatively, a transcriptional variant of the mGluR4 metabotropic glutamate receptor has been proposed to be the umami taste receptor because of its selective expression in rat taste tissue, and the similarity of the receptor-activation threshold to the glutamate psychophysical detection threshold (Chaudhari et al., *Nat. Neurosci.* 3:113-119 (2000)). This hypothesis is difficult to reconcile with the exceedingly low expression level of the mGluR4 variant in taste tissue, and the more or less unaltered glutamate taste of mGluR4 knockout mice (Chaudhari and Roper, *Ann. N.Y. Acad. Sci.* 855:398-406 (1998)). Furthermore, the taste variant is structurally implausible, lacking not only the majority of the residues that form the glutamate-binding pocket of the wild-type receptor, but also approximately half of the globular N-terminal glutamate-binding domain (Kunishima et al., *Nature* 407:971-7 (2000)).

Comparative analysis of T1R expression patterns in rodents has demonstrated that T1R2 and possibly T1R1 are each coexpressed with T1R3 (Hoon et al., *Cell* 96:541-51 (1999); Kitagawa et al., *Biochem Biophy. Res. Commun.* 283:236-242 (2001); Max et al., *Nat. Genet.* 28:58-63 (2001); Montmayeur et al., *Nat. Neurosci*

4:492-8 (2001); Sainz et al., J. Neurochem 77:896-903 (2001)). Furthermore, dimerization is emerging as a common theme of C-family receptors: the metabotropic glutamate and calcium-sensing receptor are homodimers (Romomano et al., *J. Biol. Chem.* 271:28612-6 (1996); Okamoto et al., *J. Biol. Chem.* 273: 13089-96 (1998); Han et al., *J. Biol. Chem.* 274:100008-13 (1999); Bai et al., *J. Biol. Chem.* 273:23605-10 (1998)), and the structurally related $GABA_B$ receptor is heterodimeric (Jones et al., *Nature* 396:674-9 (1998); Kaupmann et al., *Nature* 396:683-687 (1998); White et al., *Nature* 396: 679-682 (1998); Kuner et al., *Science* 283:74-77 (1999)). The present inventors have demonstrated by functional coexpression of T1Rs in heterologous cells that human T1R2 functions in combination with human T1R3 as a sweet taste receptor and that human T1R1 functions in combination with human T1R3 as an umami taste receptor.

The discoveries discussed herein are especially significant, as previously the development of improved artificial sweeteners has been hampered by the lack of assays for sweet taste. Indeed, the five commonly used commercial artificial sweeteners, all of which activate hT1R2/hT1R3, were discovered serendipitously. Similarly, other than sensory testing, a laborious process, there is no assay for identifying compounds that modulate umami taste. These problems are now alleviated because, as established by experimental results discussed infra, the human sweet and umami receptors have been identified, and assays for these receptors have been developed, particularly assays that use cells that stably express a functional T1R taste receptor, i.e. the sweet or umami taste receptor.

Based thereon the invention provides assays for detecting and characterizing taste–modulating compounds, wherein T1R family members act, as they do in the taste bud, as reporter molecules for the effect on sweet and umami taste of taste-modulating compounds. Particularly provided and within the scope of the invention are assays for identifying compounds that modulate, mimic, enhance and/or block individually, sweet and umami tastes. Methods for assaying the activity of GPCRs, and especially compounds that affect GPCR activity are well known and are applicable to the T1R family member of the present invention and functional combinations thereof. Suitable assays have been identified supra.

The invention also provides compounds that bind T1R1, T1R2, T1R3, T1R2/T1R3 or T1R1/T1R3, or any fragment, portion, or subunit thereof, as disclosed throughout.

In particular, the subject GPCRs can be used in assays to, *e.g.*, measure changes in ligand binding, ion concentration, membrane potential, current flow, ion flux, transcription, receptor-ligand interactions, second messenger concentrations, *in vitro* and *in vivo*. In another embodiment, T1R family members may be recombinantly expressed in cells, and the modulation of taste transduction via GPCR activity may be assayed by measuring changes in $Ca^{2+}$ levels and other intracellular messages such as cAMP, cGMP, or $IP_3$.

In certain assays, a domain of a T1R polypeptide, *e.g.*, an extracellular, transmembrane, or intracellular domain, is fused to a heterologous polypeptide, thereby forming a chimeric polypeptide, *e.g.*, a chimeric protein with GPCR activity. Particularly contemplated is the use of fragments of T1R1, T1R2 or T1R3 containing the N-terminal ligand-binding domain. Such proteins are useful, *e.g.*, in assays to identify ligands, agonists, antagonists, or other modulators of T1R receptors. For example, a T1R polypeptide can be expressed in a eukaryotic cell as a chimeric receptor with a heterologous, chaperone sequence that facilitates plasma membrane trafficking, or maturation and targeting through the secretory pathway. The optional heterologous sequence may be a PDZ domain-interacting peptide, such as a C-terminal PDZIP fragment (SEQ ID NO 1). PDZIP is an ER export signal, which, according to the present invention, has been shown to facilitate surface expression of heterologous proteins such as the T1R receptors described herein. More particularly, in one aspect of the invention, PDZIP can be used to promote proper targeting of problematic membrane proteins such as olfactory receptors, T2R taste receptors, and the T1R taste receptors described herein.

Examples of such chimeric receptors include trans-species receptors. Any combination of receptor subunits from various species can be used together to form a chimeric receptor, which can then be used to identify tastants, for example. Therefore, contemplated herein is a chimeric T1R2/T1R3 receptor comprising a human T1R2 subunit and a rat T1R3 subunit. Also contemplated is a chimeric T1R2/T1R3 receptor comprising, a rat T1R2 subunit and a human T1R3 subunit. Also contemplated is a chimeric T1R2 receptor subunit comprising, a human extracellular domain, a rat

transmembrane domain and a rat intracellular domain (SEQ ID NOS: 16 and 17, for example). Also contemplated is chimeric T1R3 receptor subunit comprising, a rat extracellular domain, a human transmembrane domain and a human intracellular domain (SEQ ID NOS: 18 and 19, for example.)

Such chimeric T1R receptors can be expressed in any eukaryotic cell, such as HEK-293 cells. Preferably, the cells contain a G protein, preferably a promiscuous G protein such as $G_{\alpha 15}$ or $G_{\alpha 16}$ or another type of promiscuous G protein capable of linking a wide range of GPCRs to an intracellular signaling pathway or to a signaling protein such as phospholipase C. Activation of such chimeric receptors in such cells can be detected using any standard method, such as by detecting changes in intracellular calcium by detecting FURA-2 dependent fluorescence in the cell. If preferred host cells do not express an appropriate G protein, they may be transfected with a gene encoding a promiscuous G protein such as those described in U.S. Application Serial No. 60/243,770, U.S. Application Serial No. 09/984,297, filed October 29, 2001, and U.S. Application Serial No. 09/989,497 filed November 21, 2001 which are herein incorporated by reference in its entirety.

Additional methods of assaying for modulators of taste transduction include *in vitro* ligand-binding assays using: T1R polypeptides, portions thereof, *i.e.*, the extracellular domain, transmembrane region, or combinations thereof, or chimeric proteins comprising one or more domains of a T1R family member; oocyte or tissue culture cells expressing T1R polypeptides, fragments, or fusion proteins; phosphorylation and dephosphorylation of T1R family members; G protein binding to GPCRs; ligand-binding assays; voltage, membrane potential and conductance changes; ion flux assays; changes in intracellular second messengers such as cGMP, cAMP and inositol triphosphate (IP3); and changes in intracellular calcium levels.

Further, the invention provides methods of detecting T1R nucleic acid and protein expression, allowing investigation of taste transduction regulation and specific identification of taste receptor cells. T1R family members also provide useful nucleic acid probes for paternity and forensic investigations. T1R genes are also useful as nucleic acid probes for identifying taste receptor cells, such as foliate, fungiform, circumvallate, geschmackstreifen, and epiglottis taste receptor cells. T1R receptors can

also be used to generate monoclonal and polyclonal antibodies useful for identifying taste receptor cells.

Functionally, the T1R polypeptides comprise a family of related seven transmembrane G protein-coupled receptors, which are believed to be involved in taste transduction and may interact with a G protein to mediate taste signal transduction (*see, e.g.*, Fong, *Cell Signal*, 8:217 (1996); Baldwin, *Curr. Opin. Cell Biol.*, 6:180 (1994)). Structurally, the nucleotide sequences of T1R family members encode related polypeptides comprising an extracellular domain, seven transmembrane domains, and a cytoplasmic domain. Related T1R family genes from other species share at least about 50%, and optionally 60%, 70%, 80%, or 90%, nucleotide sequence identity over a region of at least about 50 nucleotides in length, optionally 100, 200, 500, or more nucleotides in length to the T1R nucleic acid sequences disclosed herein in the Examples, or conservatively modified variants thereof, or encode polypeptides sharing at least about 35 to 50%, and optionally 60%, 70%, 80%, or 90%, amino acid sequence identity over an amino acid region at least about 25 amino acids in length, optionally 50 to 100 amino acids in length to a T1R polypeptide sequence disclosed infra in the Examples conservatively modified variants thereof.

Several consensus amino acid sequences or domains have also been identified that are characteristic of T1R family members. For example, T1R family members typically comprise a sequence having at least about 50%, optionally 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95-99%, or higher, identity to T1R consensus sequences 1 and 2 (SEQ ID NOs. 2 and 3, respectively). These conserved domains thus can be used to identify members of the T1R family, by identity, specific hybridization or amplification, or specific binding by antibodies raised against a domain. T1R consensus sequences include by way of example the following sequences:

T1R Family Consensus Sequence 1: (SEQ ID NO: 2)

(TR)C(FL)(RQP)R(RT)(SPV)(VERKT)FL(AE)(WL)(RHG)E

T1R Family Consensus Sequence 2: (SEQ ID NO: 3)

(LQ)P(EGT)(NRC)YN(RE)A(RK)(CGF)(VLI)T(FL)(AS)(ML)

These consensus sequences are inclusive of those found in the T1R polypeptides described herein, but T1R family members from other organisms may be expected to comprise consensus sequences having about 75% identity or more to the inclusive consensus sequences described specifically herein.

Specific regions of the T1R nucleotide and amino acid sequences may be used to identify polymorphic variants, interspecies homologs, and alleles of T1R family members. This identification can be made *in vitro*, *e.g.*, under stringent hybridization conditions or PCR (*e.g.*, using primers encoding the T1R consensus sequences identified above), or by using the sequence information in a computer system for comparison with other nucleotide sequences. Different alleles of T1R genes within a single species population will also be useful in determining whether differences in allelic sequences control differences in taste perception between members of the population. Classical PCR-type amplification and cloning techniques are useful for isolating new T1Rs, for example, where degenerate primers are sufficient for detecting related genes across species.

Typically, identification of polymorphic variants and alleles of T1R family members can be made by comparing an amino acid sequence of about 25 amino acids or more, *e.g.*, 50-100 amino acids. Amino acid identity of approximately at least 35 to 50%, and optionally 60%, 70%, 75%, 80%, 85%, 90%, 95-99%, or above typically demonstrates that a protein is a polymorphic variant, interspecies homolog, or allele of a T1R family member. Sequence comparison can be performed using any of the sequence comparison algorithms discussed below. Antibodies that bind specifically to T1R polypeptides or a conserved region thereof can also be used to identify alleles, interspecies homologs, and polymorphic variants.

Polymorphic variants, interspecies homologs, and alleles of T1R genes can be confirmed by examining taste-cell-specific expression of the putative T1R gene or protein. Typically, T1R polypeptides having an amino acid sequence disclosed herein can be used as a positive control in comparison to the putative T1R polypeptide to demonstrate the identification of a polymorphic variant or allele of the T1R family member. The polymorphic variants, alleles, and interspecies homologs are expected to retain the seven transmembrane structure of a G protein-coupled receptor. For further detail, *see* WO 00/06592, which discloses related T1R family members, GPCR-B3s, the contents of which are herein incorporated by reference in a manner consistent with this disclosure. GPCR-B3 receptors are referred to herein as rT1R1 and mT1R1. Additionally, *see* WO 00/06593, which also discloses related T1R family members, GPCR-B4s, the contents of which are herein incorporated by reference in a manner consistent with this disclosure. GPCR-B4 receptors are referred to herein as rT1R2 and

mT1R2. As discussed previously, the invention also includes structure-based assays that utilize the x-ray crystalline structure of a T1R or T1R combination, e.g., hT1R2/hT1R3 or hT1R1/hT1R3, to identify molecules that modulate T1R receptor activity, and thereby modulate sweet and/or umami taste.

The present invention also provides assays, preferably high throughput assays, to identify molecules that enhance, mimic, block and/or modulate T1R receptors. In some assays, a particular domain of a T1R family member is used in combination with a particular domain of another T1R family member, *e.g.*, an extracellular, transmembrane, or intracellular domain or region. In other embodiments, an extracellular domain, transmembrane region or combination thereof may be bound to a solid substrate, and used, *e.g.*, to isolate ligands, agonists, antagonists, or any other molecules that can bind to and/or modulate the activity of a T1R polypeptide.

Various conservative mutations and substitutions are envisioned to be within the scope of the invention. For instance, it is within the level of skill in the art to perform amino acid substitutions using known protocols of recombinant gene technology including PCR, gene cloning, site-directed mutagenesis of cDNA, transfection of host cells, and in-vitro transcription. The variants could then be screened for activity.

## Definitions

As used herein, the following terms have the meanings ascribed to them unless specified otherwise.

"Taste cells" include neuroepithelial cells that are organized into groups to form taste buds of the tongue, *e.g.*, foliate, fungiform, and circumvallate cells (*see, e.g.*, Roper et al., Ann. Rev. Neurosci. 12:329-353 (1989)). Taste cells are also found in the palate and other tissues, such as the esophagus and the stomach.

"T1R" refers to one or more members of a family of G protein-coupled receptors that are expressed in taste cells such as foliate, fungiform, and circumvallate cells, as well as cells of the palate, and esophagus (*see, e.g.*, Hoon *et al., Cell*, 96:541-551 (1999), herein incorporated by reference in its entirety). Members of this family are also referred to as GPCR-B3 and TR1 in WO 00/06592 as well as GPCR-B4 and TR2 in WO 00/06593. GPCR-B3 is also herein referred to as rT1R1, and GPCR-B4 is referred to as rT1R2. Taste receptor cells can also be identified on the basis of morphology (*see, e.g.*, Roper, *supra*), or by the expression of proteins specifically

expressed in taste cells. T1R family members may have the ability to act as receptors for sweet taste transduction, or to distinguish between various other taste modalities. Representative T1R sequences, including hT1R1, hT1R2 and hT1R3 are identified infra in the examples.

"T1R" nucleic acids encode a family of GPCRs with seven transmembrane regions that have "G protein-coupled receptor activity," *e.g.*, they may bind to G proteins in response to extracellular stimuli and promote production of second messengers such as IP3, cAMP, cGMP, and $Ca^{2+}$ via stimulation of enzymes such as phospholipase C and adenylate cyclase (for a description of the structure and function of GPCRs, *see*, *e.g.*, Fong, *supra*, and Baldwin, *supra*). A single taste cell may contain many distinct T1R polypeptides.

The term "T1R" family therefore refers to polymorphic variants, alleles, mutants, and interspecies homologs that: (1) have at least about 35 to 50% amino acid sequence identity, optionally about 60, 75, 80, 85, 90, 95, 96, 97, 98, or 99% amino acid sequence identity to a T1R polypeptide, preferably those identified in Example 1, over a window of about 25 amino acids, optionally 50-100 amino acids; (2) specifically bind to antibodies raised against an immunogen comprising an amino acid sequence preferably selected from the group consisting of the T1R polypeptide sequence disclosed in Example 1 and conservatively modified variants thereof; (3) are encoded by a nucleic acid molecule which specifically hybridize (with a size of at least about 100, optionally at least about 500-1000 nucleotides) under stringent hybridization conditions to a sequence selected from the group consisting of the T1R nucleic acid sequences contained in Example 1, and conservatively modified variants thereof; or (4) comprise a sequence at least about 35 to 50% identical to an amino acid sequence selected from the group consisting of the T1R amino acid sequence identified in Example 1.

Topologically, the TIRs disclosed herein have an "N-terminal domain" also called "extracellular domain" comprising a "venus flytrap domain" and a "cysteine rich domain;" "transmembrane domains" comprising seven transmembrane regions, and corresponding cytoplasmic, and extracellular loops; and a "C-terminal domain" (*see*, *e.g.*, Hoon *et al.*, *Cell*, 96:541-551 (1999); Buck & Axel, *Cell*, 65:175-187 (1991)). These domains have been structurally identified using methods known to those of skill in the art, such as sequence analysis programs that identify hydrophobic and

hydrophilic domains (Stryer, *Biochemistry*, (3rd ed. 1988). Such domains are useful for making chimeric proteins and for in vitro assays of the invention, *e.g.*, ligand binding assays. The specific binding of a compound to these structurally defined domains provides provides structural definition for the compound.

"Extracellular domains" therefore refers to the domains of T1R polypeptides that protrude from the cellular membrane and are exposed to the extracellular face of the cell. Such domains generally include the "N terminal domain" that is exposed to the extracellular face of the cell, and optionally can include portions of the extracellular loops of the transmembrane domain that are exposed to the extracellular face of the cell, *i.e.*, the loops between transmembrane regions 2 and 3, between transmembrane regions 4 and 5, and between transmembrane regions 6 and 7.

The "N-terminal domain" region starts at the N-terminus and extends to a region close to the start of the first transmembrane domain. More particularly, in one embodiment of the invention, this domain starts at the N-terminus and ends approximately at the conserved glutamic acid at amino acid position 563 plus or minus approximately 20 amino acids. These extracellular domains are useful for *in vitro* ligand-binding assays, both soluble and solid phase. In addition, transmembrane regions, described below, can also bind ligand either in combination with the extracellular domain, and are therefore also useful for *in vitro* ligand-binding assays.

"Cysteine-rich domain" refers to the domain of the polypeptides. This conserved sequence contains several highly-conserved Cys residues that form disulphide bridges, and lies outside the cell membrane.. This region corresponds to the domain of the T1R family members and is found in all three subunits, T1R1-T1R3. The cysteine rich sequence is found in amino acids 510-566 of T1R1, 508-565 of T1R2, and 512-568 or T1R3.

"Transmembrane domain," which comprises the seven "transmembrane regions," refers to the domain of T1R polypeptides that lies within the plasma membrane, and may also include the corresponding cytoplasmic (intracellular) and extracellular loops. In one embodiment, this region corresponds to the domain of T1R family members which starts approximately at the conserved glutamic acid residue at amino acid position 563 plus or minus 20 amino acids and ends approximately at the conserved tyrosine amino acid residue at position 812 plus or minus approximately 10 amino acids. The seven transmembrane regions and extracellular and cytoplasmic loops

can be identified using standard methods, as described in Kyte & Doolittle, *J. Mol. Biol.*, 157:105-32 (1982)), or in Stryer, *supra*.

"Cytoplasmic domains" refers to the domains of T1R polypeptides that face the inside of the cell, *e.g.*, the "C-terminal domain" and the intracellular loops of the transmembrane domain, *e.g.*, the intracellular loop between transmembrane regions 1 and 2, the intracellular loop between transmembrane regions 3 and 4, and the intracellular loop between transmembrane regions 5 and 6.

"C-terminal domain" refers to the region that spans the end of the last transmembrane domain and the C-terminus of the protein, and which is normally located within the cytoplasm. In one embodiment, this region starts at the conserved tyrosine amino acid residue at position 812 plus or minus approximately 10 amino acids and continues to the C-terminus of the polypeptide.

The term "ligand-binding region" or "ligand-binding domain" refers to sequences derived from a taste receptor, particularly a taste receptor that substantially incorporates at least the extracellular domain of the receptor. In one embodiment, the extracellular domain of the ligand-binding region may include the N-terminal domain and, optionally, portions of the transmembrane domain, such as the extracellular loops of the transmembrane domain. The ligand-binding region may be capable of binding a ligand, and more particularly, a compound that enhances, mimics, blocks, and/or modulates taste, e.g., sweet or umami taste.

The phrase "heteromultimer" or "heteromultimeric complex" in the context of the T1R receptors or polypeptides of the invention refers to a functional association of at least one T1R receptor and another receptor, typically another T1R receptor polypeptide (or, alternatively another non-T1R receptor polypeptide). For clarity, the functional co-dependence of the T1Rs is described in this application as reflecting their possible function as heterodimeric taste receptor complexes. However, as discussed previously, functional co-dependence may alternatively reflect an indirect interaction. For example, T1R3 may function solely to facilitate surface expression of T1R1 and T1R2, which may act independently as taste receptors. Alternatively, a functional taste receptor may be comprised solely of T1R3, which is differentially processed under the control of T1R1 or T1R2, analogous to RAMP-dependent processing of the calcium-related receptor.

The phrase "functional effects" in the context of assays for testing compounds that modulate T1R family member mediated taste transduction includes the determination of any parameter that is indirectly or directly under the influence of the receptor, *e.g.*, functional, physical and chemical effects. It includes ligand binding, changes in ion flux, membrane potential, current flow, transcription, G protein binding, GPCR phosphorylation or dephosphorylation, conformation change-based assays, signal transduction, receptor-ligand interactions, second messenger concentrations (*e.g.*, cAMP, cGMP, IP3, or intracellular $Ca^{2+}$), *in vitro*, *in vivo*, and *ex vivo* and also includes other physiologic effects such increases or decreases of neurotransmitter or hormone release.

By "determining the functional effect" in the context of assays is meant assays for a compound that increases or decreases a parameter that is indirectly or directly under the influence of a T1R family member, *e.g.*, functional, physical and chemical effects. Such functional effects can be measured by any means known to those skilled in the art, *e.g.*, changes in spectroscopic characteristics (*e.g.*, fluorescence, absorbency, refractive index), hydrodynamic (*e.g.*, shape), chromatographic, or solubility properties, patch clamping, voltage-sensitive dyes, whole cell currents, radioisotope efflux, inducible markers, oocyte T1R gene expression; tissue culture cell T1R expression; transcriptional activation of T1R genes; ligand-binding assays; voltage, membrane potential and conductance changes; ion flux assays; changes in intracellular second messengers such as cAMP, cGMP, and inositol triphosphate (IP3); changes in intracellular calcium levels; neurotransmitter release, conformational assays and the like.

A "flavor or tastant" herein refers to a compound or biologically acceptable salt thereof that induces, in a subject, the perception of smell and/or taste, which include sweet, sour, salty, bitter and umami, and others. The subject can be human, animals, and/or a biological assay, such as the ones described and cited in this application.

A "flavor or taste modifier" herein refers to a compound or biologically acceptable salt thereof that modulates, including enhancing or potentiating, inhibiting, and inducing, the smell and/or tastes of a natural or synthetic tastants in a subject.

A "flavor or taste enhancer" herein refers to a compound or biologically acceptable salt thereof that enhances the tastes or smell of a natural or synthetic

tastants, *e.g.*, monosodium glutamate (MSG) for umami taste and fructose for sweet taste.

"Umami tastant" or "umami compound" herein refers to a compound or biologically acceptable salt thereof that elicits a detectable umami taste in a subject, *e.g.*, MSG.

"Sweet tastant" or "sweet compound" herein refers to a compound or biologically acceptable salt thereof that elicits a detectable sweet taste in a subject, *e.g.*, fructose.

An "umami taste modifier" herein refers to a compound or biologically acceptable salt thereof that modulates, including enhancing or potentiating, inhibiting, and inducing, the umami taste of a natural or synthetic umami tastants, *e.g.*, monosodium glutamate (MSG) in a subject.

A "sweet taste modifier" herein refers to a compound or biologically acceptable salt thereof that modulates, including enhancing or potentiating, inhibiting, and inducing, the sweet taste of a natural or synthetic sweet tastants, *e.g.*, fructose, in a subject.

A "taste enhancing amount" herein refers to an amount of a compound that is sufficient to enhance the taste of a natural or synthetic tastants, *e.g.*, monosodium glutamate (MSG) for umami taste or fructose for sweet taste.

"Wet Soup Category" means wet/liquid soups regardless of concentration or container, including frozen Soups. For the purpose of this definition soup(s) means a food prepared from meat, poultry, fish, vegetables, grains, fruit and other ingredients, cooked in a liquid which may include visible pieces of some or all of these ingredients. It may be clear (as a broth) or thick (as a chowder), smooth, pureed or chunky, ready-to-serve, semi-condensed or condensed and may be served hot or cold, as a first course or as the main course of a meal or as a between meal snack (sipped like a beverage). Soup may be used as an ingredient for preparing other meal components and may range from broths (consommé) to sauces (cream or cheese-based soups).

"Dehydrated and Culinary Food Category" means: (i) Cooking aid products such as: powders, granules, pastes, concentrated liquid products, including concentrated bouillon, bouillon and bouillon like products in pressed cubes, tablets or powder or granulated form, which are sold separately as a finished product or as an ingredient within a product, sauces and recipe mixes (regardless of technology); (ii) Meal

solutions products such as: dehydrated and freeze dried soups, including dehydrated soup mixes, dehydrated instant soups, dehydrated ready-to-cook soups, dehydrated or ambient preparations of ready-made dishes, meals and single serve entrées including pasta, potato and rice dishes; and (iii) Meal embellishment products such as: condiments, marinades, salad dressings, salad toppings, dips, breading, batter mixes, shelf stable spreads, barbecue sauces, liquid recipe mixes, concentrates, sauces or sauce mixes, including recipe mixes for salad, sold as a finished product or as an ingredient within a product, whether dehydrated, liquid or frozen.

"Beverage Category" means beverages, beverage mixes and concentrates, including but not limited to, alcoholic and non-alcoholic ready to drink and dry powdered Other examples of foods and beverages wherein compounds according to the invention may be incorporated included by way of example carbonated and non-carbonated beverages, *e.g.*, sodas, juices, alcoholic and non-alcoholic beverages, confectionary products, *e.g.*, cakes, cookies, pies, candies, chewing gums, gelatins, ice creams, sorbets, puddings, jams, jellies, salad dressings, and other condiments, cereal, and other breakfast foods, canned fruits and fruit sauces and the like.

Additionally, the subject compounds can be used in flavor preparations to be added to foods and beverages. In preferred instances the composition will comprise another flavor or taste modifier such as a sweet tastant.

In some instances biologically acceptable salts of the subject compounds may be used. Examples of such salts include alkali and earth metal salts, organic salts, and the like. Specific examples include potassium, sodium, calcium and magnesium salts, hydrochloric or sulfuric acid salts, ethanolamine salts, and the like. The salt will be selected such that it is biologically safe for ingestion and does adversely affect the sweet taste modulatory properties of the compound.

As used herein, the term "medicinal product" includes both solids and liquids which are ingestible non-toxic materials which have medicinal value such as cough syrups, cough drops, aspirin and chewable medicinal tablets. An oral hygiene product includes solids and liquids such as toothpaste or mouthwash.

A "comestibly or medicinally acceptable carrier or excipient" is a medium that is used to prepare a desired dosage form of the inventive compound. A comestibly or medicinally acceptable carrier includes solvents, diluents, or other liquid vehicle;

dispersion or suspension aids; surface active agents; isotonic agents; thickening or emulsifying agents, preservatives; solid binders; lubricants and the like.

"Inhibitors," "activators," "enhancers" and "modulators" of T1R genes or proteins are used to refer to inhibitory, activating, enhancing or modulating molecules identified using *in vitro* and *in vivo* assays for taste transduction, *e.g.*, ligands, agonists, antagonists, and their homologs and mimetics.

Inhibitors are compounds that, *e.g.*, bind to, partially or totally block stimulation, decrease, prevent, delay activation, inactivate, desensitize, or down regulate taste transduction, *e.g.*, antagonists. Activators and enhancers are compounds that, *e.g.*, bind to, enhance, stimulate, increase, open, activate, facilitate, enhance activation, sensitize, or up regulate taste transduction, *e.g.*, agonists. Modulators include compounds that, *e.g.*, alter the interaction of a receptor with: extracellular proteins that bind activators or inhibitor (*e.g.*, ebnerin and other members of the hydrophobic carrier family); G proteins; kinases (*e.g.*, homologs of rhodopsin kinase and beta adrenergic receptor kinases that are involved in deactivation and desensitization of a receptor); and arrestins, which also deactivate and desensitize receptors. Modulators can include genetically modified versions of T1R family members, *e.g.*, with altered activity, as well as naturally occurring and synthetic ligands, antagonists, agonists, small chemical molecules and the like. Such assays for inhibitors and activators include, *e.g.*, expressing T1R family members in cells or cell membranes, applying putative modulator compounds, in the presence or absence of tastants, *e.g.*, sweet tastants, and then determining the functional effects on taste transduction, as described above. Samples or assays comprising T1R family members that are treated with a potential enhancer, activator, inhibitor, or modulator are compared to control samples without the inhibitor, activator, or modulator to examine the extent of modulation. Positive control samples (e.g. a sweet tastant without added modulators) are assigned a relative T1R activity value of 100%.

"$EC_{50}$" is defined as the amount of a compound that elicits 50% of the maximal response the compound can elicit, whether as an activator, enhancer, or modulator. A dose-dependent response curve was determined for a compound, and the compound concentration corresponding to 50% of the maximal response was derived from the curve, in one example.

"$IC_{50}$" is defined as the amount of a compound that elicits 50% of the maximal effect the compound can elicit as an inhibitor.

Regarding sweet tastants and enhancers, after a compound is identified, scores of their activities are given as percentage of the maximum fructose intensity (%). In compound dose response, an $EC_{50}$ can be calculated to reflect the potency of the compound as a sweet agonist. In the present invention, an $EC_{50}$ of lower than about 100 mM is indicative of compounds that induce T1R2/T1R3 activity as a sweet agonist. Preferably, a positive hit for a sweet agonist has an $EC_{50}$ value of less than about 1 mM; more preferably less than about a 10 μM.

In sweet enhancement assay experiments, a fructose dose response was run and a second fructose dose response was run with a certain amount of candidate compound at every fructose concentrations at the same time. Then, the $EC_{50}$ ratio can be calculated based on the following definitions:

$EC_{50}$ Ratio = $EC_{50}$ (fructose)/$EC_{50}$ (fructose + [Compound])

wherein "[compound]" refers to the concentration of compound used to elicit (or enhance or potentiate) the fructose dose response. Those concentrations could vary from a pM to an mM, more preferred, from a low nM to μM. A potent sweet enhancer would have a high $EC_{50}$ Ratio at a low concentration of the compound used.

In the present invention, an $EC_{50}$ ratio of greater than 1 is indicative of a compound that modulates (potentiates) T1R2/T1R3 activity and is an sweet enhancer. Preferably, a positive hit will have $EC_{50}$ ratio values of at least 1.20, preferably ranging from at least 1.50 to 100 or even higher.

By contrast, competing agonists (those sweet tastants that bind mutually exclusively) or inhibitors always yield values of $EC_{50}$ ratio less than 1, such as from 0-1.

Regarding umami tastants and enhancers, scores of their activities can be given as percentage of the maximum MSG intensity (%). In compound dose response, an $EC_{50}$ can be calculated to reflect the potency of the compound as umami agonist. In the present invention, an $EC_{50}$ of lower than about 10 mM is indicative of compounds that induce T1R1/T1R3 activity and an umami agonist. Preferably, a positive hit for an umami agonist will have $EC_{50}$ values of less than about 1 mM; more preferably ranging from about a pM to about a low μM.

In enhancement assay experiments, a MSG dose response was run and a second MSG dose response was run with a certain amount of candidate compound at every MSG concentrations at the same time. Then, the $EC_{50}$ ratio is calculated based on the following definitions:

$EC_{50}$ Ratio = $EC_{50}$ (MSG)/$EC_{50}$ (MSG + [Compound])

wherein "[compound]" refers to the concentration of compound used to elicit (or enhance or potentiate) the MSG dose response. Those concentrations can vary from a pM to an mM, more preferred, from a low nM to μM. A potent umami enhancer has a high $EC_{50}$ Ratio at a low concentration of the compound used.

In the present invention, an $EC_{50}$ ratio of greater than 1 is indicative of a compound that modulates (potentiates) T1R1/T1R3 activity and in an umami enhancer. Preferably, a positive hit has $EC_{50}$ ratio values of at least 1.20, preferably ranging from at least 1.50 to 100 or even higher.

Negative control samples (e.g. buffer without an added taste stimulus) are assigned a relative T1R activity value of 0%. Inhibition of a T1R is achieved when a mixture of the positive control sample and a modulator result in the T1R activity value relative to the positive control is about 80%, optionally 50% or 25-0%. Activation of a T1R by a modulator alone is achieved when the T1R activity value relative to the positive control sample is 10%, 25%, 50%, 75%, optionally 100%, optionally 150%, optionally 200-500%, or 1000-3000% higher.

The terms "purified," "substantially purified," and "isolated" as used herein refer to the state of being free of other, dissimilar compounds with which the compound of the invention is normally associated in its natural state, so that the "purified," "substantially purified," and "isolated" subject comprises at least 0.5%, 1%, 5%, 10%, or 20%, and most preferably at least 50% or 75% of the mass, by weight, of a given sample. In one preferred embodiment, these terms refer to the compound of the invention comprising at least 95% of the mass, by weight, of a given sample. As used herein, the terms "purified," "substantially purified," and "isolated," when referring to a nucleic acid or protein, also refers to a state of purification or concentration different than that which occurs naturally in the mammalian, especially human body. Any degree of purification or concentration greater than that which occurs naturally in the mammalian, especially human, body, including (1) the purification from other associated structures or compounds or (2) the association with structures or compounds

to which it is not normally associated in the mammalian, especially human, body, are within the meaning of "isolated." The nucleic acid or protein or classes of nucleic acids or proteins, described herein, may be isolated, or otherwise associated with structures or compounds to which they are not normally associated in nature, according to a variety of methods and processes known to those of skill in the art.

The term "nucleic acid" or "nucleic acid sequence" refers to a deoxy-ribonucleotide or ribonucleotide oligonucleotide in either single- or double-stranded form. The term encompasses nucleic acids, i.e., oligonucleotides, containing known analogs of natural nucleotides. The term also encompasses nucleic-acid-like structures with synthetic backbones (*see e.g.*, *Oligonucleotides and Analogues, a Practical Approach*, ed. F. Eckstein, Oxford Univ. Press (1991); Antisense Strategies, *Annals of the N.Y. Academy of Sciences*, Vol. 600, Eds. Baserga *et al.* (NYAS 1992); Milligan *J. Med. Chem.* 36:1923-1937 (1993); *Antisense Research and Applications* (1993, CRC Press), WO 97/03211; WO 96/39154; Mata, *Toxicol. Appl. Pharmacol.* 144:189-197 (1997); Strauss-Soukup, *Biochemistry* 36:8692-8698 (1997); Samstag, *Antisense Nucleic Acid Drug Dev*, 6:153-156 (1996)).

Unless otherwise indicated, a particular nucleic acid sequence also implicitly encompasses conservatively modified variants thereof (*e.g.*, degenerate codon substitutions) and complementary sequences, as well as the sequence explicitly indicated. Specifically, degenerate codon substitutions may be achieved by generating, *e.g.*, sequences in which the third position of one or more selected codons is substituted with mixed-base and/or deoxyinosine residues (Batzer *et al.*, *Nucleic Acid Res.*, 19:5081 (1991); Ohtsuka *et al.*, *J. Biol. Chem.*, 260:2605-2608 (1985); Rossolini *et al.*, *Mol. Cell. Probes*, 8:91-98 (1994)). The term nucleic acid is used interchangeably with gene, cDNA, mRNA, oligonucleotide, and polynucleotide.

The terms "polypeptide," "peptide" and "protein" are used interchangeably herein to refer to a polymer of amino acid residues. The terms apply to amino acid polymers in which one or more amino acid residue is an artificial chemical mimetic of a corresponding naturally occurring amino acid, as well as to naturally occurring amino acid polymers and non-naturally occurring amino acid polymer.

The term "plasma membrane translocation domain" or simply "translocation domain" means a polypeptide domain that, when incorporated into a polypeptide coding sequence, can with greater efficiency "chaperone" or "translocate" the hybrid

("fusion") protein to the cell plasma membrane than without the domain. For instance, a "translocation domain" may be derived from the amino terminus of the bovine rhodopsin receptor polypeptide, a 7-transmembrane receptor. However, rhodopsin from any mammal may be used, as can other translocation facilitating sequences. Thus, the translocation domain is particularly efficient in translocating 7-transmembrane fusion proteins to the plasma membrane, and a protein (*e.g.*, a taste receptor polypeptide) comprising an amino terminal translocating domain will be transported to the plasma membrane more efficiently than without the domain. However, if the N-terminal domain of the polypeptide is active in binding, as with the T1R receptors of the present invention, the use of other translocation domains may be preferred. For instance, a PDZ domain-interacting peptide, as described herein, may be used.

The "translocation domain," "ligand-binding domain", and chimeric receptors compositions described herein also include "analogs," or "conservative variants" and "mimetics" ("peptidomimetics") with structures and activity that substantially correspond to the exemplary sequences. Thus, the terms "conservative variant" or "analog" or "mimetic" refer to a polypeptide which has a modified amino acid sequence, such that the change(s) do not substantially alter the polypeptide's (the conservative variant's) structure and/or activity, as defined herein. These include conservatively modified variations of an amino acid sequence, *i.e.*, amino acid substitutions, additions or deletions of those residues that are not critical for protein activity, or substitution of amino acids with residues having similar properties (*e.g.*, acidic, basic, positively or negatively charged, polar or non-polar, *etc.*) such that the substitutions of even critical amino acids does not substantially alter structure and/or activity.

More particularly, "conservatively modified variants" applies to both amino acid and nucleic acid sequences. With respect to particular nucleic acid sequences, conservatively modified variants refers to those nucleic acids which encode identical or essentially identical amino acid sequences, or where the nucleic acid does not encode an amino acid sequence, to essentially identical sequences. Because of the degeneracy of the genetic code, a large number of functionally identical nucleic acids encode any given protein.

For instance, the codons GCA, GCC, GCG and GCU all encode the amino acid alanine. Thus, at every position where an alanine is specified by a codon, the codon can

be altered to any of the corresponding codons described without altering the encoded polypeptide.

Such nucleic acid variations are "silent variations," which are one species of conservatively modified variations. Every nucleic acid sequence herein, which encodes a polypeptide, also describes every possible silent variation of the nucleic acid. One of skill will recognize that each codon in a nucleic acid (except AUG, which is ordinarily the only codon for methionine, and TGG, which is ordinarily the only codon for tryptophan) can be modified to yield a functionally identical molecule. Accordingly, each silent variation of a nucleic acid, which encodes a polypeptide, is implicit in each described sequence.

Conservative substitution tables providing functionally similar amino acids are well known in the art. For example, one exemplary guideline to select conservative substitutions includes (original residue followed by exemplary substitution): ala/gly or ser; arg/lys; asn/gln or his; asp/glu; cys/ser; gln/asn; gly/asp; gly/ala or pro; his/asn or gln; ile/leu or val; leu/ile or val; lys/arg or gln or glu; met/leu or tyr or ile; phe/met or leu or tyr; ser/thr; thr/ser; trp/tyr; tyr/trp or phe; val/ile or leu. An alternative exemplary guideline uses the following six groups, each containing amino acids that are conservative substitutions for one another: 1) Alanine (A), Serine (S), Threonine (T); 2) Aspartic acid (D), Glutamic acid (E); 3) Asparagine (N), Glutamine (Q); 4) Arginine (R), Lysine (I); 5) Isoleucine (I), Leucine (L), Methionine (M), Valine (V); and 6) Phenylalanine (F), Tyrosine (Y), Tryptophan (W); (*see also, e.g.*, Creighton, *Proteins*, W.H. Freeman and Company (1984); Schultz and Schimer, *Principles of Protein Structure*, Springer-Vrlag (1979)). One of skill in the art will appreciate that the above-identified substitutions are not the only possible conservative substitutions. For example, for some purposes, one may regard all charged amino acids as conservative substitutions for each other whether they are positive or negative. In addition, individual substitutions, deletions or additions that alter, add or delete a single amino acid or a small percentage of amino acids in an encoded sequence can also be considered "conservatively modified variations."

The terms "mimetic" and "peptidomimetic" refer to a synthetic chemical compound that has substantially the same structural and/or functional characteristics of the polypeptides, *e.g.*, translocation domains, ligand-binding domains, or chimeric receptors of the invention. The mimetic can be either entirely composed of synthetic,

non-natural analogs of amino acids, or may be a chimeric molecule of partly natural peptide amino acids and partly non-natural analogs of amino acids. The mimetic can also incorporate any amount of natural amino acid conservative substitutions as long as such substitutions also do not substantially alter the mimetic's structure and/or activity.

As with polypeptides of the invention which are conservative variants, routine experimentation will determine whether a mimetic is within the scope of the invention, *i.e.*, that its structure and/or function is not substantially altered. Polypeptide mimetic compositions can contain any combination of non-natural structural components, which are typically from three structural groups: a) residue linkage groups other than the natural amide bond ("peptide bond") linkages; b) non-natural residues in place of naturally occurring amino acid residues; or c) residues which induce secondary structural mimicry, i.e., to induce or stabilize a secondary structure, *e.g.*, a beta turn, gamma turn, beta sheet, alpha helix conformation, and the like. A polypeptide can be characterized as a mimetic when all or some of its residues are joined by chemical means other than natural peptide bonds. Individual peptidomimetic residues can be joined by peptide bonds, other chemical bonds or coupling means, such as, *e.g.*, glutaraldehyde, N-hydroxysuccinimide esters, bifunctional maleimides, N,N'-dicyclohexylcarbodiimide (DCC) or N,N'-diisopropylcarbodiimide (DIC). Linking groups that can be an alternative to the traditional amide bond ("peptide bond") linkages include, *e.g.*, ketomethylene (*e.g.*, -C(=O)-$CH_2$- for -C(=O)-NH-), aminomethylene ($CH_2$-NH), ethylene, olefin (CH=CH), ether ($CH_2$-O), thioether ($CH_2$-S), tetrazole ($CN_4$), thiazole, retroamide, or ester (*see, e.g.*, Spatola, *Chemistry and Biochemistry of Amino Acids, Peptides and Proteins*, Vol. 7, pp 267-357, "Peptide Backbone Modifications," Marcell Dekker, NY (1983)). A polypeptide can also be characterized as a mimetic by containing all or some non-natural residues in place of naturally occurring amino acid residues; non-natural residues are well described in the scientific and patent literature.

A "label" or a "detectable moiety" is a composition detectable by spectroscopic, photochemical, biochemical, immunochemical, or chemical means. For example, useful labels include $^{32}P$, fluorescent dyes, electron-dense reagents, enzymes (*e.g.*, as commonly used in an ELISA), biotin, digoxigenin, or haptens and proteins which can be made detectable, *e.g.*, by incorporating a radiolabel into the peptide or used to detect antibodies specifically reactive with the peptide.

A "labeled nucleic acid probe or oligonucleotide" is one that is bound, either covalently, through a linker or a chemical bond, or noncovalently, through ionic, van der Waals, electrostatic, or hydrogen bonds to a label such that the presence of the probe may be detected by detecting the presence of the label bound to the probe.

As used herein a "nucleic acid probe or oligonucleotide" is defined as a nucleic acid capable of binding to a target nucleic acid of complementary sequence through one or more types of chemical bonds, usually through complementary base pairing, usually through hydrogen bond formation. As used herein, a probe may include natural (i.e., A, G, C, or T) or modified bases (7-deazaguanosine, inosine, *etc.*). In addition, the bases in a probe may be joined by a linkage other than a phosphodiester bond, so long as it does not interfere with hybridization. Thus, for example, probes may be peptide nucleic acids in which the constituent bases are joined by peptide bonds rather than phosphodiester linkages. It will be understood by one of skill in the art that probes may bind target sequences lacking complete complementarity with the probe sequence depending upon the stringency of the hybridization conditions. The probes are optionally directly labeled as with isotopes, chromophores, lumiphores, chromogens, or indirectly labeled such as with biotin to which a streptavidin complex may later bind. By assaying for the presence or absence of the probe, one can detect the presence or absence of the select sequence or subsequence.

The term "heterologous" when used with reference to portions of a nucleic acid indicates that the nucleic acid comprises two or more subsequences that are not found in the same relationship to each other in nature. For instance, the nucleic acid is typically recombinantly produced, having two or more sequences from unrelated genes arranged to make a new functional nucleic acid, *e.g.*, a promoter from one source and a coding region from another source. Similarly, a heterologous protein indicates that the protein comprises two or more subsequences that are not found in the same relationship to each other in nature (*e.g.*, a fusion protein).

A "promoter" is defined as an array of nucleic acid sequences that direct transcription of a nucleic acid. As used herein, a promoter includes necessary nucleic acid sequences near the start site of transcription, such as, in the case of a polymerase II type promoter, a TATA element. A promoter also optionally includes distal enhancer or repressor elements, which can be located as much as several thousand base pairs

from the start site of transcription. A "constitutive"promoter is a promoter that is active under most environmental and developmental conditions.

An "inducible" promoter is a promoter that is active under environmental or developmental regulation. The term "operably linked" refers to a functional linkage between a nucleic acid expression control sequence (such as a promoter, or array of transcription factor binding sites) and a second nucleic acid sequence, wherein the expression control sequence directs transcription of the nucleic acid corresponding to the second sequence.

As used herein, "recombinant" refers to a polynucleotide synthesized or otherwise manipulated *in vitro* (*e.g.*, "recombinant polynucleotide"), to methods of using recombinant polynucleotides to produce gene products in cells or other biological systems, or to a polypeptide ("recombinant protein") encoded by a recombinant polynucleotide. "Recombinant means" also encompass the ligation of nucleic acids having various coding regions or domains or promoter sequences from different sources into an expression cassette or vector for expression of, *e.g.*, inducible or constitutive expression of a fusion protein comprising a translocation domain of the invention and a nucleic acid sequence amplified using a primer of the invention.

As used herein, a "stable cell line" refers to a cell line, which stably, i.e. over a prolonged period, expresses a heterologous nucleic sequence, i.e. a T1R or G protein. In preferred embodiments, such stable cell lines will be produced by transfecting appropriate cells, typically mammalian cells, e.g. HEK-293 cells, with a linearized vector that contains a T1R expression construct, i.e. T1R1, T1R2 and/or T1R3. Most preferably, such stable cell lines will be produced by co-transfecting two linearized plasmids that express hT1R1 and hT1R3 or hT1R2 and hT1R3 and an appropriate selection procedure to generate cell lines having these genes stably integrated therein. Most preferably, the cell line will also stably express a G protein such as $G_{\alpha 15}$.

The phrase "selectively (or specifically) hybridizes to" refers to the binding, duplexing, or hybridizing of a molecule only to a particular nucleotide sequence under stringent hybridization conditions when that sequence is present in a complex mixture (*e.g.*, total cellular or library DNA or RNA).

The phrase "stringent hybridization conditions" refers to conditions under which a probe will hybridize to its target subsequence, typically in a complex mixture of nucleic acid, but to no other sequences. Stringent conditions are sequence dependent

and will be different in different circumstances. Longer sequences hybridize specifically at higher temperatures. An extensive guide to the hybridization of nucleic acids is found in Tijssen, *Techniques in Biochemistry and Molecular Biology - Hybridization with Nucleic Probes*, "Overview of principles of hybridization and the strategy of nucleic acid assays" (1993). Generally, stringent conditions are selected to be about 5-10° C lower than the thermal melting point (Tm) for the specific sequence at a defined ionic strength pH. The Tm is the temperature (under defined ionic strength, pH, and nucleic concentration) at which 50% of the probes complementary to the target hybridize to the target sequence at equilibrium (as the target sequences are present in excess, at Tm, 50% of the probes are occupied at equilibrium). Stringent conditions will be those in which the salt concentration is less than about 1.0 M sodium ion, typically about 0.01 to 1.0 M sodium ion concentration (or other salts) at pH 7.0 to 8.3 and the temperature is at least about 30° C for short probes (*e.g.*, 10 to 50 nucleotides) and at least about 60° C for long probes (*e.g.*, greater than 50 nucleotides). Stringent conditions may also be achieved with the addition of destabilizing agents such as formamide. For selective or specific hybridization, a positive signal is at least two times background, optionally 10 times background hybridization. Exemplary stringent hybridization conditions can be as following: 50% formamide, 5x SSC, and 1% SDS, incubating at 42°C, or, 5x SSC, 1% SDS, incubating at 65°C, with wash in 0.2x SSC, and 0.1 % SDS at 65°C. Such hybridizations and wash steps can be carried out for, *e.g.*, 1, 2, 5, 10, 15, 30, 60; or more minutes.

Nucleic acids that do not hybridize to each other under stringent conditions are still substantially related if the polypeptides that they encode are substantially related. This occurs, for example, when a copy of a nucleic acid is created using the maximum codon degeneracy permitted by the genetic code. In such cases, the nucleic acids typically hybridize under moderately stringent hybridization conditions. Exemplary "moderately stringent hybridization conditions" include a hybridization in a buffer of 40% formamide, 1 M NaCI, 1% SDS at 37°C, and a wash in 1X SSC at 45°C. Such hybridizations and wash steps can be carried out for, *e.g.*, 1, 2, 5, 10, 15, 30, 60, or more minutes. A positive hybridization is at least twice background. Those of ordinary skill will readily recognize that alternative hybridization and wash conditions can be utilized to provide conditions of similar stringency.

"Antibody" refers to a polypeptide comprising a framework region from an immunoglobulin gene or fragments thereof that specifically binds and recognizes an antigen. The recognized immunoglobulin genes include the kappa, lambda, alpha, gamma, delta, epsilon, and mu constant region genes, as well as the myriad immunoglobulin variable region genes. Light chains are classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, which in turn define the immunoglobulin classes, IgG, IgM, IgA, IgD and IgE, respectively.

An exemplary immunoglobulin (antibody) structural unit comprises a tetramer. Each tetramer is composed of two identical pairs of polypeptide chains, each pair having one "light" (about 25 kDa) and one "heavy" chain (about 50-70 kDa). The N-terminus of each chain defines a variable region of about 100 to 110 or more amino acids primarily responsible for antigen recognition. The terms "variable light chain" (VL) and "variable heavy chain" (VH) refer to these light and heavy chains respectively.

A "chimeric antibody" is an antibody molecule in which (a) the constant region, or a portion thereof, is altered, replaced or exchanged so that the antigen binding site (variable region) is linked to a constant region of a different or altered class, effector function and/or species, or an entirely different molecule which confers new properties to the chimeric antibody, *e.g.*, an enzyme, toxin, hormone, growth factor, drug, *etc.*; or (b) the variable region, or a portion thereof, is altered, replaced or exchanged with a variable region having a different or altered antigen specificity.

An "anti-T1R" antibody is an antibody or antibody fragment that specifically binds a polypeptide encoded by a T1R gene, cDNA, or a subsequence thereof.

The term "immunoassay" is an assay that uses an antibody to specifically bind an antigen. The immunoassay is characterized by the use of specific binding properties of a particular antibody to isolate, target, and/or quantify the antigen.

The phrase "specifically (or selectively) binds" or "specifically (or selectively) reacts with," when referring to a molecule or composition, refers to a binding reaction that is determinative of the presence of the molecule in a heterogeneous population of other biologics. Thus, under designated conditions, the specified molecules bind to a particular receptor at least two times the background and do not substantially bind in a significant amount to other molecules present in the sample. Specific binding to a

receptor under such conditions may require a receptor that is selected for its specificity for a particular molecule.

Regarding antibodies, a variety of immunoassay formats may be used to select antibodies specifically immunoreactive with a particular protein. For example, solid-phase ELISA immunoassays are routinely used to select antibodies specifically immunoreactive with a protein (*see, e.g.*, Harlow & Lane, *Antibodies, A Laboratory Manual*, (1988), for a description of immunoassay formats and conditions that can be used to determine specific immunoreactivity). Typically a specific or selective reaction will be at least twice background signal or noise and more typically more than 10 to 100 times background.

The phrase "selectively associates with" refers to the ability of a nucleic acid to "selectively hybridize" with another as defined above, or the ability of an antibody to "selectively (or specifically) bind to a protein, as defined above.

The term "expression vector" refers to any recombinant expression system for the purpose of expressing a nucleic acid sequence of the invention *in vitro* or *in vivo*, constitutively or inducibly, in any cell, including prokaryotic, yeast, fungal, plant, insect or mammalian cell. The term includes linear or circular expression systems. The term includes expression systems that remain episomal or integrate into the host cell genome. The expression systems can have the ability to self-replicate or not, i.e., drive only transient expression in a cell. The term includes recombinant expression "cassettes which contain only the minimum elements needed for transcription of the recombinant nucleic acid.

By "host cell" is meant a cell that contains an expression vector and supports the replication or expression of the expression vector. Host cells may be prokaryotic cells such as E. coli, or eukaryotic cells such as yeast, insect, amphibian, worm or mammalian cells such as CHO, Hela, HEK-293, and the like, *e.g.*, cultured cells, explants, and cells *in vivo*.

**Compounds**

As discussed above, there are different domains on the T1R receptors. T1R1, T1R2, and T1R3 each contain an N-terminal extracellular domain (also known as the Venus flytrap domain), transmembrane domains comprising seven transmembrane regions, and corresponding cytoplasmic, and extracellular loops; a cysteine rich

domain, and a C-terminal domain. Each region defines a specific set of compounds that bind specifically to that region.

In humans, the N-terminal extracellular domain comprises amino acids 1 to 560 of hT1R2 and amino acids 1 to 563 of hT1R3. In rats, the N-terminal extracellular domain comprises amino acids 1 to 564 of rT1R2, and amino acids 1 to 568 of rT1R3.

In humans, the C-terminal transmembrane domain and intracellular domain comprise amino acids 561 to 839 of hT1R2, and amino acids 564 to 852 of hT1R3. In rats, the C-terminal transmembrane domain and intracellular domain comprise amino acids 565 to 842 of rT1R2, and amino acids 569 to 858 of rT1R3.

Metabotropic glutamate receptors (mGluR) are another class of C-class G protein-coupled receptors that respond to glutamate. These are found primarily in the brain and neuronal tissue where they play a role in neuronal signaling. The mGluR N-terminal extracellular domain can be covalently linked to a T1R in order to create chimeric receptors. The mGluR receptor can be any of mGluR1-mGluR8, for example. Different ligands bind to different domains on different subunits of both the umami and the sweet receptors. For example, aspartame and neotame bind to the N-terminal extracellular domain of T1R2, while cyclamate, neohesperidin dihydrochalcone (NHDC), and lactisole bind to the transmembrane domain of T1R3. Because T1R3 is one of the two subunits in the T1R1/T1R3 umami taste receptor, cyclamate, NHDC and lactisole can interact with T1R3 in the T1R1/T1R3 umami taste receptor as well. Cyclamate and NHDC enhance the activity of the umami taste receptor, while lactisole inhibits the umami receptor.

The specific binding compounds of the invention as it relates to umami tastants comprise amides. The amide compounds also comprise certain sub-classes of amide derivatives or classes of derivatives related to amides, such as for example ureas, urethanes, oxalamides, acrylamides, and the like.

Molecules that interact with the transmembrane domain of T1R2, for example, can be modulators of sweet taste, and molecules that interact with the transmembrane domain of T1R3 can be modulators of sweet taste and/or umami taste.

Human T1R2/T1R3 recognizes a group of sweeteners which are not recognized by rat T1R2/T1R3, and human but not rat T1R2/T1R3 is inhibited by lactisole. When the extracellular domain of human T1R2 was replaced by its rat counterpart, the human

receptor lost the ability to recognize aspartame, indicating that this part of human T1R2 is required for binding to aspartame. Inversely, when the extracellular domain of rat T1R2 was replaced by its human counterpart, the rat receptor acquired the ability to recognize aspartame, indicating that this part of the human T1R2 is sufficient to bind aspartame. By the same principle, the transmembrane domain of human T1R3 was required and sufficient for

Table 6 shows the abbreviations used to represent various rat/human chimeric receptors and receptor subunits.

TABLE 6

| |
|---|
| hT1R2 – human T1R2 |
| hT1R3 – human T1R3 |
| rT1R2 – rat T1R2 |
| rT1R3 – rat T1R3 |
| hT1R2/rT1R3 – a receptor composed of human T1R2 and rat T1R3 |
| rT1R2/hT1R3 - a receptor composed of a rat T1R2 and human T1R3 |
| hT1R2/h3-r3 – a receptor composed of human T1R2 and a chimeric T1R3 with human N-terminal extracellular domain and rat transmembrane and C-terminal domain |
| rT1R2/r3-h3 – a receptor composed of rat T1R2 and a chimeric T1R3 with rat N-terminal extracellular domain and human transmembrane and C-terminal domain |
| h2-r2/rT1R3 – a receptor composed of a chimeric T1R2 with human N-terminal extracellu domain and rat transmembrane and C-terminal domain and rat T1R3 |
| r2-h2/rT1R3 – a receptor composed of a chimeric T1R2 with rat N-terminal extracellular domain and human transmembrane and C-terminal domain and rat T1R3 |
| h2-h1/hT1R3 – a receptor composed of a chimeric T1R with human T1R2 N-terminal extracellular domain and human T1R1 transmembrane and C-terminal domain and hum T1R3 |
| h1-h2/hT1R3 – a receptor composed of a chimeric T1R with human T1R1 N-terminal extracellular domain and human T1R2 transmembrane and C-terminal domain and hum T1R3 |
| h2-mGluR1/h3-mGluR1 – a receptor composed of a N-terminal extracellular domain from hT1R2 covalently linked to the transmembrane and C-terminal domain of mGluR1 and N-terminal extracellular domain from hT1R3 covalently linked to the transmembrane an C-terminal domain of mGluR1 |
| h1-mGluR/h3-mGluR1 – a receptor composed of a N-terminal extracellular domain from hT1R1 covalently linked to the transmembrane and C-terminal domain of mGluR1and a N-terminal extracellular domain from hT1R3 covalently linked to the transmembrane an |

| |
|---|
| C-terminal domain of mGluR1 |
| mGluR1-h2/mGluR1-h3 – a receptor composed of a N-terminal extracellular domain from mGluR1 covalently linked to the transmembrane and C-terminal domain of hT1R2 and a N-terminal extracellular domain from a mGluR1 covalently linked to the transmembrane and C-terminal domain of hT1R3 |
| mGluR1-h1/mGluR1-h3 – receptor composed of a N-terminal extracellular domain from mGluR1 covalently linked to the transmembrane and C-terminal domain of hT1R1 and a N-terminal extracellular domain from mGluR1 covalently linked to the transmembrane and C-terminal domain of hT1R3 |

Disclosed herein are non-naturally occurring compounds that specifically bind to the T1R2/T1R3 receptor comprising hT1R2/hT1R3 but not rT1R2/rT1R3. Examples of such compounds include, but are not limited to neotame, aspartame, cyclamate, lactisol, Compound 883360, Compound 6542888, Compound 403249, Compound 6364395, Dihydroxybenzoic acid (DHB), Compound 6542888, and neohesperidine dihydrochalcone (NHDC) Additional examples are found in Tables 1-4. The organic, non-peptide compounds can be approximately the size of a box of dimensions 15x8x8 angstroms, more preferably the dimension should be 12x5x5 angstroms.

Also disclosed are compounds that specifically bind to a T1R2/T1R3 receptor comprising hT1R2/rT1R3 but not rT1R2/hT1R3. Examples of such compounds include, but are not limited to aspartame, and neotame. Additional examples are found in Table 5.

Also disclosed are compounds that specifically bind to the N-terminal extracellular domain of T1R2 of the hT1R2/hT1R3 receptor. Examples of such compounds include, but are not limited to neotame, aspartame carbohydrate sugars (e.g. sucrose, fructose, glucose, tagatose, erythritol, sorbitol, maltose, xylitol, lactose and galactose, as well as all other carbohydrate sugars). Additional examples are found in Table 5.

Also disclosed are compounds that specifically bind to the Venus Flytrap Domain (VFD) of T1R2 of the hT1R2/hT1R3 and hT1R2/rT1R3 receptor.

Also disclosed are compounds that specifically bind to the N-terminal Venus flytrap domain of the T1R2 subunit of the T1R2/T1R3 receptor. More specifically, also disclosed are compounds that specifically bind to amino acid residues 144 and 302 of the human N-terminal Venus flytrap domain of the T1R2 subunit of theT1R2/T1R3

receptor. Examples of such compounds include, but are not limited to aspartame, neotame, carbohydrates, and sweet amino acids, such as D-Trp, Ala, and Gly.

Also disclosed are compounds that specifically bind to the cysteine-rich region of T1R2 of the hT1R2/hT1R3 receptor. Also disclosed are compounds that specifically bind to the Transmembrane Domain (TM) of T1R2 of the hT1R2/hT1R3 receptor.

Also disclosed are compounds that specifically bind to a T1R2/T1R3 receptor comprising rT1R2/hT1R3 but not hT1R2/rT1R3. Examples of such compounds include, but are not limited to cyclamate, NHDC, lactisole, Compound 883360, Compound 403249, and Compound 6364395. Additional examples are found in Table 5.

Also disclosed are compounds that specifically bind to hT1R2/hT1R3 and rT1R2/r3-h3 but not to rT1R2/rT1R3 or to hT1R2/h3-r3. Examples of such compounds include, but are not limited to cyclamate, NHDC, lactisole, Compound 883360, Compound 403249 and Compound 6364395.

Also disclosed are compounds that specifically bind to extracellular loop 2 and extracellular loop 3 of the human C-terminal domain of the T1R3 subunit of theT1R2/T1R3 receptor. Also disclosed are compounds that specifically bind to hT1R2/hT1R3 and r2-h2/rT1R3 but not to rT1R2/rT1R3 or to h2-r2/hT1R3.

Also disclosed are compounds that specifically bind to the human N-terminal extracellular domain of the T1R3 subunit of the T1R2/T1R3 receptor. Also disclosed are compounds that specifically bind to the Venus Flytrap Domain (VFD) of T1R3 of the hT1R2/hT1R3 receptor. Examples of such compounds include, but are not limited to aspartame, neotame, carbohydrates, and sweet amino acids, such as D-Trp, Ala, and Gly.

Also disclosed are compounds that specifically bind to the Transmembrane Domain of T1R3 of the hT1R2/hT1R3 receptor. Also disclosed are compounds that specifically bind to extracellular loop 2 and extracellular loop 3 of the human transmembrane domain of the T1R3 subunit of T1R2/T1R3. Examples of such compounds include, but are not limited to cyclamate.

The compound of the invention does not include sucrose, fructose, glucose, erythritol, isomalt, lactitol, mannitol, sorbitol, xylitol, certain known natural terpenoids, flavonoids, or protein sweeteners, di-peptides, tri-peptides, aspartame, saccharin, sucralose, halogenated saccharides, acesulfame-K, cyclamate, sucralose, and alitame.

neotame, perillartine, SC-45647, SC-40014, monellin, NC-002740-01, thaumatin, CC-00100, NC-00420, alitame, SC-44102, dulcin, NC-00576, slycyrrhizic Acid, stevioside, Na-Saccharin, D-tryptophan, cyclamate, DHB, glycolic Acid, glycine, D (-)fructose, homofuronol, D (-) tagatose, maltose, D (+) glucose, D-sorbitol, D (+) galactose, α-lactose, L()fructose, L (+) Compound 403249, and glucose.

Optionally, a compound of the invention is also not Compound 6364395.

Also disclosed herein are compounds that bind a truncated region of a T1R domain. For example, disclosed are compounds that specifically bind to the TM domain of T1R2 of a truncated sweet receptor comprising h2TM/h3TM, compounds that specifically bind to the TM domain of T1R3 of a truncated sweet receptor comprising h2TM/h3TM, compounds that specifically bind to the TM domain of T1R2 of a chimeric receptor comprising mGluR-h2/mGluR-h3, compounds that specifically bind to the TM domain of T1R3 of a chimeric receptor comprising mGluR-h2/mGluR-h3, compounds that binds to the TM domain of T1R1 of a truncated savory receptor comprising h1TM/h3TM, compound that binds to the TM domain of T1R3 of a truncated sweet receptor comprising h1TM/h3TM, compounds that bind to the TM domain of T1R1 of a chimeric receptor comprising mGluR-h1/mGluR-h3, and compounds that bind to the TM domain of T1R3 of a chimeric receptor comprising mGluR-h1/mGluR-h3. SEQ ID NOS: 29-33 represent these truncated receptors.

The compounds of the invention do not include monosodium glutamate ("MSG"), inosine monophosphate (IMP) or guanosine monophosphate (GMP), sucrose, fructose, glucose, erythritol, isomalt, lactitol, mannitol, sorbitol, xylitol, certain known natural terpenoids, flavonoids, or protein sweeteners, di-peptides, tri-peptides aspartame, saccharin, sucralose, halogenated saccharides, acesulfame-K, cyclamate, sucralose, alitame, monosodium glutamate ("MSG"), inosine monophosphate (IMP) or guanosine monophosphate (GMP), or adenosine monophospate.

Compound 403249 is (5-(4H-benzo[d][1,3]oxathiin-2-yl)-2-methyoxyphenol, while Compound 6364395 is 3-(3-hydroxy-4-methoxyphenethyl)benzo[d]isoxyazole-4,6-diol.

The compounds described above can demonstrate a compound-dependent increase in fluorescence with an activity compared to the maximal activity for fructose of at least 25% in a fluorescence-based assay using a FLIPR instrument (Fluorometric Intensity Plate Reader, Molecular Devices, Sunnyvale, CA). For examples of this

protocol, see Examples 12 and 18. The compounds can also demonstrate a compound-dependent decrease in the EC50 for a sweetener by at least two-fold in a fluorescence-based assay using a FLIPR (Molecular Devices) instrument. Furthermore, in a cell-based assay, the compound can result in at least 10 out of 100 cells transfected with wild-type or chimeric receptor showing a compound-dependent increase in fluorescence. An example of a cell-based assay can be found in Example 24. The compound can also demonstrate a compound-dependent increase of at least 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, two-fold or greater, or any number in between, in the number of fluorescent cells in response to a sub-maximal level of a sweetener. The response can be measured by fluorescence, calcium levels, IP3 levels, cAMP levels, GTPγS binding, or reporter gene activity (e.g. luciferase, beta-galactosidase).

Furthermore, the compounds disclosed herein can have one or more of the following characteristics in a cell: a decreased $EC_{50}$ compared to a control of at least approximately 50%, increased intracellular $Ca^{2+}$ level by at least approximately 25%, increased intracellular cAMP by at least approximately 25%, increased intracellular cGMP by at least approximately 25%, increased intracellular $IP_3$ by at least approximately 25%, or increased G protein binding of GTPγS by at least approximately 25%.

***Methods of Using the Compounds***

Also disclosed are methods modulating the savory taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a savory flavor modulating amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product; thereby modulating the savory taste of a comestible or medicinal product.

Also disclosed are methods for inhibiting the savory taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a savory flavor inhibiting amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as

to form a modified comestible or medicinal product; thereby inhibiting the savory taste of a comestible or medicinal product.

Also disclosed are methods for increasing the savory taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a savory flavor increasing amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product; thereby increasing the savory taste of a comestible or medicinal product.

Also disclosed are methods for modulating the sweet taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a sweet flavor modulating amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product; thereby modulating the sweet taste of a comestible or medicinal product.

Also disclosed are methods for inhibiting the sweet taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a sweet flavor inhibiting amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product; thereby inhibiting the sweet taste of a comestible or medicinal product.

Also disclosed are methods for increasing the sweet taste of a comestible or medicinal product comprising providing at least one comestible or medicinal product, or a precursor thereof, and combining the comestible or medicinal product or precursor thereof with at least a sweet flavor increasing amount of at least one non-naturally occurring compound as disclosed herein, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product; thereby increasing the sweet taste of a comestible or medicinal product.

Also disclosed are methods of enhancing umami taste perception comprising contacting an umami receptor with cyclamate and NHDC, and their derivatives, as well

as methods of enhancing umami taste perception comprising contacting an umami receptor with lactisole derivatives. Also disclosed are methods of enhancing sweet taste perception comprising contacting an sweet receptor with cyclamate and NHDC, and their derivatives. Also disclosed are methods of enhancing sweet taste perception comprising contacting an sweet receptor with lactisole derivatives.

***Isolation and Expression of T1R Polypeptides***

Isolation and expression of the T1Rs, or fragments or variants thereof, of the invention can be performed as described below. PCR primers can be used for the amplification of nucleic acids encoding taste receptor ligand-binding regions, and libraries of these nucleic acids can optionally be generated. Individual expression vectors or libraries of expression vectors can then be used to infect or transfect host cells for the functional expression of these nucleic acids or libraries. These genes and vectors can be made and expressed *in vitro* or *in vivo*. One of skill will recognize that desired phenotypes for altering and controlling nucleic acid expression can be obtained by modulating the expression or activity of the genes and nucleic acids (*e.g.*, promoters, enhancers and the like) within the vectors of the invention. Any of the known methods described for increasing or decreasing expression or activity can be used. The invention can be practiced in conjunction with any method or protocol known in the art, which are well described in the scientific and patent literature.

The nucleic acid sequences of the invention and other nucleic acids used to practice this invention, whether RNA, cDNA, genomic DNA, vectors, viruses or hybrids thereof, may be isolated from a variety of sources, genetically engineered, amplified, and/or expressed recombinantly. Any recombinant expression system can be used, including, in addition to mammalian cells, *e.g.*, bacterial, yeast, insect, or plant systems.

Alternatively, these nucleic acids can be synthesized *in vitro* by well-known chemical synthesis techniques, as described in, *e.g.*, Carruthers, *Cold Spring Harbor Symp. Quant. Biol.* 47:411-418 (1982); Adams, *Am. Chem. Soc.* 105:661 (1983); Belousov, *Nucleic Acids Res.* 25:3440-3444 (1997); Frenkel, *Free Radic. Biol. Med.* 19:373-380 (1995); Blommers, *Biochemistry* 33:7886-7896 (1994); Narang, *Meth. Enzymol.* 68:90 (1979); Brown, *Meth. Enzymol.* 68:109 (1979); Beaucage, *Tetra. Lett.* 22:1859 (1981); U.S. Patent No. 4,458,066. Double-stranded DNA fragments may

then be obtained either by synthesizing the complementary strand and annealing the strands together under appropriate conditions, or by adding the complementary strand using DNA polymerase with an appropriate primer sequence.

Techniques for the manipulation of nucleic acids, such as, for example, for generating mutations in sequences, subcloning, labeling probes, sequencing, hybridization and the like are well described in the scientific and patent literature. *See, e.g.*, Sambrook, ed., Molecular Cloning: a Laboratory manual (2nd ed.), Vols. 1-3, Cold Spring Harbor Laboratory (1989); Current Protocols in Molecular Biology, Ausubel, ed. John Wiley & Sons, Inc., New York (1997); Laboratory Techniques in Biochemistry and Molecular Biology: Hybridization With Nucleic Acid Probes, Part I, Theory and Nucleic Acid Preparation, Tijssen, ed. Elsevier, N.Y. (1993).

Nucleic acids, vectors, capsids, polypeptides, and the like can be analyzed and quantified by any of a number of general means well known to those of skill in the art. These include, *e.g.*, analytical biochemical methods such as NMR, spectrophotometry, radiography, electrophoresis, capillary electrophoresis, high performance liquid chromatography (HPLC), thin layer chromatography (TLC), and hyperdiffusion chromatography, various immunological methods, *e.g.*, fluid or gel precipitin reactions, immunodiffusion, immunoelectrophoresis, radioimmunoassays (RIAs), enzyme-linked immunosorbent assays (ELISAs), immuno-fluorescent assays, Southern analysis, Northern analysis, dot-blot analysis, gel electrophoresis (*e.g.*, SDS-PAGE), RT-PCR, quantitative PCR, other nucleic acid or target or signal amplification methods, radiolabeling, scintillation counting, and affinity chromatography.

Oligonucleotide primers may be used to amplify nucleic acid fragments encoding taste receptor ligand-binding regions. The nucleic acids described herein can also be cloned or measured quantitatively using amplification techniques. Amplification methods are also well known in the art, and include, *e.g.*, polymerase chain reaction, PCR (*PCR Protocols, a Guide to Methods and Applications*, ed. Innis. Academic Press, N.Y. (1990) and *PCR Strategies*, ed. Innis, Academic Press, Inc., N.Y. (1995), ligase chain reaction (LCR) (*see, e.g.*, Wu, *Genomics* 4:560 (1989); Landegren, *Science* 241:1077, (1988); Barringer, *Gene* 89:117 (1990)); transcription amplification (*see, e.g.*, Kwoh, *Proc. Natl. Acad. Sci. USA* 86:1173 (1989)); and, self-sustained sequence replication (*see, e.g.*, Guatelli, *Proc. Natl. Acad. Sci. USA* 87:1874 (1990)); Q Beta replicase amplification (*see, e.g.*, Smith, *J. Clin. Microbiol.* 35:1477-1491 (1997));

automated Q-beta replicase amplification assay (*see, e.g.*, Burg, *Mol. Cell. Probes* 10:257-271 (1996)) and other RNA polymerase mediated techniques (*e.g.*, NASBA, Cangene, Mississauga, Ontario); *see also* Berger, *Methods Enzymol.* 152:307-316 (1987); Sambrook; Ausubel; U.S. Patent Nos. 4,683,195 and 4,683,202; Sooknanan, *Biotechnology* 13:563-564 (1995). The primers can be designed to retain the original sequence of the "donor" 7-membrane receptor. Alternatively, the primers can encode amino acid residues that are conservative substitutions (*e.g.*, hydrophobic for hydrophobic residue, see above discussion) or functionally benign substitutions (*e.g.*, do not prevent plasma membrane insertion, cause cleavage by peptidase, cause abnormal folding of receptor, and the like). Once amplified, the nucleic acids, either individually or as libraries, may be cloned according to methods known in the art, if desired, into any of a variety of vectors using routine molecular biological methods; methods for cloning *in vitro* amplified nucleic acids are described, *e.g.*, U.S. Pat. No. 5,426,039.

The primer pairs may be designed to selectively amplify ligand-binding regions of the T1R family members. These regions may vary for different ligands or tastants. Thus, what may be a minimal binding region for one tastant, may be too limiting for a second tastant. Accordingly, ligand-binding regions of different sizes comprising different extracellular domain structures may be amplified.

Paradigms to design degenerate primer pairs are well known in the art. For example, a COnsensus-DEgenerate Hybrid Oligonucleotide Primer (CODEHOP) strategy computer program is accessible as http://blocks.fhcrc.org/codehop.html, and is directly linked from the BlockMaker multiple sequence alignment site for hybrid primer prediction beginning with a set of related protein sequences, as known taste receptor ligand-binding regions (*see, e.g.*, Rose, *Nucleic Acids Res.* 26:1628-1635 (1998); Singh, *Biotechniques* 24:318-319 (1998)).

Means to synthesize oligonucleotide primer pairs are well known in the art. "Natural" base pairs or synthetic base pairs can be used. For example, use of artificial nucleobases offers a versatile approach to manipulate primer sequence and generate a more complex mixture of amplification products. Various families of artificial nucleobases are capable of assuming multiple hydrogen bonding orientations through internal bond rotations to provide a means for degenerate molecular recognition. Incorporation of these analogs into a single position of a PCR primer allows for

generation of a complex library of amplification products. *See, e.g.*, Hoops, *Nucleic Acids Res.* 25:4866-4871 (1997). Nonpolar molecules can also be used to mimic the shape of natural DNA bases. A non-hydrogen-bonding shape mimic for adenine can replicate efficiently and selectively against a nonpolar shape mimic for thymine (*see, e.g.*, Morales, *Nat. Struct. Biol.* 5:950-954 (1998)). For example, two degenerate bases can be the pyrimidine base 6H, 8H-3,4-dihydropyrimido[4,5-c][1,2]oxazin-7-one or the purine base N6-methoxy-2,6-diaminopurine (*see, e.g.*, Hill, *Proc. Natl. Acad. Sci. USA* 95:4258-4263 (1998)). Exemplary degenerate primers of the invention incorporate the nucleobase analog 5'-Dimethoxytrityl-N-benzoyl-2'-deoxy-Cytidine,3'-[(2-cyanoethyl)-(N,N-diisopropyl)]-phosphoramidite (the term "P" in the sequences, see above). This pyrimidine analog hydrogen bonds with purines, including A and G residues.

Polymorphic variants, alleles, and interspecies homologs that are substantially identical to a taste receptor disclosed herein can be isolated using the nucleic acid probes described above. Alternatively, expression libraries can be used to clone T1R polypeptides and polymorphic variants, alleles, and interspecies homologs thereof, by detecting expressed homologs immunologically with antisera or purified antibodies made against a T1R polypeptide, which also recognize and selectively bind to the T1R homolog.

Nucleic acids that encode ligand-binding regions of taste receptors may be generated by amplification (*e.g.*, PCR) of appropriate nucleic acid sequences using degenerate primer pairs. The amplified nucleic acid can be genomic DNA from any cell or tissue or mRNA or cDNA derived from taste receptor-expressing cells.

In one embodiment, hybrid protein-coding sequences comprising nucleic acids encoding T1Rs fused to translocation sequences may be constructed. Also provided are hybrid T1Rs comprising the translocation motifs and tastant-binding domains of other families of chemosensory receptors, particularly taste receptors. These nucleic acid sequences can be operably linked to transcriptional or translational control elements, *e.g.*, transcription and translation initiation sequences, promoters and enhancers, transcription and translation terminators, polyadenylation sequences, and other sequences useful for transcribing DNA into RNA. In constitutive of recombinant expression cassettes, vectors, and transgenics, a promoter fragment can be employed to direct expression of the desired nucleic acid in all desired cells or tissues.

In another embodiment, fusion proteins may include C-terminal or N-terminal translocation sequences. Further, fusion proteins can comprise additional elements, *e.g.*, for protein detection, purification, or other applications. Detection and purification facilitating domains include, *e.g.*, metal chelating peptides such as polyhistidine tracts, histidine-tryptophan modules, or other domains that allow purification on immobilized metals; maltose binding protein; protein A domains that allow purification on immobilized immunoglobulin; or the domain utilized in the FLAGS extension/affinity purification system (Immunex Corp., Seattle, WA).

The inclusion of a cleavable linker sequences such as Factor Xa (*see, e.g.*, Ottavi, *Biochimie* 80:289-293 (1998)), subtilisin protease recognition motif (*see, e.g.*, Polyak, *Protein Eng.* 10:615-619 (1997)); enterokinase (Invitrogen, San Diego, CA), and the like, between the translocation domain (for efficient plasma membrane expression) and the rest of the newly translated polypeptide may be useful to facilitate purification. For example, one construct can include a polypeptide encoding a nucleic acid sequence linked to six histidine residues followed by a thioredoxin, an enterokinase cleavage site (*see, e.g.*, Williams, *Biochemistry* 34:1787-1797 (1995)), and an C-terminal translocation domain. The histidine residues facilitate detection and purification while the enterokinase cleavage site provides a means for purifying the desired protein(s) from the remainder of the fusion protein. Technology pertaining to vectors encoding fusion proteins and application of fusion proteins are well described in the scientific and patent literature, *see, e.g.*, Kroll, *DNA Cell. Biol.* 12:441-53 (1993).

Expression vectors, either as individual expression vectors or as libraries of expression vectors, comprising the ligand-binding domain encoding sequences may be introduced into a genome or into the cytoplasm or a nucleus of a cell and expressed by a variety of conventional techniques, well described in the scientific and patent literature. *See, e.g.*, Roberts, *Nature* 328:731 (1987); Berger *supra*; Schneider, *Protein Expr. Purif.* 6435:10 (1995); Sambrook; Tijssen; Ausubel. Product information from manufacturers of biological reagents and experimental equipment also provide information regarding known biological methods. The vectors can be isolated from natural sources, obtained from such sources as ATCC or GenBank libraries, or prepared by synthetic or recombinant methods.

The nucleic acids can be expressed using expression cassettes, vectors or viruses which are stably or transiently expressed in cells (*e.g.*, episomal expression

systems). Selection markers can be incorporated into expression cassettes and vectors to confer a selectable phenotype on transformed cells and sequences. For example, selection markers can code for episomal maintenance and replication such that integration into the host genome is not required. For example, the marker may encode antibiotic resistance (*e.g.*, chloramphenicol, kanamycin, G418, blasticidin, hygromycin) or herbicide resistance (*e.g.*, chlorosulfuron or Basta) to permit selection of those cells transformed with the desired DNA sequences (*see, e.g.*, Blondelet-Rouault, *Gene* 190:315-317 (1997); Aubrecht, *J. Pharmacol. Exp. Ther.* 281:992-997 (1997)). Because selectable marker genes conferring resistance to substrates like neomycin or hygromycin can only be utilized in tissue culture, chemoresistance genes are also used as selectable markers *in vitro* and *in vivo*.

A chimeric nucleic acid sequence may encode a T1R ligand-binding domain within any 7-transmembrane polypeptide. Because 7-transmembrane receptor polypeptides have similar primary sequences and secondary and tertiary structures, structural domains (*e.g.*, extracellular domain, TM domains, cytoplasmic domain, *etc.*) can be readily identified by sequence analysis. For example, homology modeling, Fourier analysis and helical periodicity detection can identify and characterize the seven domains with a 7-transmembrane receptor sequence. Fast Fourier Transform (FFT) algorithms can be used to assess the dominant periods that characterize profiles of the hydrophobicity and variability of analyzed sequences. Periodicity detection enhancement and alpha helical periodicity index can be done as by, *e.g.*, Donnelly, *Protein Sci.* 2:55-70 (1993). Other alignment and modeling algorithms are well known in the art, *see, e.g.*, Peitsch, *Receptors Channels* 4:161-164 (1996); Kyte & Doolittle, *J. Med. Bio.*, 157:105-132 (1982); Cronet, *Protein Eng.* 6:59-64 (1993).

The present invention also includes not only the DNA and proteins having the specified nucleic and amino acid sequences, but also DNA fragments, particularly fragments of, *e.g.*, 40, 60, 80, 100, 150, 200, or 250 nucleotides, or more, as well as protein fragments of, *e.g.*, 10, 20, 30, 50, 70, 100, or 150 amino acids, or more. Optionally, the nucleic acid fragments can encode an antigenic polypeptide, which is capable of binding to an antibody raised against a T1R family member. Further, a protein fragment of the invention can optionally be an antigenic fragment, which is capable of binding to an antibody raised against a T1R family member.

Also contemplated are chimeric proteins, comprising at least 10, 20, 30, 50, 70, 100, or 150 amino acids, or more, of one of at least one of the T1R polypeptides described herein, coupled to additional amino acids representing all or part of another GPCR, preferably a member of the 7 transmembrane superfamily. These chimeras can be made from the instant receptors and another GPCR, or they can be made by combining two or more of the present T1R receptors. In one embodiment, one portion of the chimera corresponds to or is derived from the extracellular domain of a T1R polypeptide of the invention. In another embodiment, one portion of the chimera corresponds to, or is derived from the extracellular domain and one or more of the transmembrane domains of a T1R polypeptide described herein, and the remaining portion or portions can come from another GPCR. Chimeric receptors are well known in the art, and the techniques for creating them and the selection and boundaries of domains or fragments of G protein-coupled receptors for incorporation therein are also well known. Thus, this knowledge of those skilled in the art can readily be used to create such chimeric receptors. The use of such chimeric receptors can provide, for example, a taste selectivity characteristic of one of the receptors specifically disclosed herein, coupled with the signal transduction characteristics of another receptor, such as a well known receptor used in prior art assay systems.

As noted above, such chimeras, analogous to the native T1R receptor, or native T1R receptor combination or association will bind to and/or be activated by molecules that normally affect sweet taste or umami taste. Functional chimeric T1R receptors or receptor combinations are molecules which when expressed alone or in combination with other T1Rs or other GPCRs (which may themselves be chimeric) bind to or which are activated by taste stimuli, particularly sweet (T1R2/3) or umami taste stimuli (T1R1/3). Molecules that elicit sweet taste include natural and artificial sweeteners such as sucrose, aspartame, xylitol, cyclamate, et al., Molecules that elicit umami taste include glutamate and glutamate analogs and other compounds that bind to native T1R1 and/or T1R3, such as 5'-nucleotides.

For example, a domain such as a ligand-binding domain, an extracellular domain, a transmembrane domain, a transmembrane domain, a cytoplasmic domain, an N-terminal domain, a C-terminal domain, or any combination thereof, can be covalently linked to a heterologous protein. For instance, an T1R extracellular domain can be linked to a heterologous GPCR transmembrane domain, or a heterologous

GPCR extracellular domain can be linked to a T1R transmembrane domain. Other heterologous proteins of choice can be used; *e.g.*, green fluorescent protein.

Also within the scope of the invention are host cells for expressing the T1Rs, fragments, chimeras or variants of the invention. To obtain high levels of expression of a cloned gene or nucleic acid, such as cDNAs encoding the T1Rs, fragments, or variants of the invention, one of skill typically subclones the nucleic acid sequence of interest into an expression vector that contains a strong promoter to direct transcription, a transcription/translation terminator, and if for a nucleic acid encoding a protein, a ribosome binding site for translational initiation. Suitable bacterial promoters are well known in the art and described, *e.g.*, in Sambrook *et al.* However, bacterial or eukaryotic expression systems can be used.

Any of the well-known procedures for introducing foreign nucleotide sequences into host cells may be used. These include the use of calcium phosphate transfection, polybrene, protoplast fusion, electroporation, liposomes, microinjection, plasma vectors, viral vectors and any of the other well known methods for introducing cloned genomic DNA, cDNA, synthetic DNA or other foreign genetic material into a host cell (*see, e.g.,* Sambrook *et al.*) It is only necessary that the particular genetic engineering procedure used be capable of successfully introducing at lest one nucleic acid molecule into the host cell capable of expressing the T1R, fragment, or variant of interest.

After the expression vector is introduced into the cells, the transfected cells are cultured under conditions favoring expression of the receptor, fragment, or variant of interest, which is then recovered from the culture using standard techniques. Examples of such techniques are well known in the art. *See, e.g.*, WO 00/06593, which is incorporated by reference in a manner consistent with this disclosure.

***Detection of T1R polypeptides***

In addition to the detection of T1R genes and gene expression using nucleic acid hybridization technology, one can also use immunoassays to detect T1Rs, *e.g.*, to identify taste receptor cells, and variants of T1R family members. Immunoassays can be used to qualitatively or quantitatively analyze the T1Rs. A general overview of the applicable technology can be found in Harlow & Lane, *Antibodies: A Laboratory Manual* (1988).

**1. Antibodies to T1R family members**

Methods of producing polyclonal and monoclonal antibodies that react specifically with a T1R family member are known to those of skill in the art (*see, e.g.*, Coligan, *Current Protocols in Immunology* (1991); Harlow & Lane, supra; Goding, *Monoclonal Antibodies: Principles and Practice* (2d ed. 1986); and Kohler & Milstein, *Nature*, 256:495-497 (1975)). Such techniques include antibody preparation by selection of antibodies from libraries of recombinant antibodies in phage or similar vectors, as well as preparation of polyclonal and monoclonal antibodies by immunizing rabbits or mice (*see, e.g.*, Huse *et al.*, *Science*, 246:1275-1281 (1989); Ward *et al.*, *Nature*, 341:544-546 (1989)).

A number of T1R-comprising immunogens may be used to produce antibodies specifically reactive with a T1R family member. For example, a recombinant T1R polypeptide, or an antigenic fragment thereof, can be isolated as described herein. Suitable antigenic regions include, *e.g.*, the consensus sequences that are used to identify members of the T1R family. Recombinant proteins can be expressed in eukaryotic or prokaryotic cells as described above, and purified as generally described above. Recombinant protein is the preferred immunogen for the production of monoclonal or polyclonal antibodies. Alternatively, a synthetic peptide derived from the sequences disclosed herein and conjugated to a carrier protein can be used an immunogen. Naturally occurring protein may also be used either in pure or impure form. The product is then injected into an animal capable of producing antibodies. Either monoclonal or polyclonal antibodies may be generated, for subsequent use in immunoassays to measure the protein.

Methods of production of polyclonal antibodies are known to those of skill in the art. For example, an inbred strain of mice (*e.g.*, BALB/C mice) or rabbits is immunized with the protein using a standard adjuvant, such as Freund's adjuvant, and a standard immunization protocol. The animal's immune response to the immunogen preparation is monitored by taking test bleeds and determining the titer of reactivity to the T1R. When appropriately high titers of antibody to the immunogen are obtained, blood is collected from the animal and antisera are prepared. Further fractionation of the antisera to enrich for antibodies reactive to the protein can be done if desired (*see* Harlow & Lane, *supra*).

Monoclonal antibodies may be obtained by various techniques familiar to those skilled in the art. Briefly, spleen cells from an animal immunized with a desired antigen may be immortalized, commonly by fusion with a myeloma cell (*see* Kohler & Milstein, *Eur. J. Immunol.*, 6:511-519 (1976)). Alternative methods of immortalization include transformation with Epstein Barr Virus, oncogenes, or retroviruses, or other methods well known in the art. Colonies arising from single immortalized cells are screened for production of antibodies of the desired specificity and affinity for the antigen, and yield of the monoclonal antibodies produced by such cells may be enhanced by various techniques, including injection into the peritoneal cavity of a vertebrate host. Alternatively, one may isolate DNA sequences which encode a monoclonal antibody or a binding fragment thereof by screening a DNA library from human B cells according to the general protocol outlined by Huse *et al.*, *Science*, 246:1275-1281 (1989).

Monoclonal antibodies and polyclonal sera are collected and titered against the immunogen protein in an immunoassay, for example, a solid phase immunoassay with the immunogen immobilized on a solid support. Typically, polyclonal antisera with a titer of 104 or greater are selected and tested for their cross reactivity against non-T1R polypeptides, or even other T1R family members or other related proteins from other organisms, using a competitive binding immunoassay. Specific polyclonal antisera and monoclonal antibodies will usually bind with a Kd of at least about 0.1 mM, more usually at least about 1 pM, optionally at least about 0.1 pM or better, and optionally 0.01 pM or better.

Once T1R family member specific antibodies are available, individual T1R proteins and protein fragments can be detected by a variety of immunoassay methods. For a review of immunological and immunoassay procedures, *see Basic and Clinical Immunology* (Stites & Terr eds., 7th ed. 1991). Moreover, the immunoassays of the present invention can be performed in any of several configurations, which are reviewed extensively in Enzyme Immunoassay (Maggio, ed., 1980); and Harlow & Lane, *supra*.

**2. Immunological binding assays**

T1R proteins, fragments, and variants can be detected and/or quantified using any of a number of well-recognized immunological binding assays (*see*, *e.g.*, U.S.

Patents 4,366,241; 4,376,110; 4,517,288; and 4,837,168). For a review of the general immunoassays, *see also Methods in Cell Biology: Antibodies in Cell Biology*, volume 37 (Asai, ed. 1993); *Basic and Clinical Immunology* (Stites & Terr, eds., 7th ed. 1991). Immunological binding assays (or immunoassays) typically use an antibody that specifically binds to a protein or antigen of choice (in this case a T1R family member or an antigenic subsequence thereof). The antibody (*e.g.*, anti-T1R) may be produced by any of a number of means well known to those of skill in the art and as described above.

Immunoassays also often use a labeling agent to specifically bind to and label the complex formed by the antibody and antigen. The labeling agent may itself be one of the moieties comprising the antibody/antigen complex. Thus, the labeling agent may be a labeled T1R polypeptide or a labeled anti-T1R antibody. Alternatively, the labeling agent may be a third moiety, such a secondary antibody that specifically binds to the antibody/T1R complex (a secondary antibody is typically specific to antibodies of the species from which the first antibody is derived). Other proteins capable of specifically binding immunoglobulin constant regions, such as protein A or protein G may also be used as the label agent. These proteins exhibit a strong non-immunogenic reactivity with immunoglobulin constant regions from a variety of species (*see, e.g.*, Kronval *et al.*, *J. Immunol.*, 111:1401-1406 (1973); *Akerstrom et al.*, *J. Immunol.*, 135:2589-2542 (1985)). The labeling agent can be modified with a detectable moiety, such as biotin, to which another molecule can specifically bind, such as streptavidin. A variety of detectable moieties are well known to those skilled in the art.

Throughout the assays, incubation and/or washing steps may be required after each combination of reagents. Incubation steps can vary from about 5 seconds to several hours, optionally from about 5 minutes to about 24 hours. However, the incubation time will depend upon the assay format, antigen, volume of solution, concentrations, and the like. Usually, the assays will be carried out at ambient temperature, although they can be conducted over a range of temperatures, such as 10°C to 40°C.

A. Non-competitive assay formats

Immunoassays for detecting a T1R polypeptide in a sample may be either competitive or noncompetitive. Noncompetitive immunoassays are assays in which the

amount of antigen is directly measured. In one preferred "sandwich" assay, for example, the anti-T1R antibodies can be bound directly to a solid substrate on which they are immobilized. These immobilized antibodies then capture the T1R polypeptide present in the test sample. The T1R polypeptide is thus immobilized is then bound by a labeling agent, such as a second T1R antibody bearing a label. Alternatively, the second antibody may lack a label, but it may, in turn, be bound by a labeled third antibody specific to antibodies of the species from which the second antibody is derived. The second or third antibody is typically modified with a detectable moiety, such as biotin, to which another molecule specifically binds, *e.g.*, streptavidin, to provide a detectable moiety.

B. Competitive assay formats

In competitive assays, the amount of T1R polypeptide present in the sample is measured indirectly by measuring the amount of a known, added (exogenous) T1R polypeptide displaced (competed away) from an anti-T1R antibody by the unknown T1R polypeptide present in a sample. In one competitive assay, a known amount of T1R polypeptide is added to a sample and the sample is then contacted with an antibody that specifically binds to the T1R. The amount of exogenous T1R polypeptide bound to the antibody is inversely proportional to the concentration of T1R polypeptide present in the sample. In a particularly preferred embodiment, the antibody is immobilized on a solid substrate. The amount of T1R polypeptide bound to the antibody may be determined either by measuring the amount of T1R polypeptide present in a T1R/antibody complex, or alternatively by measuring the amount of remaining uncomplexed protein. The amount of T1R polypeptide may be detected by providing a labeled T1R molecule.

A hapten inhibition assay is another preferred competitive assay. In this assay the known T1R polypeptide is immobilized on a solid substrate. A known amount of anti-T1R antibody is added to the sample, and the sample is then contacted with the immobilized T1R. The amount of anti-T1R antibody bound to the known immobilized T1R polypeptide is inversely proportional to the amount of T1R polypeptide present in the sample. Again, the amount of immobilized antibody may be detected by detecting either the immobilized fraction of antibody or the fraction of the antibody that remains in solution. Detection may be direct where the antibody is labeled or indirect by the

subsequent addition of a labeled moiety that specifically binds to the antibody as described above.

C. Cross-reactivity determinations

Immunoassays in the competitive binding format can also be used for cross-reactivity determinations. For example, a protein at least partially encoded by the nucleic acid sequences disclosed herein can be immobilized to a solid support. Proteins (*e.g.*, T1R polypeptides and homologs) are added to the assay that compete for binding of the antisera to the immobilized antigen. The ability of the added proteins to compete for binding of the antisera to the immobilized protein is compared to the ability of the T1R polypeptide encoded by the nucleic acid sequences disclosed herein to compete with itself. The percent cross-reactivity for the above proteins is calculated, using standard calculations. Those antisera with less than 10% cross-reactivity with each of the added proteins listed above are selected and pooled. The cross-reacting antibodies are optionally removed from the pooled antisera by immunoabsorption with the added considered proteins, *e.g.*, distantly related homologs. In addition, peptides comprising amino acid sequences representing conserved motifs that are used to identify members of the T1R family can be used in cross-reactivity determinations.

The immunoabsorbed and pooled antisera are then used in a competitive binding immunoassay as described above to compare a second protein, thought to be perhaps an allele or polymorphic variant of a T1R family member, to the immunogen protein (*i.e.*, T1R polypeptide encoded by the nucleic acid sequences disclosed herein). In order to make this comparison, the two proteins are each assayed at a wide range of concentrations and the amount of each protein required to inhibit 50% of the binding of the antisera to the immobilized protein is determined. If the amount of the second protein required to inhibit 50% of binding is less than 10 times the amount of the protein encoded by nucleic acid sequences disclosed herein required to inhibit 50% of binding, then the second protein is said to specifically bind to the polyclonal antibodies generated to a T1R immunogen.

Antibodies raised against T1R conserved motifs can also be used to prepare antibodies that specifically bind only to GPCRs of the T1R family, but not to GPCRs from other families.

Polyclonal antibodies that specifically bind to a particular member of the T1R family can be made by subtracting out cross-reactive antibodies using other T1R family members. Species-specific polyclonal antibodies can be made in a similar way. For example, antibodies specific to human T1R1 can be made by, subtracting out antibodies that are cross-reactive with orthologous sequences, *e.g.*, rat T1R1 or mouse T1R1.

D. Other assay formats

Western blot (immunoblot) analysis is used to detect and quantify the presence of T1R polypeptide in the sample. The technique generally comprises separating sample proteins by gel electrophoresis on the basis of molecular weight, transferring the separated proteins to a suitable solid support, (such as a nitrocellulose filter, a nylon filter, or derivatized nylon filter), and incubating the sample with the antibodies that specifically bind the T1R polypeptide. The anti-T1R polypeptide antibodies specifically bind to the T1R polypeptide on the solid support. These antibodies may be directly labeled or alternatively may be subsequently detected using labeled antibodies (*e.g.*, labeled sheep anti-mouse antibodies) that specifically bind to the anti-T1R antibodies.

Other, assay formats include liposome immunoassays (LIA), which use liposomes designed to bind specific molecules (*e.g.*, antibodies) and release encapsulated reagents or markers. The released chemicals are then detected according to standard techniques (*see* Monroe *et al.*, *Amer. Clin. Prod. Rev.*, 5:34-41 (1986)).

E. Reduction of non-specific binding

One of skill in the art will appreciate that it is often desirable to minimize non-specific binding in immunoassays. Particularly, where the assay involves an antigen or antibody immobilized on a solid substrate it is desirable to minimize the amount of non-specific binding to the substrate. Means of reducing such non-specific binding are well known to those of skill in the art. Typically, this technique involves coating the substrate with a proteinaceous composition. In particular, protein compositions such as bovine serum albumin (BSA), nonfat powdered milk, and gelatin are widely used with powdered milk being most preferred.

F. Labels

The particular label or detectable group used in the assay is not a critical aspect of the invention, as long as it does not significantly interfere with the specific binding of the antibody used in the assay. The detectable group can be any material having a detectable physical or chemical property. Such detectable labels have been well developed in the field of immunoassays and, in general, most any label useful in such methods can be applied to the present invention. Thus, a label is any composition detectable by spectroscopic, photochemical, biochemical, immunochemical, electrical, optical, or chemical means. Useful labels in the present invention include magnetic beads (*e.g.*, DYNABEADSTM), fluorescent dyes (*e.g.*, fluorescein isothiocyanate, Texas red, rhodamine, and the like), radiolabels (*e.g.*, $^{3}H$, $^{125}I$, $^{14}C$, $^{35}S$), enzymes (*e.g.*, horseradish peroxidase, alkaline phosphates and others commonly used in an ELISA), and colorimetric labels such as colloidal gold or colored glass or plastic beads (*e.g.*, polystyrene, polypropylene, latex, *etc.*).

The label may be coupled directly or indirectly to the desired component of the assay according to methods well known in the art. As indicated above, a wide variety of labels may be used, with the choice of label depending on sensitivity required, ease of conjugation with the compound, stability requirements, available instrumentation, and disposal provisions.

Non-radioactive labels are often attached by indirect means. Generally, a ligand molecule (*e.g.*, biotin) is covalently bound to the molecule. The ligand then binds to another molecules (*e.g.*, streptavidin) molecule, which is either inherently detectable or covalently bound to a signal system, such as a detectable enzyme, a fluorescent compound, or a chemiluminescent compound. The ligands and their targets can be used in any suitable combination with antibodies that recognize a T1R polypeptide, or secondary antibodies that recognize anti-T1R.

The molecules can also be conjugated directly to signal generating compounds, *e.g.*, by conjugation with an enzyme or fluorophore. Enzymes of interest as labels will primarily be hydrolases, particularly phosphatases, esterases and glycosidases, or oxidotases, particularly peroxidases. Fluorescent compounds include fluorescein and its derivatives, rhodamine and its derivatives, dansyl, umbelliferone, *etc.* Chemiluminescent compounds include luciferin, and 2,3-dihydrophthalazinediones, *e.g.*, luminol. For a review of various labeling or signal producing systems that may be used, *see* U.S. Patent No. 4,391,904.

Means of detecting labels are well known to those of skill in the art. Thus, for example, where the label is a radioactive label, means for detection include a scintillation counter or photographic film as in autoradiography. Where the label is a fluorescent label, it may be detected by exciting the fluorochrome with the appropriate wavelength of light and detecting the resulting fluorescence. The fluorescence may be detected visually, by means of photographic film, by the use of electronic detectors such as charge-coupled devices (CCDs) or photomultipliers and the like. Similarly, enzymatic labels may be detected by providing the appropriate substrates for the enzyme and detecting the resulting reaction product. Finally simple colorimetric labels may be detected simply by observing the color associated with the label. Thus, in various dipstick assays, conjugated gold often appears pink, while various conjugated beads appear the color of the bead.

Some assay formats do not require the use of labeled components. For instance, agglutination assays can be used to detect the presence of the target antibodies. In this case, antigen-coated particles are agglutinated by samples comprising the target antibodies. In this format, none of the components need be labeled and the presence of the target antibody is detected by simple visual inspection.

***Detection of Modulators***

Compositions and methods for determining whether a test compound specifically binds to a T1R receptor of the invention, both *in vitro* and *in vivo*, are described below. Many aspects of cell physiology can be monitored to assess the effect of ligand binding to a T1R polypeptide of the invention. These assays may be performed on intact cells expressing a chemosensory receptor, on permeabilized cells, or on membrane fractions produced by standard methods or in vitro de novo synthesized proteins.

In vivo, taste receptors bind tastants and initiate the transduction of chemical stimuli into electrical signals. An activated or inhibited G protein will in turn alter the properties of target enzymes, channels, and other effector proteins. Some examples are the activation of cGMP phosphodiesterase by transducin in the visual system, adenylate cyclase by the stimulatory G protein, phospholipase C by Gq and other cognate G proteins, and modulation of diverse channels by Gi and other G proteins. Downstream

consequences can also be examined such as generation of diacyl glycerol and IP3 by phospholipase C, and in turn, for calcium mobilization by IP3.

The T1R proteins or polypeptides of the assay will preferably be selected from a polypeptide having the T1R polypeptide sequence selected from those disclosed in Example 1, or fragments or conservatively modified variants thereof. Optionally, the fragments and variants can be antigenic fragments and variants which bind to an anti-T1R antibody. Optionally, the fragments and variants can bind to or are activated by sweeteners or umami tastants.

Alternatively, the T1R proteins or polypeptides of the assay can be derived from a eukaryotic host cell and can include an amino acid subsequence having amino acid sequence identity to the T1R polypeptides disclosed in Example 1, or fragments or conservatively modified variants thereof. Generally, the amino acid sequence identity will be at least 35 to 50%, or optionally 75%, 85%, 90%, 95%, 96%, 97%, 98%, or 99%. Optionally, the T1R proteins or polypeptides of the assays can comprise a domain of a T1R protein, such as an extracellular domain, transmembrane region, transmembrane domain, cytoplasmic domain, ligand-binding domain, and the like. Further, as described above, the T1R protein or a domain thereof can be covalently linked to a heterologous protein to create a chimeric protein used in the assays described herein.

Modulators of T1R receptor activity are tested using T1R proteins or polypeptides as described above, either recombinant or naturally occurring. The T1R proteins or polypeptides can be isolated, co-expressed in a cell, co-expressed in a membrane derived from a cell, co-expressed in tissue or in an animal, either recombinant or naturally occurring. For example, tongue slices, dissociated cells from a tongue, transformed cells, or membranes can be used. Modulation can be tested using one of the *in vitro* or *in vivo* assays described herein.

For example, as disclosed in the experiment examples infra, it has been discovered that certain 5' nucleotides, e.g., 5' IMP or 5' GMP, enhance the activity of L-glutamate to activate the umami taste receptor, or block the activation of the umami taste receptor by umami taste stimuli such as L-glutamate and L-aspartate.

### 1. *In vitro* binding assays

Taste transduction can also be examined *in vitro* with soluble or solid state reactions, using the T1R polypeptides of the invention. In a particular embodiment, T1R ligand-binding domains can be used *in vitro* in soluble or solid state reactions to assay for ligand binding.

For instance, the T1R N-terminal domain is predicted to be involved in ligand binding. More particularly, the T1Rs belong to a GPCR sub-family that is characterized by large, approximately 600 amino acid, extracellular N-terminal segments. These N-terminal segments are thought to form the ligand-binding domains, and are therefore useful in biochemical assays to identify T1R agonists and antagonists. It is possible that the ligand-binding domain may be formed by additional portions of the extracellular domain, such as the extracellular loops of the transmembrane domain.

*In vitro* binding assays have been used with other GPCRs that are related to the T1Rs, such as the metabotropic glutamate receptors (*see, e.g.,* Han and Hampson, *J. Biol. Chem.* 274:10008-10013 (1999)). These assays might involve displacing a radioactively or fluorescently labeled ligand, measuring changes in intrinsic fluorescence or changes in proteolytic susceptibility, *etc.*

Ligand binding to a hetero-multimeric complex of T1R polypeptides of the invention can be tested in solution, in a bilayer membrane, optionally attached to a solid phase, in a lipid monolayer, or in vesicles. Binding of a modulator can be tested using, *e.g.*, changes in spectroscopic characteristics (*e.g.*, fluorescence, absorbence, refractive index) hydrodynamic (*e.g.*, shape), chromatographic, or solubility properties.

**[0207]** In another embodiment of the invention, a GTPγ$^{35}$S assay may be used. As described above, upon activation of a GPCR, the Gα subunit of the G protein complex is stimulated to exchange bound GDP for GTP. Ligand-mediated stimulation of G protein exchange activity can be measured in a biochemical assay measuring the binding of added radioactively labeled GTPγ$^{35}$S to the G protein in the presence of a putative ligand. Typically, membranes containing the chemosensory receptor of interest are mixed with a complex of G proteins. Potential inhibitors and/or activators and GTPγ$^{35}$S are added to the assay, and binding of GTPγ$^{35}$S to the G protein is measured. Binding can be measured by liquid scintillation counting or by any other means known in the art, including scintillation proximity assays (SPA). In other assays formats, fluorescently labeled GTPγS can be utilized.

**2. Fluorescence Polarization Assays**

In another embodiment, Fluorescence Polarization ("FP") based assays may be used to detect and monitor ligand binding. Fluorescence polarization is a versatile laboratory technique for measuring equilibrium binding, nucleic acid hybridization, and enzymatic activity. Fluorescence polarization assays are homogeneous in that they do not require a separation step such as centrifugation, filtration, chromatography, precipitation, or electrophoresis. These assays are done in real time, directly in solution and do not require an immobilized phase. Polarization values can be measured repeatedly and after the addition of reagents since measuring the polarization is rapid and does not destroy the sample. Generally, this technique can be used to measure polarization values of fluoropliores from low picomolar to micromolar levels. This section describes how fluorescence polarization can be used in a simple and quantitative way to measure the binding of ligands to the T1R polypeptides of the invention.

When a fluorescently labeled molecule is excited with plane-polarized light, it emits light that has a degree of polarization that is inversely proportional to its molecular rotation. Large fluorescently labeled molecules remain relatively stationary during the excited state (4 nanoseconds in the case of fluorescein) and the polarization of the light remains relatively constant between excitation and emission. Small fluorescently labeled molecules rotate rapidly during the excited state and the polarization changes significantly between excitation and emission. Therefore, small molecules have low polarization values and large molecules have high polarization values. For example, a single-stranded fluorescein-labeled oligonucleotide has a relatively low polarization value but when it is hybridized to a complementary strand, it has a higher polarization value. When using FP to detect and monitor tastant-binding which may activate or inhibit the chemosensory receptors of the invention, fluorescence-labeled tastants or auto-fluorescent tastants may be used.

Fluorescence polarization (P) is defined as:

$$P = \frac{Int_{\parallel} - Int_{\perp}}{Int_{\parallel} + Int_{\perp}}$$

Where $\prod$ is the intensity of the emission light parallel to the excitation light plane and Int $\perp$ is the intensity of the emission light perpendicular to the excitation light plane. P, being a ratio of light intensities, is a dimensionless number. For example, the Beacon

® and Beacon 2000 ™ System may be used in connection with these assays. Such systems typically express polarization in millipolarization units (1 Polarization Unit =1000 mP Units).

The relationship between molecular rotation and size is described by the Perrin equation and the reader is referred to Jolley, M. E. (1991) in Journal of Analytical Toxicology, pp. 236-240, which gives a thorough explanation of this equation. Summarily, the Perrin equation states that polarization is directly proportional to the rotational relaxation time, the time that it takes a molecule to rotate through an angle of approximately 68.5° Rotational relaxation time is related to viscosity (η), absolute temperature (T), molecular volume (V), and the gas constant (R) by the following equation:

$$Rotational\,\mathrm{Re}laxationTime = \frac{3\eta V}{RT}$$

The rotational relaxation time is small (≈ 1 nanosecond) for small molecules (*e.g.* fluorescein) and large (≈ 100 nanoseconds) for large molecules (*e.g.* immunoglobulins). If viscosity and temperature are held constant, rotational relaxation time, and therefore polarization, is directly related to the molecular volume. Changes in molecular volume may be due to interactions with other molecules, dissociation, polymerization, degradation, hybridization, or conformational changes of the fluorescently labeled molecule. For example, fluorescence polarization has been used to measure enzymatic cleavage of large fluorescein labeled polymers by proteases, DNases, and RNases. It also has been used to measure equilibrium binding for protein/protein interactions, antibody/antigen binding, and protein/DNA binding.

A. Solid state and soluble high throughput assays

In yet another embodiment, the invention provides soluble assays using a hetero-oligomeric T1R polypeptide complex; or a cell or tissue co-expressing T1R polypeptides. Preferably, the cell will comprise a cell line that stably co-expresses a functional T1R1/T1R3 (umami) taste receptor or T1R2/T1R3 (sweet) taste receptor. In another embodiment, the invention provides solid phase based *in vitro* assays in a high throughput format, where the T1R polypeptides, or cell or tissue expressing the T1R polypeptides is attached to a solid phase substrate or a taste stimulating compound and

contacted with a T1R receptor, and binding detected using an appropriate tag or antibody raised against the T1R receptor.

In the high throughput assays of the invention, it is possible to screen up to several thousand different modulators or ligands in a single day. In particular, each well of a microtiter plate can be used to run a separate assay against a selected potential modulator, or, if concentration or incubation time effects are to be observed, every 5-10 wells can test a single modulator. Thus, a single standard microtiter plate can assay about 100 (*e.g.*, 96) modulators. If 1536 well plates are used, then a single plate can easily assay from about 1000 to about 1500 different compounds. It is also possible to assay multiple compounds in each plate well. It is possible to assay several different plates per day; assay screens for up to about 6,000-20,000 different compounds is possible using the integrated systems of the invention. More recently, microfluidic approaches to reagent manipulation have been developed.

The molecule of interest can be bound to the solid state component, directly or indirectly, via covalent or non-covalent linkage, *e.g.*, via a tag. The tag can be any of a variety of components. In general, a molecule which binds the tag (a tag binder) is fixed to a solid support, and the tagged molecule of interest (*e.g.*, the taste transduction molecule of interest) is attached to the solid support by interaction of the tag and the tag binder.

A number of tags and tag binders can be used, based upon known molecular interactions well described in the literature. For example, where a tag has a natural binder, for example, biotin, protein A, or protein G, it can be used in conjunction with appropriate tag binders (avidin, streptavidin, neutravidin, the Fc region of an immunoglobulin, *etc.*). Antibodies to molecules with natural binders such as biotin are also widely available and appropriate tag binders (*see*, SIGMA Immunochemicals 1998 catalogue SIGMA, St. Louis MO).

Similarly, any haptenic or antigenic compound can be used in combination with an appropriate antibody to form a tag/tag binder pair. Thousands of specific antibodies are commercially available and many additional antibodies are described in the literature. For example, in one common configuration, the tag is a first antibody and the tag binder is a second antibody which recognizes the first antibody. In addition to antibody-antigen interactions, receptor-ligand interactions are also appropriate as tag and tag-binder pairs. For example, agonists and antagonists of cell membrane receptors

(*e.g.*, cell receptor-ligand interactions such as transferrin, c-kit, viral receptor ligands, cytokine receptors, chemokine receptors, interleukin receptors, immunoglobulin receptors and antibodies, the cadherein family, the integrin family, the selectin family, and the like; *see*, *e.g.*, Pigott & Power, The Adhesion Molecule Facts Book I (1993)). Similarly, toxins and venoms, viral epitopes, hormones (*e.g.*, opiates, steroids, *etc.*), intracellular receptors (*e.g.*, which mediate the effects of various small ligands, including steroids, thyroid hormone, retinoids and vitamin D; peptides), drugs, lectins, sugars, nucleic acids (both linear and cyclic polymer configurations), oligosaccharides, proteins, phospholipids and antibodies can all interact with various cell receptors.

Synthetic polymers, such as polyurethanes, polyesters, polycarbonates, polyureas, polyamides, polyethyleneimines, polyarylene sulfides, polysiloxanes, polyimides, and polyacetates can also form an appropriate tag or tag binder. Many other tag/tag binder pairs are also useful in assay systems described herein, as would be apparent to one of skill upon review of this disclosure.

Common linkers such as peptides, polyethers, and the like can also serve as tags, and include polypeptide sequences, such as poly gly sequences of between about 5 and 200 amino acids. Such flexible linkers are known to persons of skill in the art. For example, poly(ethelyne glycol) linkers are available from Shearwater Polymers, Inc. Huntsville, Alabama. These linkers optionally have amide linkages, sulfhydryl linkages, or heterofunctional linkages.

Tag binders are fixed to solid substrates using any of a variety of methods currently available. Solid substrates are commonly derivatized or functionalized by exposing all or a portion of the substrate to a chemical reagent which fixes a chemical group to the surface which is reactive with a portion of the tag binder. For example, groups which are suitable for attachment to a longer chain portion would include amines, hydroxyl, thiol, and carboxyl groups. Aminoalkylsilanes and hydroxyalkylsilanes can be used to functionalize a variety of surfaces, such as glass surfaces. The constitutive of such solid phase biopolymer arrays is well described in the literature. *See*, *e.g.*, Merrifield, *J. Am. Chem. Soc.*, 85:2149-2154 (1963) (describing solid phase synthesis of, *e.g.*, peptides); Geysen *et al.*, *J. Immun. Meth.*, 102:259-274 (1987) (describing synthesis of solid phase components on pins); Frank & Doring, *Tetrahedron*, 44:60316040 (1988) (describing synthesis of various peptide sequences on cellulose disks); Fodor *et al.*, *Science*, 251:767-777 (1991); *Sheldon et*

*al., Clinical Chemistry*, 39(4):718-719 (1993); and Kozal *et al., Nature Medicine*, 2(7):753759 (1996) (all describing arrays of biopolymers fixed to solid substrates). Non-chemical approaches for fixing tag binders to substrates include other common methods, such as heat, cross-linking by UV radiation, and the like.

5

**3. Cell-based assays**

In a preferred embodiment of treatment, a combination of T1R proteins or polypeptides are transiently or stably co-expressed in a eukaryotic cell either in unmodified forms or as chimeric, variant or truncated receptors with or preferably 10 without a heterologous, chaperone sequence that facilitates its maturation and targeting through the secretory pathway. Such T1R polypeptides can be expressed in any eukaryotic cell, such as HEK-293 cells. Preferably, the cells comprise a functional G protein, *e.g.*, Gα15 or the chimeric G protein previously identified, or another G protein that is capable of coupling the chimeric receptor to an intracellular signaling pathway 15 or to a signaling protein such as phospholipase C. Also, preferably a cell will be produced that stably co-expresses T1R1/T1R3 or T1R2/T1R3 as such cells have been found (as shown in the experimental examples) to exhibit enhanced responses to taste stimuli (relation to cells that transiently express the same T1R combination). Activation of T1R receptors in such cells can be detected using any standard method, 20 such as by detecting changes in intracellular calcium by detecting Fluo-4 dependent fluorescence in the cell. Such an assay is the basis of the experimental findings presented in this application.

Activated GPCR receptors often are substrates for kinases that phosphorylate the C-terminal tail of the receptor (and possibly other sites as well). Thus, activators 25 will promote the transfer of $^{32}P$ from radiolabeled ATP to the receptor, which can be assayed with a scintillation counter. The phosphorylation of the C-terminal tail will promote the binding of arrestin-like proteins and will interfere with the binding of G proteins. For a general review of GPCR signal transduction and methods of assaying signal transduction, *see, e.g., Methods in Enzymology*, vols. 237 and 238 (1994) and 30 volume 96 (1983); Bourne *et al., Nature*, 10:349:117-27 (1991); Bourne *et al., Nature*, 348:125-32 (1990); Pitcher *et al., Annu. Rev. Biochem.*, 67:653-92 (1998).

T1R modulation may be assayed by comparing the response of T1R polypeptides treated with a putative T1R modulator to the response of an untreated

control sample or a sample containing a known "positive" control. Such putative T1R modulators can include molecules that either inhibit or activate T1R polypeptide activity. In one embodiment, control samples (untreated with activators or inhibitors) are assigned a relative T1R activity value of 100. Inhibition of a T1R polypeptide is achieved when the T1R activity value relative to the control is about 90%, optionally 50%, optionally 25-0%. Activation of a T1R polypeptide is achieved when the T1R activity value relative to the control is 110%, optionally 150%, 200-500%, or 1000-2000%.

Changes in ion flux may be assessed by determining changes in ionic polarization (*i.e.*, electrical potential) of the cell or membrane expressing a T1R polypeptide. One means to determine changes in cellular polarization is by measuring changes in current (thereby measuring changes in polarization) with voltage-clamp and patch-clamp techniques (*see, e.g.*, the "cell-attached" mode, the "inside-out" mode, and the "whole cell" mode, *e.g.*, Ackerman *et al.*, *New Engl. J Med.*, 336:1575-1595 (1997)). Whole cell currents are conveniently determined using the standard. Other known assays include: radiolabeled ion flux assays and fluorescence assays using voltage-sensitive dyes (*see, e.g.*, Vestergarrd-Bogind *et al.*, *J. Membrane Biol.*, 88:67-75 (1988); Gonzales & Tsien, *Chem. Biol.*, 4:269277 (1997); Daniel *et al.*, *J. Pharmacol. Meth.*, 25:185-193 (1991); Holevinsky *et al.*, *J. Membrane Biology*, 137:59-70 (1994)).

The effects of the test compounds upon the function of the polypeptides can be measured by examining any of the parameters described above. Any suitable physiological change that affects GPCR activity can be used to assess the influence of a test compound on the polypeptides of this invention. When the functional consequences are determined using intact cells or animals, one can also measure a variety of effects such as transmitter release, hormone release, transcriptional changes to both known and uncharacterized genetic markers (*e.g.*, northern blots), changes in cell metabolism such as cell growth or pH changes, and changes in intracellular second messengers such as $Ca^{2+}$, IP3, cGMP, or cAMP.

Preferred assays for GPCRs include cells that are loaded with ion or voltage sensitive dyes to report receptor activity. Assays for determining activity of such receptors can also use known agonists and antagonists for other G protein-coupled receptors as controls to assess activity of tested compounds. In assays for identifying

modulatory compounds (*e.g.*, agonists, antagonists), changes in the level of ions in the cytoplasm or membrane voltage will be monitored using an ion sensitive or membrane voltage fluorescent indicator, respectively. Among the ion-sensitive indicators and voltage probes that may be employed are those disclosed in the Molecular Probes 1997 Catalog. For G protein-coupled receptors, promiscuous G proteins such as Gα15 and Gα16 can be used in the assay of choice (Wilkie *et al.*, *Proc. Nat'l Acad. Sci.*, 88:10049-10053 (1991)).

Receptor activation initiates subsequent intracellular events, *e.g.*, increases in second messengers. Activation of some G protein-coupled receptors stimulates the formation of inositol triphosphate (IP3) through phospholipase C-mediated hydrolysis of phosphatidylinositol (Berridge & Irvine, *Nature*, 312:315-21 (1984)). IP3 in turn stimulates the release of intracellular calcium ion stores. Thus, a change in cytoplasmic calcium ion levels, or a change in second messenger levels such as IP3 can be used to assess G protein-coupled receptor function. Cells expressing such G protein-coupled receptors may exhibit increased cytoplasmic calcium levels as a result of contribution from both calcium release from intracellular stores and extracellular calcium entry via plasma membrane ion channels.

In a preferred embodiment, T1R polypeptide activity is measured by stably or transiently co-expressing T1R genes, preferably stably, in a heterologous cell with a promiscuous G protein that links the receptor to a phospholipase C signal transduction pathway (*see* Offermanns & Simon, *J. Biol. Chem.*, 270:15175-15180 (1995)). In a preferred embodiment, the cell line is HEK-293 (which does not normally express T1R genes) and the promiscuous G protein is Gα15 (Offermanns & Simon, *supra*). Modulation of taste transduction is assayed by measuring changes in intracellular $Ca^{2+}$ levels, which change in response to modulation of the T1R signal transduction pathway via administration of a molecule that associates with T1R polypeptides. Changes in $Ca^{2+}$ levels are optionally measured using fluorescent $Ca^{2+}$ indicator dyes and fluorometric imaging.

In another embodiment, phosphatidyl inositol (PI) hydrolysis can be analyzed according to U.S. Patent 5,436,128, herein incorporated by reference. Briefly, the assay involves labeling of cells with 3H-myoinositol for 48 or more hrs. The labeled cells are treated with a test compound for one hour. The treated cells are lysed and extracted in chloroform-methanol-water after which the inositol phosphates were

separated by ion exchange chromatography and quantified by scintillation counting. Fold stimulation is determined by calculating the ratio of cpm in the presence of agonist, to cpm in the presence of buffer control. Likewise, fold inhibition is determined by calculating the ratio of cpm in the presence of antagonist, to cpm in the presence of buffer control (which may or may not contain an agonist).

Other receptor assays can involve determining the level of intracellular cyclic nucleotides, *e.g.*, cAMP or cGMP. In cases where activation of the receptor results in a decrease in cyclic nucleotide levels, it may be preferable to expose the cells to agents that increase intracellular cyclic nucleotide levels, *e.g.*, forskolin, prior to adding a receptor-activating compound to the cells in the assay. In one embodiment, the changes in intracellular cAMP or cGMP can be measured using immunoassays. The method described in Offermanns & Simon, *J. Bio. Chem.*, 270:15175-15180 (1995), may be used to determine the level of cAMP. Also, the method described in Felley-Bosco *et al.*, *Am. J. Resp. Cell and Mol. Biol.*, 11:159-164 (1994), may be used to determine the level of cGMP. Further, an assay kit for measuring cAMP and/or cGMP is described in U.S. Patent 4,115,538, herein incorporated by reference.

In another embodiment, transcription levels can be measured to assess the effects of a test compound on signal transduction. A host cell containing T1R polypeptides of interest is contacted with a test compound for a sufficient time to effect any interactions, and then the level of gene expression is measured. The amount of time to effect such interactions may be empirically determined, such as by running a time course and measuring the level of transcription as a function of time. The amount of transcription may be measured by using any method known to those of skill in the art to be suitable. For example, mRNA expression of the protein of interest may be detected using northern blots or their polypeptide products may be identified using immunoassays. Alternatively, transcription based assays using reporter gene may be used as described in U.S. Patent 5,436,128, herein incorporated by reference. The reporter genes can be, *e.g.*, chloramphenicol acetyltransferase, luciferase, beta-galactosidase beta-lactamase and alkaline phosphatase. Furthermore, the protein of interest can be used as an indirect reporter via attachment to a second reporter such as green fluorescent protein (*see*, *e.g.*, Mistili & Spector, *Nature Biotechnology*, 15:961-964 (1997)).

The amount of transcription is then compared to the amount of transcription in either the same cell in the absence of the test compound, or it may be compared with the amount of transcription in a substantially identical cell that lacks the T1R polypeptide(s) of interest. A substantially identical cell may be derived from the same cells from which the recombinant cell was prepared but which had not been modified by introduction of heterologous DNA. Any difference in the amount of transcription indicates that the test compound has in some manner altered the activity of the T1R polypeptides of interest.

**4. Transgenic non-human animals expressing chemosensory receptors**

Non-human animals expressing a combination of T1R taste receptor sequences of the invention can also be used for receptor assays. Such expression can be used to determine whether a test compound specifically binds to a mammalian taste transmembrane receptor complex *in vivo* by contacting a non-human animal stably or transiently transfected with nucleic acids encoding chemosensory receptors or ligand-binding regions thereof with a test compound and determining whether the animal reacts to the test compound by specifically binding to the receptor polypeptide complex.

Animals transfected or infected with the vectors of the invention are particularly useful for assays to identify and characterize taste stimuli that can bind to a specific or sets of receptors. Such vector-infected animals expressing human taste receptor sequences can be used for *in vivo* screening of taste stimuli and their effect on, *e.g.*, cell physiology (*e.g.*, on taste neurons), on the CNS, or behavior. Alternatively, stable cell lines that express a T1R or combination thereof, can be used as nucleic transfer donors to produced cloned transgenic animals that stably express a particular T1R or combination. Methods of using nucleic transfer to produce cloned animals that express a desired heterologous DNA are the subject of several issued U.S. patents granted to the University of Massachusetts (licensed to Advanced Cell Technology, Inc.) and Roslin Institute (licensed to Geron Corp.).

Means to infect/express the nucleic acids and vectors, either individually or as libraries, are well known in the art. A variety of individual cell, organ, or whole animal parameters can be measured by a variety of means. The T1R sequences of the

invention can be for example co-expressed in animal taste tissues by delivery with an infecting agent, *e.g.*, adenovirus expression vector.

The endogenous taste receptor genes can remain functional and wild-type (native) activity can still be present. In other situations, where it is desirable that all taste receptor activity is by the introduced exogenous hybrid receptor, use of a knockout line is preferred. Methods for the constitutive of non-human transgenic animals, particularly transgenic mice, and the selection and preparation of recombinant constructs for generating transformed cells are well known in the art.

Constitutive of a "knockout" cell and animal is based on the premise that the level of expression of a particular gene in a mammalian cell can be decreased or completely abrogated by introducing into the genome a new DNA sequence that serves to interrupt some portion of the DNA sequence of the gene to be suppressed. Also, "gene trap insertion" can be used to disrupt a host gene, and mouse embryonic stem (ES) cells can be used to produce knockout transgenic animals (*see, e.g.*, Holzschu, *Transgenic Res* 6:97-106 (1997)). The insertion of the exogenous is typically by homologous recombination between complementary nucleic acid sequences. The exogenous sequence is some portion of the target gene to be modified, such as exonic, intronic or transcriptional regulatory sequences, or any genomic sequence which is able to affect the level of the target gene's expression; or a combination thereof. Gene targeting via homologous recombination in pluripotential embryonic stem cells allows one to modify precisely the genomic sequence of interest. Any technique can be used to create, screen for, propagate, a knockout animal, *e.g.*, *see* Bijvoet, *Hum. Mol. Genet.* 7:53-62 (1998); Moreadith, *J. Mol. Med.* 75:208-216 (1997); Tojo, *Cytotechnology* 19:161-165 (1995); Mudgett, *Methods Mol. Biol.* 48:167-184 (1995); Longo, *Transgenic Res.* 6:321-328 (1997); U.S. Patents Nos. 5,616,491; 5,464,764; 5,631,153; 5,487,992; 5,627,059; 5,272,071; WO 91/09955; WO93/09222; WO 96/29411; WO 95/31560; WO 91/12650.

The nucleic acids of the invention can also be used as reagents to produce "knockout" human cells and their progeny. Likewise, the nucleic acids of the invention can also be used as reagents to produce "knock-ins" in mice. The human or rat T1R gene sequences can replace the orthologous T1R in the mouse genome. In this way, a mouse expressing a human or rat T1R is produced. This mouse can then be used to analyze the function of human or rat T1Rs, and to identify ligands for such T1Rs.

*a. Modulators*

The compounds tested as modulators of a T1R family member can be any small chemical compound, or a biological entity, such as a protein, nucleic acid or lipid. Examples thereof include $5^1$ IMP and $5^1$ GMP. Essentially any chemical compound can be used as a potential modulator or ligand in the assays of the invention, although most often compounds that are soluble in aqueous solutions are tested. Assays can be designed to screen large chemical libraries by automating the assay steps and providing compounds from any convenient source; these assays are typically run in parallel (*e.g.*, in microtiter formats on microtiter plates in robotic assays). It will be appreciated that chemical libraries can be synthesized by one of many chemical reactions (e.g. Senomyx proprietary chemistries). Additionally, there are many suppliers of chemical compounds, including Sigma (St. Louis, MO), Aldrich (St. Louis, MO), Sigma-Aldrich (St. Louis, MO), Fluka Chemika-Biochemica Analytika (Buchs, Switzerland) and the like.

In one preferred embodiment, high throughput screening methods involve providing a combinatorial chemical or peptide library containing a large number of potential taste affecting compounds (potential modulator or ligand compounds). Such "combinatorial chemical libraries" or "ligand libraries" are then screened in one or more assays, as described herein, to identify those library members (particular chemical species or subclasses) that display a desired characteristic activity. The compounds thus identified can serve as conventional "lead compounds" or can themselves be used as potential or actual taste modulators.

Preferably, such libraries will be screened against cells or cell lines that stably express a T1R or combination of T1Rs, i.e. T1R1/T1R3 or T1R2/T1R3 and preferably a suitable G protein, e.g. $G_{\alpha 15}$. As shown in the examples infra, such stable cell lines exhibit very pronounced responses to taste stimuli, e.g. umami or sweet taste stimuli. However, cells and cell lines that transiently express one or more T1Rs may also be used in such assays.

A combinatorial chemical library is a collection of diverse chemical compounds generated by either chemical synthesis or biological synthesis, by combining a number of chemical "building blocks" such as reagents. For example, a linear combinatorial chemical library such as a polypeptide library is formed by combining a set of chemical building blocks (amino acids) in every possible way for a given compound length (*i.e.*,

the number of amino acids in a polypeptide compound). Thousands to millions of chemical compounds can be synthesized through such combinatorial mixing of chemical building blocks.

Preparation and screening of combinatorial chemical libraries is well known to those of skill in the art. Such combinatorial chemical libraries include, but are not limited to, peptide libraries (*see, e.g.*, U.S. Patent 5,010,175, Furka, *Int. J. Pept. Prot. Res.*, 37:487-493 (1991) and Houghton *et al.*, *Nature*, 354:84-88 (1991)). Other chemistries for generating chemically diverse libraries can also be used. Such chemistries include, but are not limited to: peptoids (*e.g.*, PCT Publication No. WO 91/19735), encoded peptides (*e.g.*, PCT Publication WO 93/20242), random bio-oligomers (*e.g.*, PCT Publication No. WO 92/00091), benzodiazepines (*e.g.*, U.S. Pat. No. 5,288,514), diversomers such as hydantoins, benzodiazepines and dipeptides (Hobbs *et al.*, *Proc. Nat. Acad. Sci.*, 90:6909-6913 (1993)), vinylogous polypeptides (Hagihara *et al.*, *J. Amer. Chem. Soc.*, 114:6568 (1992)), nonpeptidal peptidomimetics with glucose scaffolding (Hirschmann *et al.*, *J. Amer. Chem. Soc.*, 114:9217-9218 (1992)), analogous organic syntheses of small compound libraries (Chen *et al.*, *J. Amer. Chem. Soc.*, 116:2661 (1994)), oligocarbamates (Cho *et al.*, *Science*, 261:1303 (1993)), peptidyl phosphonates (Campbell *et al.*, *J. Org. Chem.*, 59:658 (1994)), nucleic acid libraries (Ausubel, Berger and Sambrook, all *supra*), peptide nucleic acid libraries (U.S. Patent 5,539,083), antibody libraries (Vaughn *et al.*, *Nature Biotechnology*, 14(3):309-314 (1996) and PCT/US96/10287), carbohydrate libraries (Liang *et al.*, *Science*, 274:1520-1522 (1996) and U.S. Patent 5,593,853), small organic molecule libraries (benzodiazepines, Baum, *C&EN*, Jan 18, page 33 (1993); thiazolidinones and metathiazanones, U.S. Patent 5,549,974; pynrolidines, U.S. Patents 5,525,735 and 5,519,134; morpholino compounds, U.S. Patent 5,506,337; benzodiazepines, 5,288,514, and the like).

Devices for the preparation of combinatorial libraries are commercially available (*see, e.g.*, 357 MPS, 390 MPS (Advanced Chem Tech, Louisville KY), Symphony (Rainin, Woburn, MA), 433A (Applied Biosystems, Foster City, CA), 9050 Plus (Millipore, Bedford, MA)). In addition, numerous combinatorial libraries are themselves commercially available (*see, e.g.*, ComGenex, Princeton, NJ; Tripos, Inc., St. Louis, MO; 3D Pharmaceuticals, Exton, PA; Martek Biosciences; Columbia, MD; *etc.*).

In one aspect of the invention, the T1R modulators can be used in any food product, confectionery, pharmaceutical composition, or ingredient thereof to thereby modulate the taste of the product, composition, or ingredient in a desired manner. For instance, T1R modulators that enhance sweet taste sensation can be added to sweeten a product or composition; T1R modulators that enhance umami taste sensation can be added to foods to increase savory tastes. Alternatively, T1R antagonists can be used to block sweet and/or umami taste.

*b. Kits*

T1R genes and their homologs are useful tools for identifying chemosensory receptor cells, for forensics and paternity determinations, and for examining taste transduction. T1R family member-specific reagents that specifically hybridize to T1R nucleic acids, such as T1R probes and primers, and T1R specific reagents that specifically bind to a T1R polypeptide, *e.g.*, T1R antibodies are used to examine taste cell expression and taste transduction regulation.

Nucleic acid assays for the presence of DNA and RNA for a T1R family member in a sample include numerous techniques are known to those skilled in the art, such as southern analysis, northern analysis, dot blots, RNase protection, S1 analysis, amplification techniques such as PCR, and *in situ* hybridization. In *in situ* hybridization, for example, the target nucleic acid is liberated from its cellular surroundings in such as to be available for hybridization within the cell while preserving the cellular morphology for subsequent interpretation and analysis. The following articles provide an overview of the art of *in situ* hybridization: Singer *et al.*, *Biotechniques*, 4:230250 (1986); Haase *et al.*, *Methods in Virology*, vol. VII, pp. 189-226 (1984); and *Nucleic Acid Hybridization: A Practical Approach* (Names *et al.*, eds. 1987). In addition, a T1R polypeptide can be detected with the various immunoassay techniques described above. The test sample is typically compared to both a positive control (*e.g.*, a sample expressing a recombinant T1R polypeptide) and a negative control.

The present invention also provides for kits for screening for modulators of T1R family members. Such kits can be prepared from readily available materials and reagents. For example, such kits can comprise any one or more of the following materials: T1R nucleic acids or proteins, reaction tubes, and instructions for testing

T1R activity. Optionally, the kit contains a biologically active T1R receptor or cell line that stably or transiently expresses a biologically active T1R containing taste receptor. A wide variety of kits and components can be prepared according to the present invention, depending upon the intended user of the kit and the particular needs of the user.

## EXAMPLES

While the invention has been described in detail supra, the following examples are provided to illustrate preferred embodiments. These examples are intended to be illustrative and not limitative of the scope of the invention.

In the protein sequences presented herein, the one-letter code X or Xaa refers to any of the twenty common amino acid residues. In the DNA sequences presented herein, the one letter codes N or n refers to any of the of the four common nucleotide bases, A, T, C, or G.

### Example 1

**Production of Intronless hT1R Expression Constructs**

Intronless hT1R expression constructs were cloned by a combination of cDNA-based and genomic DNA-based methods. To generate the full-length hT1R1 expression construct, two 5' coding exons identified in a cloned hT1R1 interval (accession # AL159177) were combined by PCR-overlap, and then joined to a 5'-truncated testis cDNA clone. The hT1R2 expression construct was generated from a partially sequenced hT1R2 genomic interval. Two missing hT1R2 5' exons were identified by screening shotgun libraries of the cloned genomic interval using probes derived from the corresponding rat coding sequence. Coding exons were then combined by PCR-overlap to produce the full-length expression construct. The hT1R3 expression construct was generated by PCR-overlap from a sequenced hT1R3 genomic interval (accession # AL139287). Rat T1R3 was isolated from a rat taste tissue-derived cDNA library using an rT1R3 exon fragment generated by hT1R3-based degenerate PCR. The partial hT1R1 cDNA, rT1R2 cDNA, and partial hT1R2 genomic sequences were obtained from Dr. Charles Zuker (University of California, San Diego).

The nucleic acid and amino acid sequences for the above-identified T1R cloned sequences as well as other full-length and partial T1R sequences are set forth in the sequence listing.

Also, the following conceptual translations, which correspond to the C-termini of two orthologous pairs of fish T1Rs, are derived from unpublished genomic sequence fragments and provided. Fugu T1RA was derived from accession 'scaffold 164'; Fugu T1RB was derived from accession LPC61711; Tetradon T1RA was derived from accession AL226735; Tetradon T1RB was derived from accession AL222381. Ambiguities in the conceptual translations ('X') result from ambiguities in database sequences. These sequences can be found in the sequence listing.

Additionally, the accession number and reference citations relating to mouse and rat T1Rs and allelic variants thereof in the public domain are is set forth below: rT1R1 (Accession # AAD18069) (Hoon et al., Cell 96 (4): 541-51 (1999)); rT1R2 (Accession # AAD18070) (Hoon et al., Cell 96(4): 541-59 (1999)); mT1R1 (Accession # AAK39437); mT1R2 (Accession #AAK 39438); mT1R3 (Accession AAK 55537) (Max et al., Nat. Genet. 28(l): 58-63 (2001)); rT1R1 (Accession # AAK7092) (Li et al., Mamm. Genome (12(l): 13-16 (2001)); mT1R1 (Accession # NP 114073); mT1R1 (Accession # AAK07091) (Li et al., Mamm. Genome (12l):13-16 (2001)); rT1R2 (Accession # AAD18070) (Hoon et al., Cell 9664): 541-551 (1999)); mT1R2 (Accession # NP114079); mT1R3 (Accession # AAK39436); mT1R3 (Accession # BAB47181); (Kitagawa et al., Biochem. Biophys. Res. Comm. 283(l):236-42 (2001)); mT1R3 (Accession #NP114078); mT1R3 (Accession # AAK55536) (Max et al., Nat. Genet. 28(l):58-63 (2001)); and mT1R3 (Accession No. AAK01937).

## Example 2

### Sequence Alignment of Human and Rat T1Rs

Cloned T1R sequences selected from those identified above were aligned against the corresponding rat T1Rs. As shown in Figure 1, human T1R1, human T1R2 and human T1R3 and rat T1R3 were aligned with previously described T1Rs (rT1R1 having Accession # AAD18069 and rT1R2 having Accession # AAD18070), the rat mGluR1 metabotropic, glutamate receptor (Accession # P23385); and the human calcium-sensing receptor (Accession #P41180). For clarity of the comparison, the

mGluR1 and calcium-sensing receptor C-termini are truncated. The seven potential transmembrane segments are boxed in blue. Residues that contact the glutamate side-chain carbutylate in the mGluR1 crystal structure are boxed in red, and residues that contact the glutamate α-amino acid moiety are boxed in green. The mGluR1 and calcium-sensing receptor cysteine residues implicated in intersubunit disulfide-based formation are circled in purple. These cysteines are not conserved in T1R1 and T1R2, but are located in a degraded region of the alignment that contains a potentially analogous T1R3 cysteine residue, also circled.

**Example 3**

**Demonstration by RT-PCR that hT1R2 and hT1R3 are expressed in taste tissue**

As shown in Figure 2, hT1R2 and hT1R3 are expressed in taste tissue: expression of both genes can be detected by RT-PCR from resected human circumvallate papillae.

**Example 4**

**Methods for Heterologous Expression of T1Rs in Heterologous Cells**

An HEK-293 derivative (Chandrashekar et al., Cell 100(6): 703-11 (2000)), which stably expresses Gα15, was grown and maintained at 37°C in Dulbecco's Modified Eagle Medium (DMEM, Gibco BRL) supplemented with 10% FBS, MEM non-essential amino acids (Gibco BRL), and 3 μg/ml blasticidin. For calcium-imaging experiments, cells were first seeded onto 24-well tissue-culture plates (approximately 0.1 million cells per well), and transfected by lipofection with Mirus TransIt-293 (PanVera). To minimize glutamate-induced and glucose-induced desensitization, supplemented DMEM was replaced with low-glucose DMEM/GlutaMAX (Gibco BRL) approximately 24 hours after transfection. 24 hours later, cells were loaded with the calcium dye Fluo-4 (Molecular Probes), 3μM in Dulbecco's PBS buffer (DPBS, GibcoBRL), for 1.5 hours at room temperature. After replacement with 250μl DPBS, stimulation was performed at room temperature by addition of 200μl DPBS supplemented with taste stimuli. Calcium mobilization was monitored on a Axiovert S100 TV microscope (Zeiss) using Imaging Workbench 4.0 software (Axon). T1R1/T1R3 and T1R2/T1R3 responses were strikingly transient – calcium increases rarely persisted longer than 15 seconds – and asynchronous. The number of responding

cells was thus relatively constant over time; therefore, cell responses were quantitated by manually counting the number of responding cells at a fixed time point, typically 30 seconds after stimulus addition.

## Example 5

**Human T1R2/T1R3 functions as a sweet taste receptor**

HEK cells stably expressing Gα15 were transiently transfected with human T1R2, T1R3 and T1R2/T1R3, and assayed for increases in intracellular calcium in response to increasing concentrations of sucrose (Figure 3(a)). Also, T1R2/T1R3 dose responses were determined for several sweet taste stimuli (Figure 3(b)). The maximal percentage of responding cells was different for different sweeteners, ranging from 10-30%. For clarity, dose responses were normalized to the maximal percentage of responding cells. The values in Figure 3 represent the mean ± s.e. of four independent responses. X-axis circles mark psychophysical detection thresholds determined by taste testing. Gurmarin (50-fold dilution of a filtered 10g/l *Gymnema sylvestre* aqueous extract) inhibited the response of T1R2/T1R3 to 250 mM sucrose, but not the response of endogenous β2-adrenergic receptor to 20 μM isoproterenol (Figure 3(b)). Figure 3(c) contains the normalized response of T1R2/T1R3 co-expressing cell lines to different sweeteners(sucrose, aspartame, D-tryptophan and saccharin).

## Example 6

### Rat T1R2/T1R3 also functions as a sweet taste receptor

HEK cells stably expressing Gα15 were transiently transfected with hT1R2/hT1R3, rT1R2/rT1R3, hT1R2/rT1R3, and rT1R2/hT1R3. These transfected cells were then assayed for increased intracellular calcium in response to 350 mM sucrose, 25 mM tryptophan, 15 mM aspartame, and 0.05% of monellin. The results with sucrose and aspartame are contained in Figure 4 and indicate that rT1R2/rT1R3 also functions as a sweet taste receptor. Also, these results suggest that T1R2 may control T1R2/T1R3 ligand specificity.

## Example 7

### T1R2/T1R3 responses using an automated fluorescence based assay

HEK cells stably expressing Gα15 were transiently transfected with hT1R2 and hT1R3. These cells were loaded with the calcium dye Fluo-4, and their responses to a sweetener measured using a fluorescence plate reader. Figure 5 contains cyclamate (12.5 mM) responses for cells expressing hT1R2/hT1R3 and for cells expressing only hT1R3 (J19-22). The fluorescence results obtained indicate that responses to these taste stimuli only occurred in the cells expressing hT1R2/hT1R3. Figure 6 contains normalized dose-response curves, the results of which show that hT1R2 and hT1R3 function together as a human taste receptor based on their dose-specific interaction with various sweet stimuli . Particularly, Figure 6 contains dose-responses for sucrose, tryptophan and various other commercially available sweeteners. These results indicate that T1R2/T1R3 is a human sweet taste receptor as the rank order and threshold values obtained in the assay closely mirror values for human sweet taste.

## Example 8

### Ligand-binding residues of mGluR1 are conserved in T1R1

As shown in Figure 6, the key ligand-binding residues of mGluR1 are conserved in T1R1. The interaction of glutamate with mGluR1 is shown with several key residues highlighted according to the same color scheme as Figure 1.

## Example 9

### Human T1R1/T1R3 functions as umami taste receptors

HEK cells stably expressing Gα15 were transiently transfected with human T1R1, T1R3 and T1R1/T1R3 and assayed for increases in intracellular calcium in response to increasing concentrations of glutamate (Figure 8(a)), and 0.5 mM glutamate), 0.2 mM IMP, and 0.5 mM glutamate plus 0.2 mM IMP (Figure 8(b)). Human T1R1/T1R3 dose responses were determined for glutamate in the presence and absence of 0.2 mM IMP (Figure 8(c)). The maximal percentages of responding cells was approximately 5% for glutamate and approximately 10% for glutamate plus IMP. For clarity, does responses are normalized to the maximal percentage of responding cells. The values represent the mean $\pm$ s.e. of four independent responses. X-axis circles mark taste detection thresholds determined by taste testing.

## Example 10

### PDZIP as an Export Sequence

The six residue PDZIP sequence (SVSTW (SEQ ID NO:1)) was fused to the C-terminus of hT1R2 and the chimeric receptor (i.e. hT1R2-PDZIP) was transfected into an HEK-293 host cell. The surface expression of hT1R2 was then monitored using immunofluorescence and FACS scanning data. As shown in Figures 9A and 9B, the inclusion of the PDZIP sequence increased the surface expression of hT1R2-PDZIP relative to hT1R2. More specifically, Figure 9A shows an immunofluorescence staining of myc-tagged hT1R2 demonstrating that PDZIP significantly increases the amount of hT1R2 protein on the plasma membrane. Figure 9B shows FACS analysis data demonstrating the same result– Cells expressing myc-tagged hT1R2 are indicated by the dotted line and cells expressing myc-tagged hT1R2-PDZIP are indicated by the solid line. Particularly, Figure 10A shows untransfected Gα15 stable host cells in HBS

buffer, Figure 10B shows hT1R2-PDZIP transfected Gα15 stable hose cells in sweetener pool no. 5 (saccharin, sodium cyclamate, Acesulfame K, and Aspartame-20 mM each in HBS buffer), Figure 10C shows T1R3-PDZIP transfected Gα15 stable host cells in sweetener pool no. 5, and Figure 10D shows hT1R2-PDZIP/hT1R3-PDZIP co-transfected Gα15 stable host cells in sweetener pool no. 5. Further, Figures 10E-10H show dose-dependent response of hT1R2/hT1R3 co-transfected Gα15 stable host cells to sucrose-E: 0mM in HBS buffer; F: 30 mM; G: 60 mM; and H: 250 mM. Figures 10I-10L shown the responses of hT1R2/hT1R3 co-transfected Gα15 stable host cells to individual sweeteners – I: Aspartame (1.5 mM); J: Acesulfame K (1 mM); K: Neotame (20mM); L: Sodium cyclamate (20mM). As demonstrated by the calcium-images of Figure 10, hT1R2 and hT1R3 are both required for the activities triggered by the sweet stimuli.

**Example 11**

**Generation of Cell Lines that Stably Co-Express T1R1/T1R3 or T1R2/T1R3**

Human cell lines that stably co-express human T1R2/T1R3 or human T1R1/T1R3 were generated by transfecting linearized PEAK10-derived (Edge Biosystems) vectors and pCDNA 3.1/ZEO-derived (Invitrogen) vectors respectively containing hT1R1 or hT1R2 expression construct (plasmid SAV2485 for T1R1, SAV2486 for T1R2) and hT1R3 (plasmid SXV550 for T1R3) into a $G_{\alpha 15}$ expressing cell line. Specifically, T1R2/T1R3 stable cell lines were produced by co-transfecting linearized SAV2486 and SXV550 into Aurora Bioscience's HEK-293 cell line that stably expresses $G_{\alpha 15}$. T1R1/T1R3 stable cell lines were produced by co-transfecting linearized SAV2485 and SXV550 into the same HEK-293 cell line that stably expresses $G_{\alpha 15}$. Following SAV2485/SXV550 and SAV2486/SXV550 transfections, puromycin-resistant and zeocin-resistant colonies were selected, expanded, and tested by calcium imaging for responses to sweet or umami taste stimuli. Cells were selected in 0.0005 mg/ml puromycin (CALBIOCHEM) and 0.1 mg/ml zeocin (Invitrogen) at 37°C in low-glucose DMEM supplemented with GlutaMAX, 10% dialyzed FBS, and 0.003 mg/ml blasticidin. Resistant colonies were expanded, and their responses to sweet taste stimuli evaluated by Fluorescence microscopy. For automated fluorimetric imaging on VIPR-II instrumentation (Aurora Biosciences), T1R2/T1R3 stable cells were first seeded onto 96-well plates (approximately 100,000 cells per well). Twenty-

four hours later, cells were loaded with the calcium dye fluo-3-AM (Molecular Probes), 0.005 mM in PBS, for one hour at room temperature. After replacement with 70 µl PBS, stimulation was performed at room temperature by addition of 70 µl PBS supplemented with taste stimuli. Fluorescence (480 nm excitation and 535 nm emission) responses from 20 to 30 seconds following compound addition were averaged, corrected for background fluorescence measured prior to compound addition, and normalized to the response to 0.001 mM ionomycin (CALBIOCHEM), a calcium ionophore.

It was then observed that when these cell lines were exposed to sweet or umami stimuli, that for active clones typically 80-100% of cells responded to taste stimuli. Unexpectedly, the magnitude of individual cell responses was markedly larger than that of transiently transfected cells.

Based on this observation, the inventors tested the activity of T1R stable cell lines by automated fluorescence imaging using Aurora Bioscience's VIPR instrumentation as described above. The responses of two T1R1/T1R3 and one T1R2/T1R3 cell line are shown in Figure 11 and Figure 12 respectively.

Remarkably, the combination of increased numbers of responding cells and increased response magnitudes resulted in a greater than 10-fold increase in activity relative to transiently transfected cells. (By way of comparison, the percent ionomycin response for cells transiently transfected with T1R2/T1R3 was approximately 5% under optimal conditions.) Moreover, dose responses obtained for stably expressed human T1R2/T1R3 and T1R1/T1R3 correlated with human taste detection thresholds. The robust T1R activity of these stable cell lines suggests that they are well suited for use in high-throughput screening of chemical libraries in order to identify compounds, e.g. small molecules, that modulate the sweet or umami taste receptor and which therefore modulate, enhance, block or mimic sweet or umami taste.

## Example 12

**Generation of cell lines that inducibly co-express T1R1/T1R3 which selectively respond to umami taste stimuli**

T1R1/T1R3 HEK 293 cell lines that stably expressed the umami taste receptor display robust improved activity relative to transiently tranfected cites. However, a disadvantage is that they can rapidly lose activity during cell propagation.

Also, these findings show that (i) T1R1/T1R3 is a umami taste receptor, i.e., and (ii) that cell lines which robustly express T1R1/T1R3, preferably stable and/or inducible T1R1/T1R3 cell lines can be used in assays, preferably for high throughput screening of chemical libraries to identify novel modulators of umami taste. Modulators that enhance umami taste may be used.

To overcome the instability of the T1R1/T1R3 stable cell lines, the HEK-$G_{\alpha 15}$ cells have been engineered to inducibly express T1R1/T1R3 using the GeneSwitch system (Invitrogen). pGene-derived zeocin-resistant expression vectors for human T1R1 and T1R3 (plasmid SXV603 for T1R1 and SXV611 for T1R3) and a puromycin-resistant pSwitch-derived vector that carries the GeneSwitch protein (plasmid SXV628) were linearized and cotransfected into the HEK-$G_{\alpha 15}$ cell line. Zeocin-resistant and puromycin-resistant colonies were selected, expanded, induced with variable amounts of mifepristone, and tested by calcium imaging for responses to umami taste stimuli.

Inducible expression of T1R1/T1R3 resulted in robust activity. For example, approximately 80% of induced cells but only approximately 10% of transiently transfected cells responded to L-glutamate; More specifically, pGene derived Zeocin-resistant expression vectors that express human T1R1 and human T1R3 and a puromycn-resistant pSwitch-derived vector that carries the GeneSwitch protein were linearized and co-tranfected into $G_{\alpha 15}$ cells. Cells were selected in 0.5 μg/ml puromycin (CAL BIOCHEM) and 100 μg/ml Zeocin (Invitrogen) at 37°C in Dulbecco's Modified Eagle Medium supplemented with GlutaMAX, (10 % dialyzed FBS, and 3 ug/ml blasticidin. Resistant colonies were expanded, and their responses to umami taste stimuli following induction with $10^{-10}$ M mifepristone determined by fluorescence microscopy following the methods of Li et al., PNAS 99(7): 4692-4696 (2002).

For automated fluorometric imaging on FLIPR instrumentation (Molecular Device), cells from one clone (designated clone I-17) were seeded into 96-well plates (approximately 80,000 cell per well) in the presence of $10^{-10}$ M mifepristone and incubated for 48 hours. Cells were then loaded with the calcium dye fluo-4-AM (Molecular Probes), 3 μM in PBS, for 1.5 hours at room temperature.

After replacement with 50 μl PBS, stimulation was performed at room temperature by the addition of 50 μl PBS supplemented with different stimuli. In contrast to previous transient T1R1/T1R3 umami receptor expression systems that

necessitated quantifying T1R1/T1R3 receptor activity by individually counting responding cells (Li et al., PNAS 99(7): 4692-4696 (2002)) (because of the low activity of the receptor therein), the subject inducible expression system resulted in a clone I-17 having substantially increased activity that allowed receptor activity to be quantified by determining maximal fluorescence increases (480 nm excitation and 535 nm emission) summated over fields of imaged cells. The maximal fluorescence from four independent determinations was averaged, corrected for background fluorescence measured prior to compound addition, and normalized to the response to 0.002 mM ionomycin (CALBIOCHEM).

These results are contained in Figure 13. Particularly, Figure 13 contains a dose-response curve determined for L-glutamate in the presence and absence of 0.2 mM IMP. In the figure, each value represents average summated maximal fluorescence (corrected for background fluorescence) for four independent determinations. These dose-response curves correspond to those determined for cells transiently transfected with T1R1/T1R3.

The selectivity of the umami T1R1/T1R3 taste receptor was also evaluated by screening with different L-amino acids. The results obtained indicated that T1R1/T1R3 is selectively activated by the umami-tasting L-amino acids (L-glutamate and L-aspartate).

The results of experiments wherein the responses of the I-17 clone was resulted in tested in the presence of different L-amino acids are contained in Figure 14 and Figure 15. Figure 14 shows the results of an experiment wherein the I-17 cell line was contacted with different L-amino acids at a concentration of 10mM in the presence and absence of 1mM IMP.

Figure 15 contains a dose-response curve for active amino acids determined in the presence of 0.2mM IMP. Each value represents the average of four independent determinations.

The results obtained in these experiments support the specificity and selectivity of the umami taste receptor to umami taste stimuli. Whereas the umami taste stimuli L-glutamate and L-aspartate significantly activated the T1R1/T1R3 receptor at different concentrations (see Figure 14 and 15), the other L-amino acids which activated the human T1R1/T1R3 receptor only activated the receptor weakly and at much higher concentrations.

Therefore, these results support the selectivity of the T1R1/T1R3 receptor for umami taste stimuli and the suitability of this inducible stable expression system for use in high throughput screening assays using automated fluorometric imaging instrumentation to identify compounds that activate the umami taste receptor, for example L-glutamate or L-aspartate , or which enhance the activity of L-glutamate to activate the umami taste receptor, for example 5'-IMP or 5'-GMP, or block the activation of the umami taste receptor by umami taste stimuli such as L-glutamate and L-aspartate.

Compounds identified using these assays have potential application as flavorants in foods and beverage compositions for mimicing or blocking umami taste stimuli.

**Example 13**

**Lactisole Inhibits the Receptor Activities of Human T1R2/T1R3 and T1R1/T1R3 , and Sweet and Umami Taste**

Lactisole, an aralkyl carboxylic acid, was thought to be a selective sweet-taste inhibitor (See e.g., Lindley (1986) U.S. Patent 4,567,053; and Schiffman et al. Chem Senses 24:439-447 (1999)). Responses of HEK-$G_{\alpha 15}$ cells transiently transfected with T1R2/T1R3 to 150 mM sucrose in the presence of variable concentrations of lactisole were measured. Lactisole inhibits the activity of human T1R2/T1R3 with an $IC_{50}$ of 24 μM.

The T1R1/T1R3 umami and T1R2/T1R3 sweet taste receptor may share a common subunit. It has therefore been theorized that lactisole, which inhibit the T1R2/T1R3 sweet taste receptor, may have a similar effect on the T1R1/T1R3 umami taste receptor. The present inventors tested the effect of lactisole on the response of human T1R1/T1R3 to 10mM L-Glutamate. As with the T1R2/T1R3 sweet receptor, lactisole inhibited T1R1/T1R3 with an $IC_{50}$ of 165 μM. Lactisole inhibition likely reflects antagonism at the T1R receptors instead of, for example, non-specific inhibition of $G_{\alpha 15}$-mediated signaling because the response of muscarinic acetylcholine receptors was not inhibited by lactisole.

The present inventors then evaluated the effect of lactisole on human umami taste. Taste thresholds in the presence of 1 and 2 mM lactisole were determined for the umami taste stimuli L-Glutamate with or without 0.2 mM IMP, the sweet taste stimuli

sucrose and D-tryptophan, and the salty taste stimulus sodium chloride following the methods of Schiffman et al. (Chem. Senses 24: 439-447 (1989)). Millimolar concentrations of lactisole dramatically increased detection thresholds for sweet and umami but not salt taste stimuli. These results are contained in Figure 16.

In conclusion, (i) these findings further support the inventors' hypothesis that T1R1/T1R3 is the only umami taste receptor, and (ii) the T1R1/T1R3 and T1R2/T1R3 receptors may share a structurally related lactisole-binding domain.

While the foregoing detailed description has described several embodiments of the present invention, it is to be understood that the above description is illustrative only and not limiting of the disclosed invention. The invention is to be limited only by the claims which follow.

**Example 14**

**Mapping of Ligand Interaction Sites on the Sweet Receptor**

Through coexpression of T1R2R-H with human T1R3, part of the human sweet receptor (the N-terminal domain of T1R2) was replaced with rat protein sequence. The responses to aspartame and neotame are abolished, showing that the N- terminal domain of human T1R2 is required for recognizing aspartame and neotame. Similarly, the rat T1R2 N-terminal domain was also replaced with human protein sequence by coexpressing T1R2H-R with rat T1R3. The chimeric receptor gains the ability to respond to aspartame and neotame, suggesting that the same domain of human T1R2 is also sufficient (in the context of sweet receptors) to recognize those two sweeteners (Fig. 22B). These *in vitro* functional expression data indicate that the important interaction determinants are located in the N-terminal extracellular domain.

In contrast, replacing either half of human T1R2 with rat protein sequence does not affect its response to cyclamate. Instead, the C-terminal domain of human T1R3 is required and sufficient, when co-expressed with T1R2, to recognize cyclamate (Fig. 22C). The transmembrane domain of family C GPCRs has been known to contain binding sites for allosteric modulators (Gasparini, F., R. Kuhn, and J.P. Pin, Curr Opin Pharmacol 2002 Feb;2(1):43-9). This is the first case in family C GPCR, where an agonist binds directly to the transmembrane domain and activates the receptor in the absence of other ligand. .

Lactisole, an aralkyl carboyxlic acid, is a specific human sweet taste inhibitor, which has physiological effect on the rodent taste. Consistent with the taste effect, lactisole inhibits the human but not rat T1R2/T1R3 response to sucrose in our assay system (Fig. 22A). The same kind of mapping experiments on lactisol interaction site using the T1R chimeras was performed. Like cyclamate, lactisole requires the human T1R3 C-terminal domain to inhibit the receptor's response to sucrose and acesulfame K
(Fig. 22D). This result further demonstrates the importance of T1R3 C-terminal domain in the sweet receptor function. The chimeras in all 16 possible combinations were tested, and all functional combinations generated results consistent with our model.

Mutagenesis studies were conducted on both T1R2 and T1R3 to narrow down the essential amino acids in recognition of aspartame, neotame, and cyclamate. If T1R2 and T1R3 are responsible for recognizing different sweeteners, mutations in T1R2 N-terminal domain would affect responses to aspartame and neotame, but not cyclamate. In addition, mutations in T1R3 C-terminal domain would have the opposite effect. To select the crucial amino acid residues in the T1R2 N-terminal domain, the sequence of T1R2 was aligned with mGluR1 (Fig. 23A). Among the eight residues that are crucial in ligand binding in mGluR1 (Kunishima, N., et al., Nature, 2000. 407(6807): p. 971-7), three are conserved in human T1R2 (S144, Y218, and E302). Each of the three residues were mutated and the resulting receptors were tested for their response to different sweeteners. Substitution of Y218 to A abolished the responses to all sweeteners tested, showing Y218 is important for the overall conformation of the receptor. The two other hT1R2 variants, containing S144A and E302A, selectively affected the response to aspartame and neotame but not cyclamate. Stable cell lines expressing S144A and E302A hT1R2 variants (coexpressed with wild type hT1R3 and $G_{\alpha 15}$) did not respond to aspartame or neotame at the physiological concentrations, but did respond to cyclamate (Fig. 23B).

In order to further map the cyclamate-binding site, the three extracellular loops in the T1R3 C-terminal domain were focused on. Alignment of human and rodent T1R3s reveal multiple amino acid differences in the three extracellular loops (Fig. 23C). Replacing extracellular loop-2 or loop-3 with rat sequences abolished the cyclamate response without affecting the sucrose or aspartame responses. In contrast,

replacing extracellular loop 1 had no obvious effect on response to cyclamate, showing an important role for EC loops 2 and 3 in recognizing cyclamate (Fig. 23D). None of those loop-replacements affected the inhibition effect of lactisole, showing a different binding mechanism. In summary, amino acid substitutions in T1R2 or T1R3 result in selective interference of activities induced by different sweeteners, consistent with the chimeric receptor results.

The above results demonstrate that the human sweet receptor function as a heteromeric complex of T1R2 and T1R3. Both subunits are required for recognizing different sweeteners, and the data indicate the existence of multiple binding pockets on the receptor for different classes of agonists. The presence of multiple ligand-binding sites provides structural guidance and definition for the specifically binding compounds of the invention.

**Example 15**

**Mapping of Receptor-G protein Interactions**

The human and rat sweet receptors are also different in their G protein-coupling efficiency. Even though both human and rat receptors can couple efficiently to $G_{\alpha 15/il}$, only the human receptor can couple efficiently to $G_{\alpha 15}$ (Fig. 24A). This species difference allows for mapping of the receptor G protein interactions using the same chimeric receptors as described above. T1R2 but not T1R3 appears to be critical for $G_{\alpha 15}$-coupling, since replacing the C-terminus of human T1R2 with the corresponding rat sequence abolished coupling, and replacing rat T1R2 C-terminal half with human sequence enabled the receptor to couple to $G_{\alpha 15}$ and respond to sucrose and acesulfame K (Fig. 24); Swapping the T1R3 C-terminal sequences had no effect on $G_{\alpha 15}$–coupling (Fig. 24B). This observation demonstrates the important role of T1R2 in G protein-coupling in the functional expression system. Gustducin (Wong, G.T., K.S. Gannon, and R.F. Margolskee, Nature, 1996. 381(6585): p. 796-800) has been proposed to be an endogenous G protein for the sweet taste receptor, and T1R2 can be the subunit responsible for *in vivo* coupling in taste cells. $GABA_BR$ is the other example of heteromeric family C GPCR, whereas one subunit ($GABA_BR1$) is responsible for ligand- binding, and the other ($GABA_BR2$) for G protein coupling (Margeta-Mitrovic, M., Paroc Natl Acad Sci U S A, 2001. 98(25): p. 14643-8; Margeta-Mitrovic, M., Proc Natl Acad Sci U S A, 2001. 98(25): p. 14649-54). The sweet receptor is different from $GABA_BR$ in that T1R2 is required for both ligand recognition and G- protein coupling.

## Example 16

## Lactisole Antagonizes Human T1R1/T1R3 and Inhibits Human Umami Taste

It was hypothesized that since T1R1/T1R3 function as heteromeric receptors as well as the sweet receptor, that lactisole should have similar effect on T1R1/T1R3 activity, since T1R3 is a common subunit between the sweet and the umami receptors. Indeed, lactisole antagonized human T1R1/T1R3 (Fig. 25A). Lactisole acts as a noncompetitive inhibitor of T1R1/T1R3, since the $IC_{50}$ values are apparently not dependent on glutamate concentration (Fig. 25B), and lactisole reduces the maximal activities of the receptor without significantly changing the $EC_{50}$ of agonists (Fig. 25C). These results demonstrate that lactisole binds to a different site from L-glutamate, and are consistent with the hypothesis that the glutamate-binding pocket is located in T1R1. Lactisole appears to be a competitive inhibitor of the sweet receptor, as its $IC_{50}$s are dependent on the concentrations of the sweeteners, and it increases the $EC_{50}$s of the sweeteners without significantly affecting the maximal activities.

The inhibition effect of lactisole is mediated by the T1R receptors since it had no effect on the endogenous muscarinic acetylcholine receptor in HEK cells or on a mouse bitter receptor, mT2R5, transiently expressed in HEK cells. As was the case for the T1R2/T1R3 receptor, lactisole inhibition of the T1R1/T1R3 response to umami taste stimuli was reversible following washout and restimulation.

To correlate the receptor activity with behavior, the effect of lactisole on human umami taste was tested. As predicted, millimolar concentrations of lactisole dramatically increased detection thresholds for sweet and umami but not salt taste stimuli (Fig. 25D). Lactisole was previously not known to be an umami taste inhibitor. The correlation between receptor activity and taste results demonstrates a crucial role of T1Rs in human umami taste.

## Example 17

## Cyclamate Enhances Human T1R1/T1R3 Receptor Activities

Based on the same heteromeric model of T1Rs (Fig. 26), it was predicted that cyclamate would also modulate the activity of the human T1R1/T1R3 umami receptor by acting on T1R3. Although cyclamate alone had no effect on T1R1/T1R3, it enhanced the activity of the receptor in the presence of L-glutamate (Fig. 27E). This

effect is specific for the human T1R1/T1R3, as cyclamate had no effect on the activities of the endogenous muscarinic acetylcholine receptor in the presence of carbachol (Fig. 27E). It is noteworthy that cyclamate has comparable $EC_{50}$s for the sweet receptor (Fig. 23B) and umami receptor. Cyclamate reproducibly left-shifts the dose-response curves for L-glutamate by ~2 fold in the presence or absence of IMP (Fig. 25F). IMP has a more dramatic effect of enhancing the receptor, and the effect of cyclamate is observed in the presence of IMP (Fig. 25F), suggesting a different mechanism from IMP in enhancing the receptor. IMP appears to bind to T1R1, since it has no effect on the sweet receptor. Other sweeteners, including sucrose, aspartame, saccharin, and D-tryptophan, had no effect on the human T1R1/T1R3 activities.

In summary, it has been demonstrated that both T1R2 and T1R3 are required in a functional sweet receptor, that aspartame and neotame require the N-terminal extracellular domain of T1R2, G protein-coupling requires C-terminal half of T1R2, and that cyclamate and lactisole require the transmembrane domain of T1R3. These findings demonstrate the different functional roles of T1R subunits in a heteromeric complex and the presence of multiple sweetener interaction sites on the sweet receptor. Because T1R3 is the common subunit in the sweet and the umami receptors, it was predicted and confirmed the effect of cyclamate and lactisole on the umami receptor. Furthermore, a correlation was able to be made between the lactisole effect on the receptor activities with taste. Based on these observations, a model was created (Fig. 26) for the structure-function relationships of the T1R family taste receptors. Natural carbohydrate sweeteners bind to the N-terminal domain of T1R2, similar to aspartame and neotame, and there are other ligand binding sites on the sweet receptor as well, for example, the transmembrane domain of T1R2. The umami receptor functions similarly as a heteromeric complex, and MSG and IMP each appears to bind to the T1R1 subunit, since neither has any effect on the sweet receptor, and the transmembrane domain of T1R1 is responsible for coupling to G proteins.

## Example 18

### HTS Protocol for Sweet Tastants

An HEK293 cell line derivative (Chandrashekar, J., Mueller, K.L., Hoon, M.A., Adler, E., Feng, L., Guo, W., Zuker, C.S., Ryba, N.J.,. *Cel,l* 2000, *100,* 703-711.) that stably expresses Gα15 and hT1R2/hT1R3 (Li, X., Staszewski, L., Xu, H., Durick, K., Zoller, M., Adler, E. *Proc Natl Acad Sci U S A* 2002, *99*, 4692-4696, World Patent # WO 03/001876 A2, herein incorporated by reference in their entirety) was used to identify compounds with sweet taste enhancing properties.

Compounds were initially selected based on their activity on the hT1R2/hT1R3-HEK293-Gα15 cell line (Li, et al. *vide supra*). Activity was determined using an automated fluorometric imaging assay on a FLIPR instrument (Fluorometric Intensity Plate Reader, Molecular Devices, Sunnyvale, CA) (designated FLIPR assay). Cells from one clone (designated S-9 cells) were seeded into 384-well plates (at approximately 50,000 cells per well) in a medium containing DMEM Low Glucose (Invitrogen, Carlsbad, CA), 10% dialyzed fetal bovine serum (Invitrogen, Carlsbad, CA), 100 Units/ml Penicillin G, and 100 μg/ml Streptomycin (Invitrogen, Carlsbad, CA) (Li, et al. *vide supra*) see also World Patent #WO 03/001876 A2). S-9 cells were grown for 24 hours at 37 °C. S-9 cells were then loaded with the calcium dye Fluo-3AM (Molecular Probes, Eugene, OR), 4 μM in a phosphate buffered saline (D-PBS) (Invitrogen, Carlsbad, CA), for 1 hour at room temperature. After replacement with 25 μl D-PBS, stimulation was performed in the FLIPR instrument and at room temperature by the addition of 25 μl D-PBS supplemented with different stimuli at concentrations corresponding to twice the desired final level. Receptor activity was quantified by determining the maximal fluorescence increases (using a 480 nm excitation and 535 nm emission) after normalization to basal fluorescence intensity measured before stimulation.

For dose-responses analysis, stimuli were presented in duplicates at 10 different concentrations ranging from 60 nM to 30 μM. Activities were normalized to the response obtained with 400 mM D-fructose, a concentration that elicits maximum receptor response. $EC_{50}$s were determined using a non-linear regression algorithm

(using Senomyx, Inc. software), where the Hill slope, bottom asymptotes and top asymptotes were allow to vary. Identical results were obtained when analyzing the dose-response data using commercially available software for non-linear regression analysis such as GraphPad PRISM (San Diego, CA).

In order to determine the dependency of hT1R2/hT1R3 for the cell response to different stimuli, selected compounds were subjected to a similar analysis on HEK293-Gα15 cells (not expressing the human sweet receptor). The HEK293-Gα15 cells do not show any functional response in the FLIPR assay to D-Fructose or any other known sweeteners. Similarly, compounds described herein do not induce any functional response when using HEK293-Gα15 cells in the FLIPR assay.

**Example 19**

**Flavor Enhancement Measurements for Sweet Tastants using Human Volunteers**

Basic screening of sensory taste testers: Potential panelists were tested for their abilities to rank and rate intensities of solutions representing the five basic tastes. Panelists ranked and rated intensity of five different concentrations of each of the five following compounds: sucrose (sweet), sodium chloride (salty), citric acid (sour), caffeine (bitter), and monosodium glutamate (umami). Panelists tasted a total of 25 samples per session (5 samples of each of the 5 solution types). In the first session, panelists ranked the five concentrations for intensity of the attribute in question. This was repeated four more times with other samples. In the second session, panelists rated intensity of the five concentrations of each sample using a line scale called the "Labeled Magnitude Scale" (LMS). The LMS is anchored with intensities (e.g. barely detectable, weak, moderate, strong, very strong, and strongest imaginable) to assist panelists in rating the samples. Samples were tasted in 10ml volumes at room temperature and labeled with 3-digit blinding codes. Samples were presented in randomized, counterbalanced order within each sample solution (e.g. sucrose, citric acid, etc.).

In order to be selected for participation in testing, panelists needed to correctly rank and rate samples for intensity, with a reasonable number of errors. Approximately 25 people successfully completed this procedure.

Panelists selected in the above procedure were deemed qualified for performing Preliminary Taste Testing procedures. The preliminary taste tests are used to evaluate

new compounds for intensity of basic tastes and off-tastes. A small group of panelists (n=5) taste approximately 5 concentrations of the compound (range typically between 1-100uM, in half-log cycles, e.g. 1, 3, 10, 30, and 100uM) in water or buffer and in a solution of 4% (w/v, 117 mM) sucrose to evaluate enhancement. Typically samples also contain 0.1% ethanol in order to aid dispersion of the compound in a water-based solution. Panelists rate the five basic tastes (sweet, salty, sour, bitter, and umami) as well as off-tastes (such as chemical, metallic, sulfur) on the LMS. Samples are served in 10ml portions at room temperature. The purpose of the test is to determine the highest concentration at which there is no objectionable off-taste, and determine if obvious enhancement of sweet taste exists at any of the concentrations tested.

If the compound is effective and does not have objectionable off-tastes, it is tested with a trained (expert panel) in a larger study.

For example: Five panelists evaluated 1, 3, 10, 30, and 100uM XVI-3 in water and in 4% sucrose solution. All samples with compound were balanced for ethanol at 0.1% (aids in dispersion of compound). Panelists were asked to rate basic tastes and off-tastes using the LMS for each sample tasted. When panelists noted sweetness in any sample, they were asked to taste reference samples of sucrose (2, 4, 6, 8% sucrose) to estimate equivalent sweetness.

A trained (expert) panel was used to further evaluate compounds that had been tested with the preliminary taste test.

Panelists for the trained panel were selected from the larger group of qualifying taste panelists. Panelists were further trained on sweet taste by ranking and rating experiments using sucrose solutions. Panelists completed a series of ranking, rating, and difference from reference tests with sweet solutions. In ranking and rating experiments, panelists evaluated sucrose concentrations (2, 4, 6, 8 % (w/v)) sucrose.

Compounds tested by the trained panel were evaluated in difference from reference experiments. Panelists were given reference samples of various concentrations (2,4,6, or 8 % (w/v) sucrose) and asked to rate samples on a scale of –5 to +5 in terms of difference in sweet taste from the reference (score: –5= much less sweet taste than the reference; 0=same sweet taste as the reference; +5=much more sweet taste than the reference). Test samples were solutions with varying amounts of sucrose and compound. Typically, each session compared the reference sample (labeled as REF) to numerous test samples (labeled with 3-digit blinding codes). Tests

typically included various samples with varying concentrations of sucrose, as well as one blind sample of the reference itself, to evaluate panel accuracy. Compounds were tested against the reference in samples with and without 4% or 6% sucrose. All samples were presented in 10ml volumes at room temperature. Futhermore, to determine the sweetness of the compound alone, a reference solution was prepared at the designated concentration and compared to the threshold sweetness of sucrose (2%).

**Example 20**

**HTS Protocol for Umami Tastants**

HEK-$G_{\alpha 15}$ cells were engineered to inducibly express T1R1/T1R3 using the GeneSwitch system (Invitrogen). pGene-derived zeocin-resistant expression vectors for human T1R1 and T1R3 (plasmid SXV603 for T1R1 and SXV611 for T1R3) and a puromycin-resistant pSwitch-derived vector that carries the GeneSwitch protein (plasmid SXV628) were linearized and cotransfected into the HEK-$G_{\alpha 15}$ cell line. Zeocin-resistant and puromycin-resistant colonies were selected, expanded, induced with variable amounts of mifepristone, and tested by calcium imaging for responses to umami taste stimuli. Cells were selected in 0.5 μg/ml puromycin (CAL BIOCHEM) and 100 μg/ml Zeocin (Invitrogen) at 37°C in Dulbecco's Modified Eagle Medium supplemented with GlutaMAX, (10 % dialyzed FBS, and 3 ug/ml blasticidin. Resistant colonies were expanded, and their responses to umami taste stimuli following induction with $10^{-10}$ M mifepristone determined by fluorescence microscopy following the methods of Li, *et al.*, *PNAS* (2002) 99(7):4692-4696. For automated fluorometric imaging on FLIPR instrumentation (Molecular Device), cells from one clone (designated clone I-17) were seeded into 96- or 384-well plates (approximately 80,000 cell per well) in the presence of $10^{-10}$ M mifepristone and incubated for 48 hours. Cells were then loaded with the calcium dye fluo-4-AM (Molecular Probes), 3 μM in PBS, for 1.5 hours at room temperature. After replacement with 50 μl PBS, stimulation was performed at room temperature by the addition of 50 μl PBS supplemented with different stimuli. The maximal fluorescence from four independent determinations were averaged, corrected for background fluorescence measured prior to compound addition, and normalized to the response to 0.002 mM ionomycin (CALBIOCHEM).

**Example 21**

**Taste Test Protocol for Umami Tastants**

Basic Training of Sensory Tasters: Tasters were trained to evaluate the taste of aqueous solutions (5 mL each, "swash and spit") of the following standard taste compounds by using the triangle test as described in the literature: sucrose (50 mM) for sweet taste; citric acid (5 mM) or lactic acid (20 mM) for sour taste; NaCl (12 mM) for salty taste, quinine (10 μM) or caffeine (1 mM) for bitter taste; and monosodium glutamate (8 mM) for umami or "savory" taste.

Training for Umami Taste: Tasters were given 1-3 sets of 6 MSG and/or MSG-IMP samples ranging from 3-60 mM MSG and 0-200 μM IMP, each arranged in the tray in ascending concentration. This exercise gave the subject practice doing dose response evaluations. Then another set was made up of the same six samples, but were given in random order. The subject was then asked to arrange the samples in ascending intensity and then to rate their umami intensity.

Qualifying Taste Panelists: Tasters were subjected to a standard two alternative forced choice (2AFC) test with 5 pairs of taste samples. They were asked to make a choice of the most umami sample from two samples (a pair). The test contains two easy pairs, two with medium difficulty, and one difficult pair. Tasters who could differentiate the medium difficulty pairs were selected as panelists.

Pilot/Qualitative taste test of Umami Enhancer Candidate (UEC) by a small group of panelists: Taste samples of appropriate concentrations (usually 1-50 μM) were made in water (use minimum amount of ethanol if not soluble); Taste UEC alone at 30 and/or 50 μM for umami and other attributes. Rate those taste attributes on the appropriate Labeled Magnitude Scale (LMS) on the screening ballot; if UEC has no/low umami and other tastes, then move forward to discrimination test; compare certain concentration of MSG, *e.g.*, 12 mM and 12 mM MSG + 30 μM UEC to determine if there is any enhancement; rate the perceived umami intensity on the appropriate LMS on the screening ballot; vary concentration of UEC and/or MSG to find the best combination; decide what solutions to use in panel screening; record all procedures and data including description of study, sample prep, sample arrangement, ballots and sign up sheet for panelists, data entry and evaluation.

2AFC Panel Screening of UEC: Run panel screening with qualified panelists using protocols generated from the pilot tasting; record all procedures and data; prepare summary report with statistically significant conclusions, if any.

## Example 22

### Quantitative Taste Tests for Compounds 2725761 and 3756807

Quantitative taste tests for compounds 2725761 and 3756807 were run according to procedures presented above. It was found that both of them have some enhancement for MSG, in addition to their additive effect of the umami intensity.

## Example 23

### Synthesis of Compounds 2725761 and 3756807

Compounds 2725761 and 3756807 are prepared as shown in Example 22, from their corresponding acids and amines. The products are purified by conventional methods, *e.g.*, basic and acidic aqueous washes, or preparative HPLC. The structures of those compounds were confirmed based on usual analytical methods, *e.g.*, NMR and LCMS. This method can also be used to synthesize any of the compounds found in Tables 1-5.

## Example 24

### Cell Based Assays

Cells were grown and maintained at 37°C in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% FBS and MEM non-essential amino acids (Gibco BRL); media for $G_{\alpha 15}$ cells also contained 3 $\mu g\ ml^{-1}$ blasticidin (Gibco BRL). For calcium-imaging experiments, cells were first seeded onto 48-well tissue-culture plates (approximately 30,000 cells per well), and transfected using Mirus TransIt-293 (PanVera). Transfection efficiencies, which were estimated by cotransfection with an RFP expression vector, were typically approximately 60%. To minimize glutamate-induced and glucose-induced desensitization, supplemented DMEM was replaced with low-glucose DMEM supplemented with GlutaMAX and 10% dialyzed FBS (Gibco BRL) approximately 24 hours after transfection. After an additional 24 hours, cells were loaded with the calcium dye fluo-4-AM (Molecular Probes), 3 μM in Dulbecco's PBS buffer (DPBS, GibcoBRL), for 1.5 hours at room temperature. After replacement with 100 μl DPBS, stimulation was performed at room temperature by addition of 100 μl DPBS supplemented with taste stimuli. Calcium mobilization was monitored on an Axiovert S100 microscope equipped with an inverted 10X/0.5 LWD plano fluor objective (Zeiss) and a cooled CCD camera (Princeton Instruments). Fluorescence

images were acquired at 480 nm excitation and 535 nm emission, and analyzed with Imaging Workbench 4.0 software (Axon Instruments). T1R receptor activity was quantitated by counting the number of responding cells 30 seconds after stimulus addition.

**What is claimed:**

1. A method for modulating the savory taste of a comestible or medicinal product comprising:

providing at least one comestible or medicinal product, or a precursor thereof, and

combining the comestible or medicinal product or precursor thereof with at least a savory flavor modulating amount of at least one non-naturally occurring compound that specifically binds to a T1R1/T1R3 receptor composed of hT1R1/hT1R3 having a potency as umami flavor taste tastant, enhancer or modifer as determined by an $EC_{50}$ of less than 1mM, wherein the at least one non-naturally occurring compound is an amide compound or an oxalamide compound, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product;

thereby modulating the savory taste of a comestible or medicinal product.

2. The method of claim 1, wherein the at least one non-naturally occurring compound has an $EC_{50}$ ratio being defined as the ratio of the concentration of MSG to the concentration of the compound plus MSG that is necessary to elicit the MSG dose response, greater than 1.

3. The method of claim 1, wherein decrease of $EC_{50}$ as determined by a fluorescence-based assay using a FLIPR instrument is at least two-fold.

4. The method of claim 1, wherein the at least one non-naturally occurring compound has an activity compared to the maximal activity of glutamate, as determined by a compound-dependant increase in fluorescence, of at least 25% in a fluorescence-based assay using a FLIPR instrument.

5. The method of claim 1, wherein the at least one non-naturally occurring compound has a potency such that at least 10 out of 100 cells transfected with the receptor show a compound-dependent increase in fluorescence.

6. The method of claim 1, wherein the at least one non-naturally occurring compound has a potency such that the number of fluorescent cells in response to a sub-maximal level of glutamate is increased by at least two-fold.

7. The method of claim 1, wherein the at least one non-naturally occurring compound shows an increase in a response of cells to a sub-maximal level of glutamate of at least 1.25-fold compared to the response to the sweetener alone wherein the response is measured by fluorescence, calcium levels, IP3 levels, cAMP levels, GTPγS binding, or reporter gene activity.

8. A method for modulating the sweet taste of a comestible or medicinal product comprising:

providing at least one comestible or medicinal product, or a precursor thereof, and

combining the comestible or medicinal product or precursor thereof with at least a sweet flavor modulating amount of at least one non-naturally occurring amide compound that specifically binds to a T1R2/T1R3 receptor composed of hT1R2/hT1R3 having a potency as a sweet agonist as determined by an $EC_{50}$ of less than 10μm, or a comestibly acceptable salt thereof, so as to form a modified comestible or medicinal product;

thereby modulating the sweet taste of a comestible or medicinal product.

9. The method of claim 8, wherein the at least one non-naturally occurring compound has a size of about 12x5x5 angstroms.

10. The method of claim 8 or 9, wherein the at least one non-naturally occurring compound has one or more of the following characteristics in a cell that co-expresses hT1R2 and hT1R3

decreased $EC_{50}$ compared to a control of at least 50%,

increased intracellular Ca2+ levels by at least approximately 25%,

increased intracellular cAMP by at least approximately 25%,

increased intracellular cGMP by at least approximately 25%, or

increased intracellular $IP_3$ by at least approximately 25%.

11. The method of claim 10, wherein the cell that co-expresses hT1R2 and hT1R3 is an HEK cell that stably expresses Gα15.

12. The method of claim 11, wherein the at least one non-naturally occurring compound shows an increase in the response of cells to a sub-maximal level of a sweetener of at least 1.25-fold compared to the response to the sweetener alone, wherein the response is measured by fluorescence, calcium levels, IP3 levels, cAMP levels, GTPγS binding, or reporter gene activity.

13. The method of claim 12, wherein the at least one non-naturally occurring compound has an activity compared to the maximal activity of fructose as determined by a compound-dependant increase in fluorescence of at least 25% in a fluorescence-based assay using a FLIPR instrument.

14. The method of claim 13, wherein the at least one non-naturally occurring compound has an activity compared to the maximal activity of fructose as determined by a compound-dependant increase in fluorescence that demonstrates a compound-dependent decrease in the $EG_{50}$ for fructose by at least two-fold in a fluorescence-based assay using a FLIPR instrument.

15. The method of claim 13, wherein the at least one non-naturally occurring compound has a potency such that at least 10 out of 100 transfected cells show a compound-dependent increase in fluorescence measured with a fluorescent microscope.

16. The method of claim 13, wherein the at least one non-naturally occurring compound has a potency such that the number of fluorescent cells in response to a sub-maximal level of fructose is increased by at least two-fold.

17. The method of any one of claims 1 to 16, wherein the comestible is selected from the group consisting of: a wet/liquid soup, a dehydrated or culinary food, and a beverage.

18. The method of claim 1, wherein the amide compound is represented by compounds of Table 1.

19. The method of claim 1, wherein the oxalamide compound is represented by compounds of Table 2.