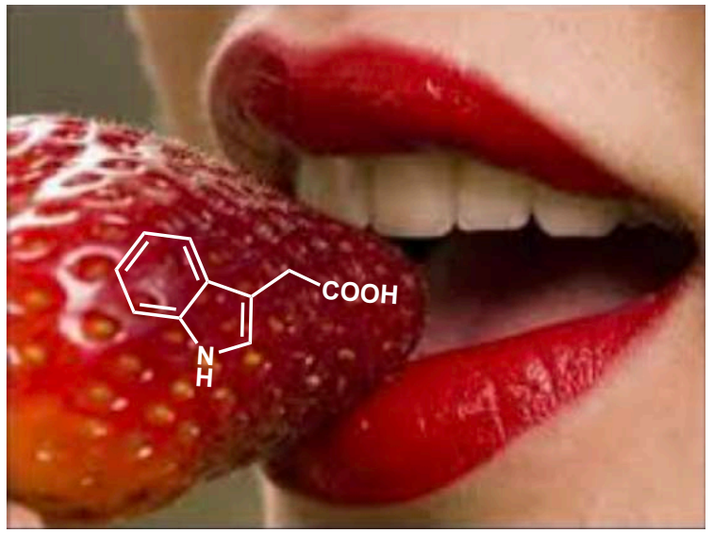
Food, Food Chemistry and Gustatory Sense



María González Esguevillas

MacMillan Group Meeting

May 12th, 2020

Food and Food Chemistry Introduction

Concepts

Food

any nourishing substance eaten or drunk to sustain life, provide energy and promote growth

any substance containing nutrients that can be ingested by a living organism and metabolized into energy and body tissue

social act

pleasure

country

culture

age

election

It is fundamental for our life

Food and Food Chemistry Introduction

Concepts

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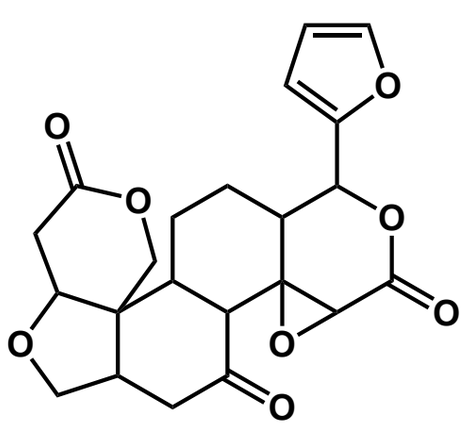
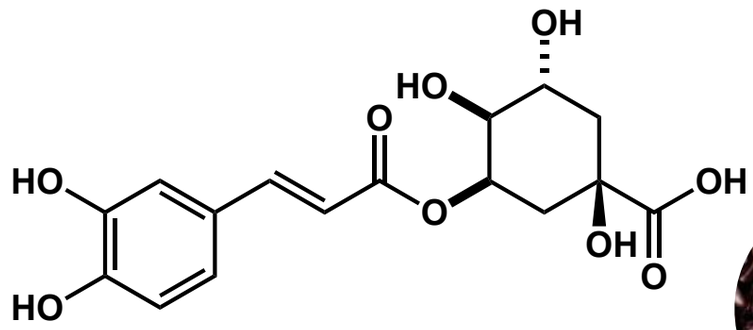
any substance containing nutrients that can be ingested by a living organism and metabolized into energy and body tissue



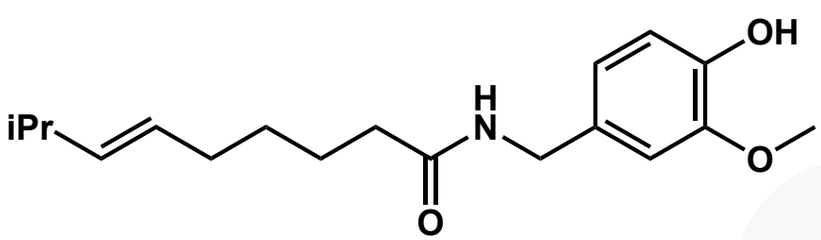
limonin

orange taste



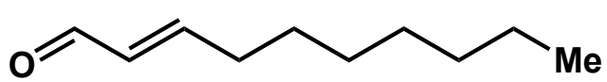
5-caffeoylquinic acid

Coffee taste



Capsaicinoids

Chilli burning sensation



2-decanal

Coriander taste

Astray, G. *EJEAFChe.* **2007**, *6*, 1742-1763

Food and Food Chemistry Introduction

Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances ***areas*** ***food processing techniques***

de Man, J. M. *Principles of Food Chemistry* **1999**, Springer Science

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

Food Chemistry

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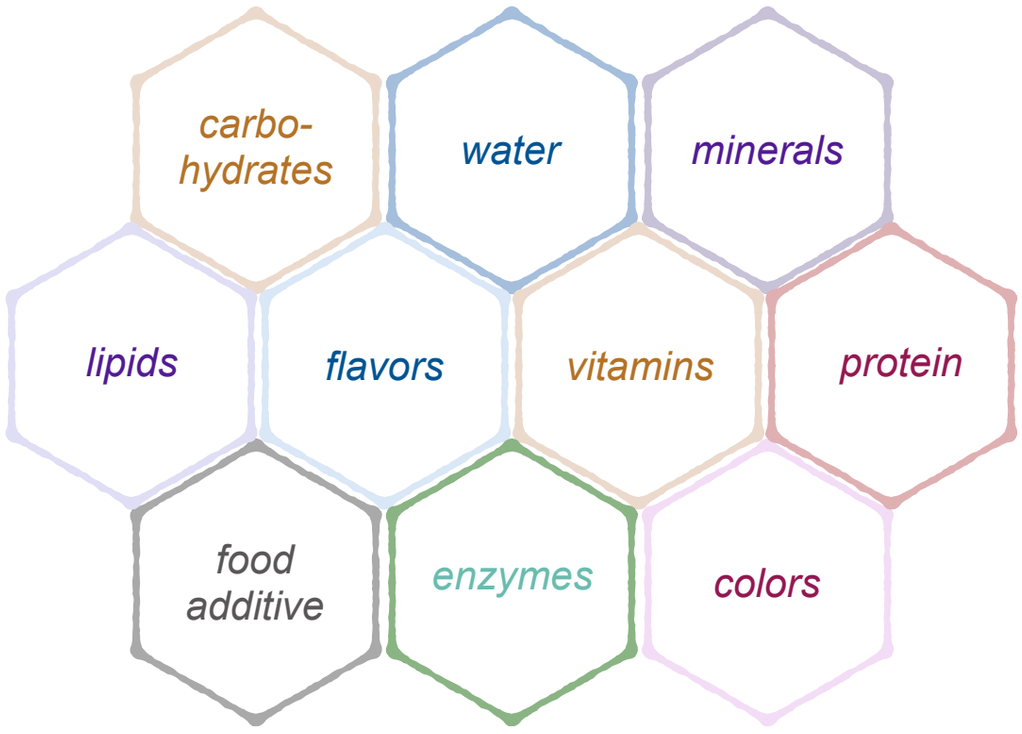


Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

major component of food

50% meat

up to 95% vegetables

reduce for food preservation

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

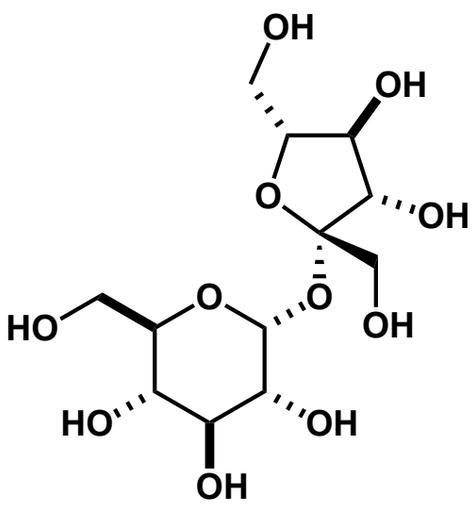
Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

80% food intake



provide enerrgy

mostly from vegetables

important role

blood pressure regulation

bones, muscular and nervous function

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

fatty acids *phospholipids*

triglycerides

energy

metabolism regulation

satiety and satiation

50% dry weight of a living cell

essential for growth and survival

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

preserve or improve

flavour *taste*

appearance

sensory analysis purposes

biochemical catalyst

baking *brewing*

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

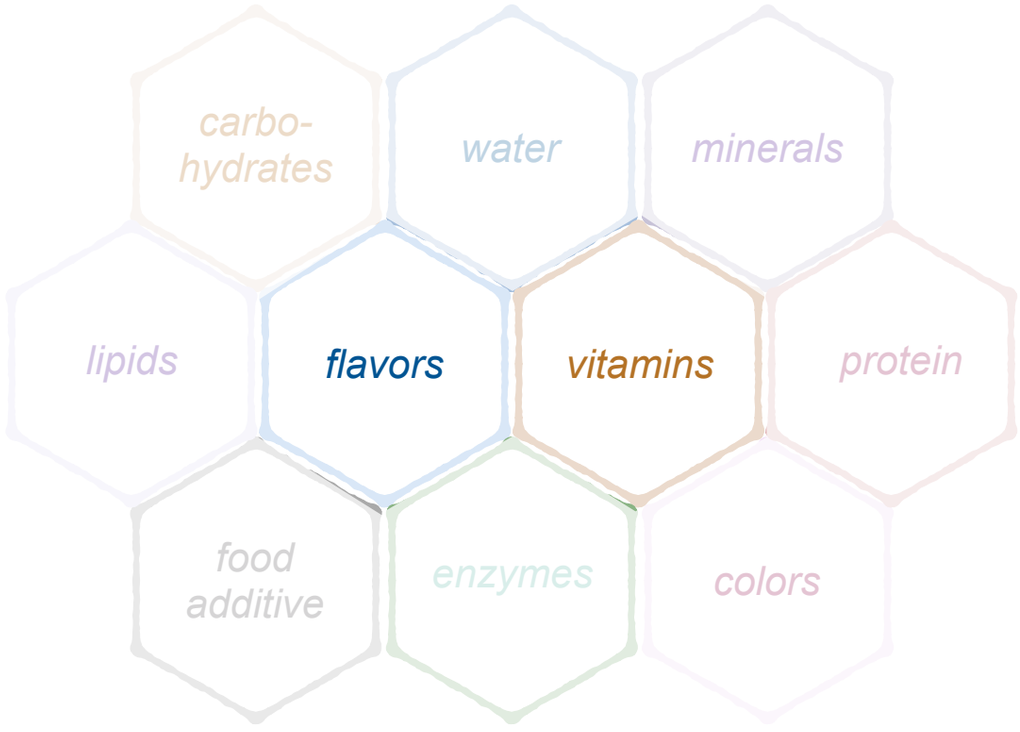
Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

sensory analysis

taste *smell*



nutrients for essential metabolic reactions

prevent diseases

Fennema, O. R. *Food Chemistry.* **1985**, 2nd edition New York: Marcel Dekker, Inc

Food and Food Chemistry Introduction

Concepts

Food Chemistry

the study of chemical processes and interactions of all biological and non-biological components of foods

biological substances — ***areas*** — *food processing techniques*

Important to obtain food suitable for consumption

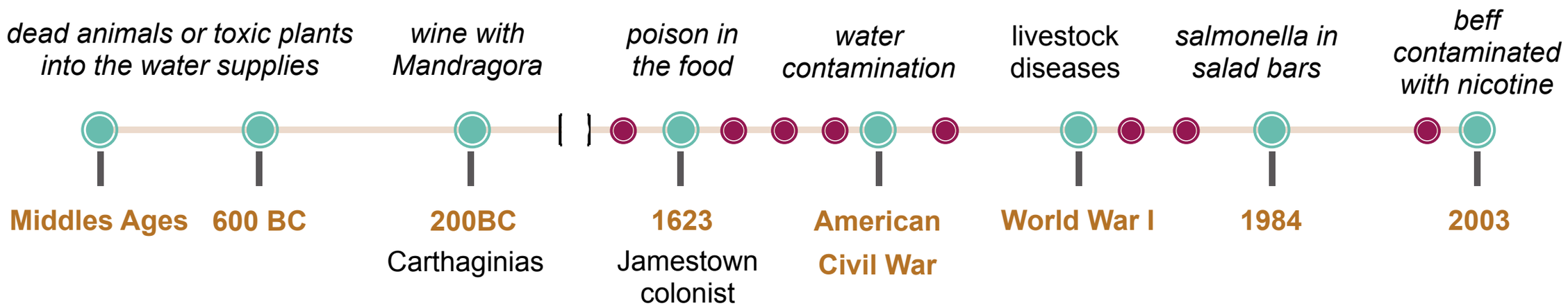
Rules and food control regulation (FDA and EU normatives)

Why is this important?

Food can be altered as a weapon

Food as a Weapon

Historical Perspective



High control to detect bio- and chemical agents

based on the natural detections

development of new techniques

analysis and understanding of the mammals nature

SENSORY SYSTEM

Armstrong, D. J. *Advances in Microbial Food Safety* **2006**, Chapter 21

Sensory System

A sensory system is a part of the nervous system responsible for processing sensory information

The sensing organs associated with each sense send information to the brain to help us understand and perceive the world around us

touch

pressure, pain and temperature.
Receptors in the skin

sight

perception of images of visible light (electomagneticc waves)

hearing

sound (pressure waves), frequency.
Vibration receptors in the ears

responsive to physical parameters easily quantified and described

Sensory System

touch

sight

hearing

chemical senses

> 300 different receptors
bind a molecule

smell

taste

5 taste sensation
up to 10000 taste receptors

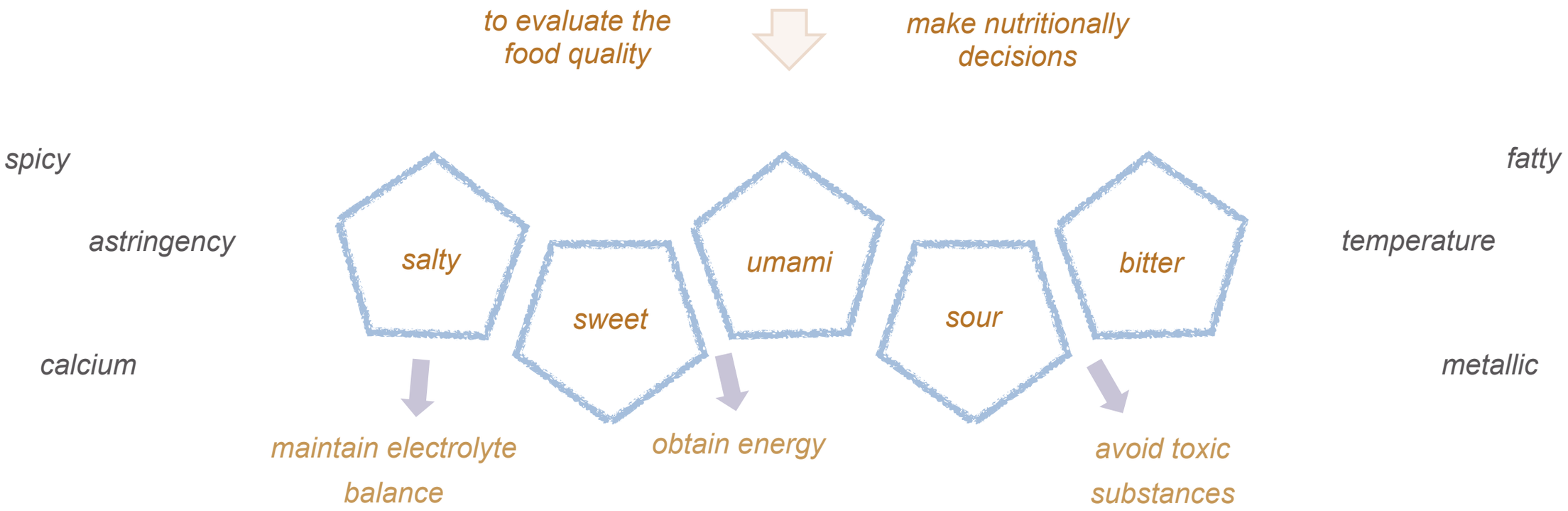
detection of chemicals by nose or tongue

Sense of Taste or Gustatory System

Introduction and Basic Tastes

Gustatory system is the sensory system that is partially responsible for the perception of flavor of food and other substances along with smell and trigeminal nerve stimulation (registering texture, pain, and temperature).

Taste is the perception produced or stimulated when a substance in the mouth reacts chemically with taste receptor cells located mostly in the tongue.



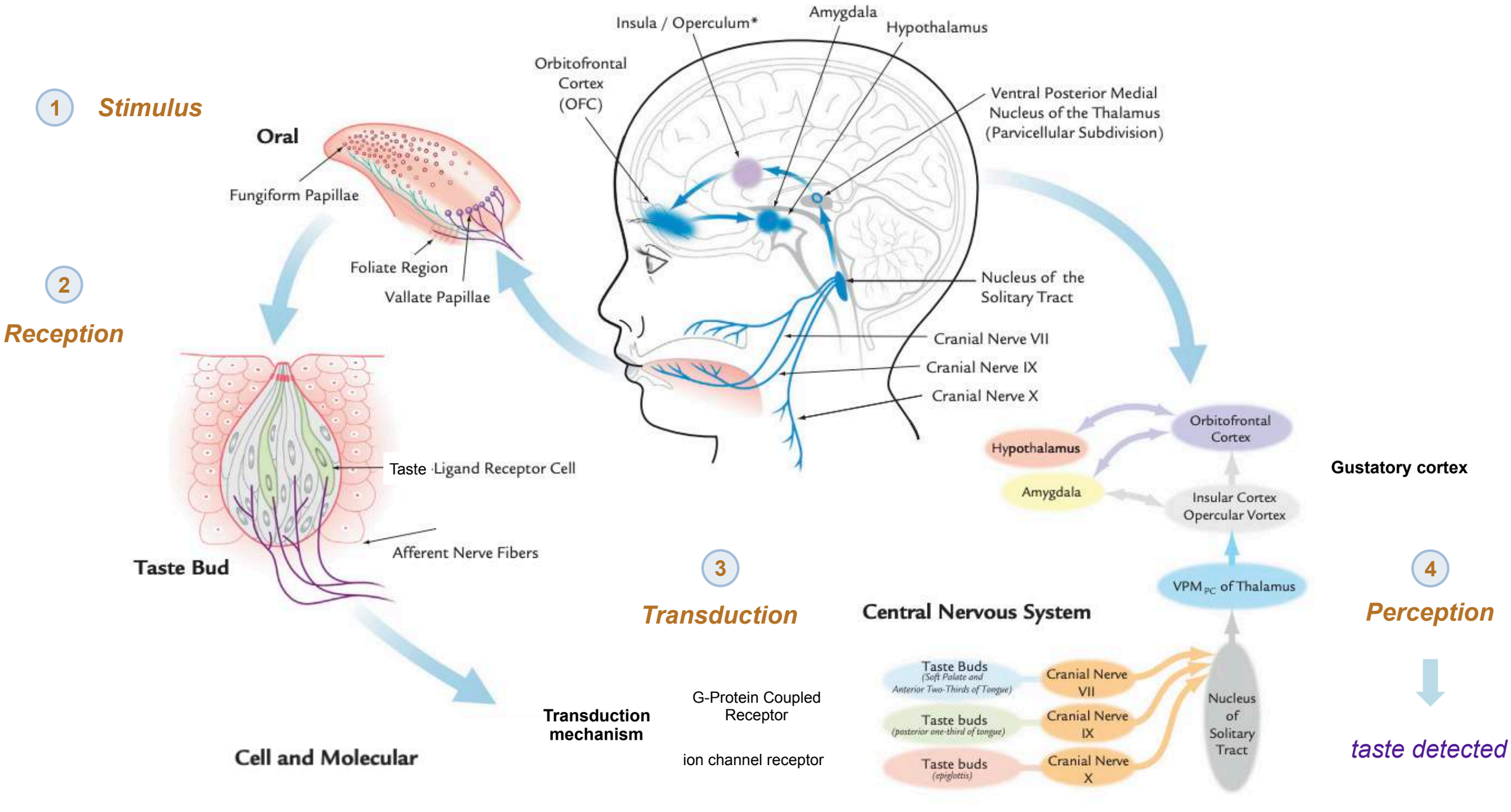
Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11

Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348

Doty, R. L. *WIREs Cogn. Sci.* **2012**, *3,* 29-46

Anatomy and Physiology of Taste

Process Perception. From the Mouth to the Brain



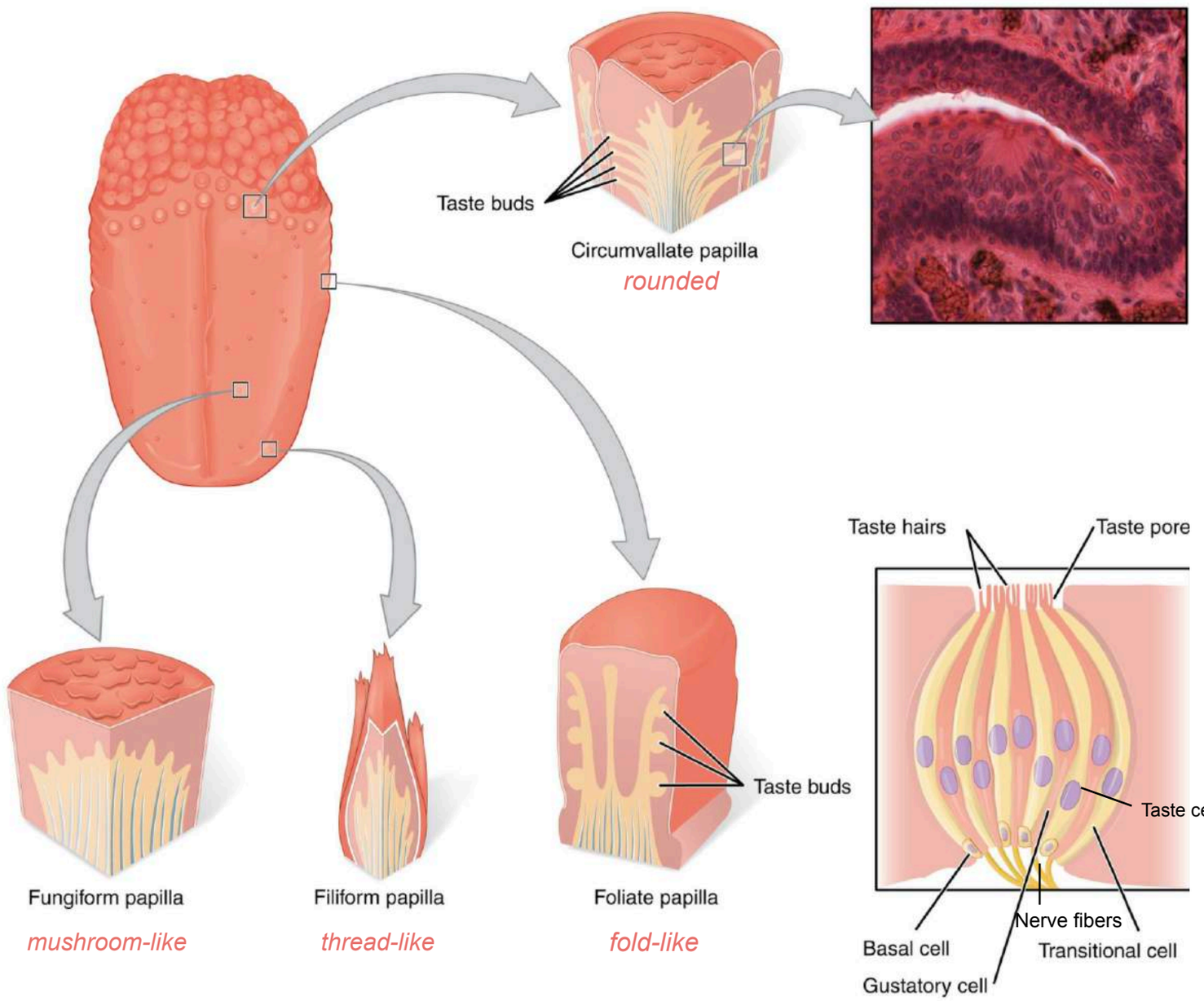
Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11

Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348

Menella, J. A. et al. *Clinical Therapeutics.* **2013**, *35,* 1225-1246

Anatomy and Physiology of Taste

Papillae and taste buds



Papillae

visible protuberances located on the surface of the tongue

Four major types

different number and sizes

up to 10000 taste buds

50-150 taste receptor cell (TRC)

type I, II, and III

transduction mechanism to identify a taste

Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11

Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348

Doty, R. L. *WIREs Cogn. Sci.* **2012**, *3,* 29-46

Anatomy and Physiology of Taste

Transduction in the Taste Cells

Type II: Sweet, Bitter and Umami

G-Protein-Coupled Receptor (GPCR)

bind to receptor

↓

activate PLC

↓

PIP2

↓

IP3 DAG

↓ ↓

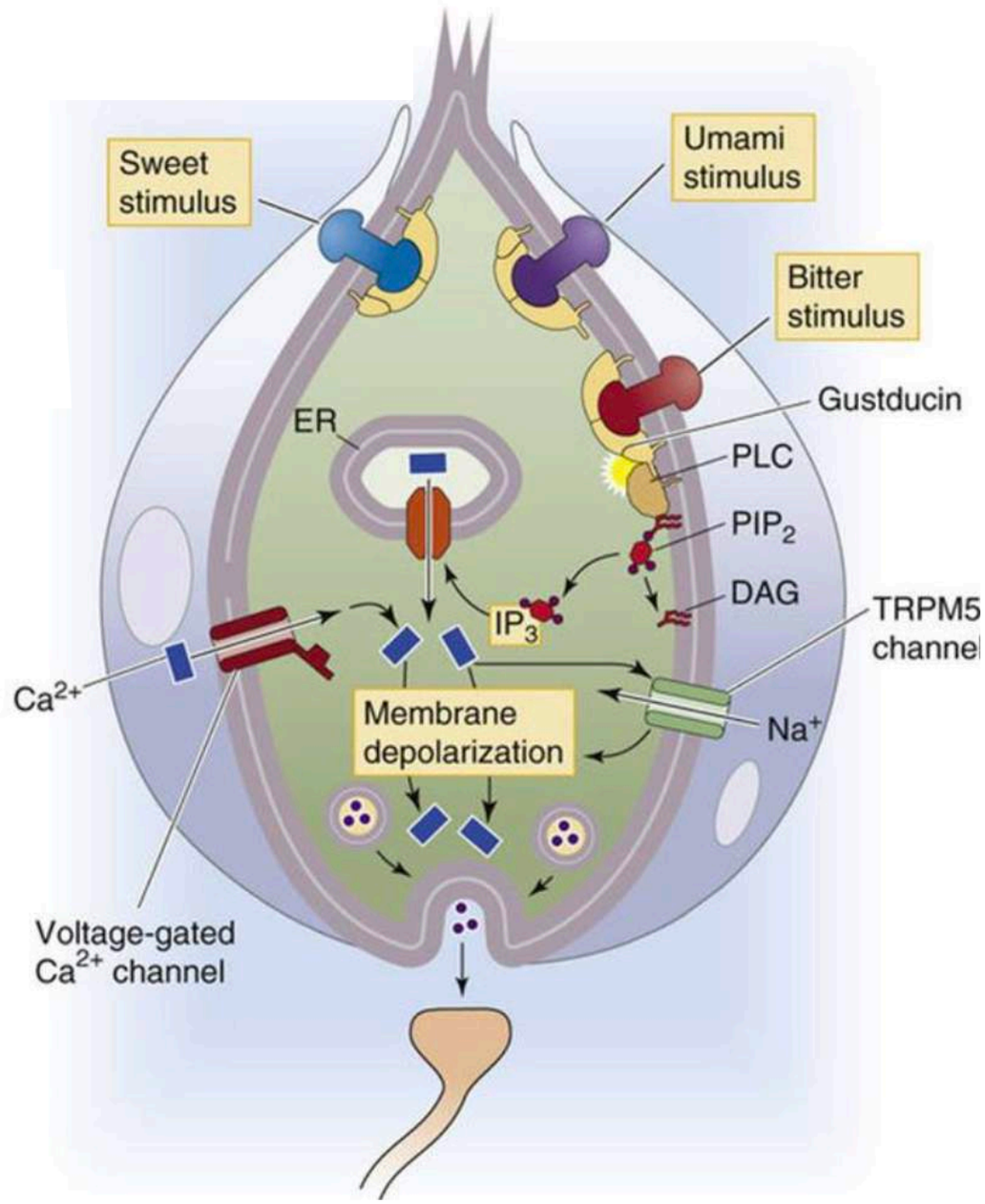
ER PKC

↓ ↓

Ca^{2+} ← ion channels activation

↓

depolarization/activation/stimulation nerve



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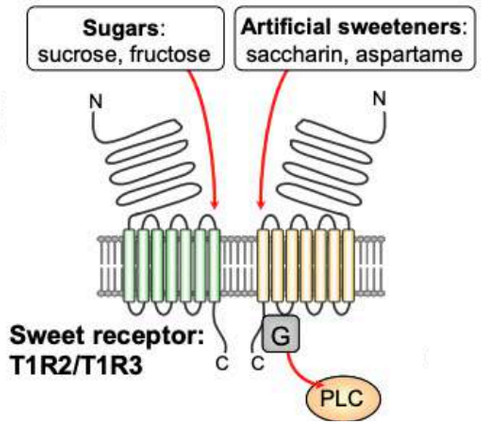
Anatomy and Physiology of Taste

Transduction in the Taste Cells

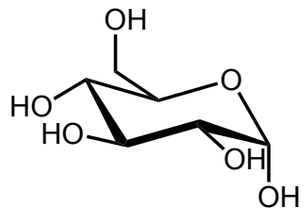


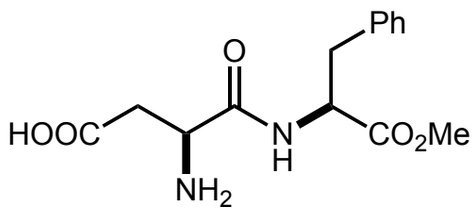
Type II: Sweet, Bitter and Umami

G-Protein-Coupled Receptor (GPCR)

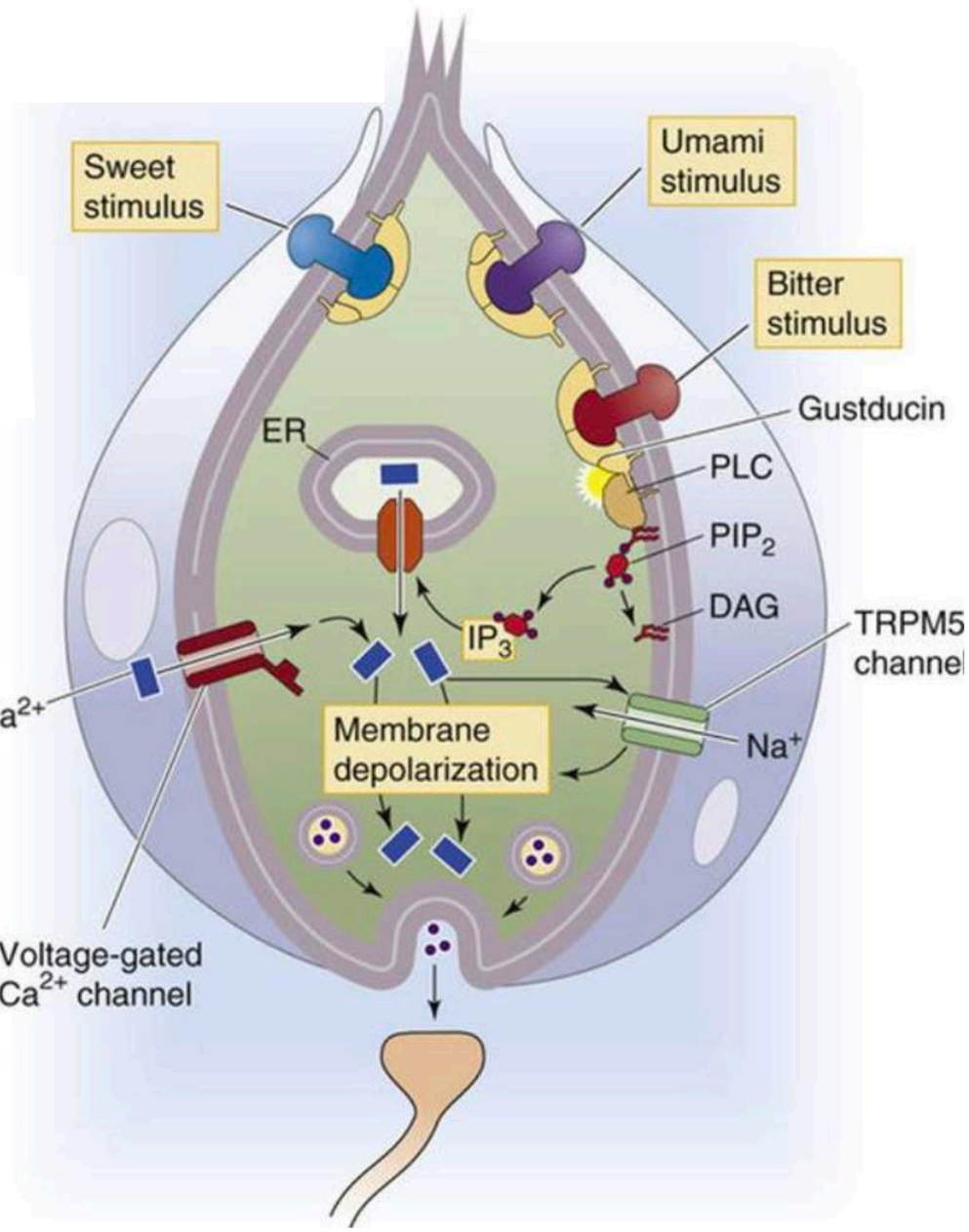
Sweet

sugars (mono-, polysaccharides), artificial sweeteneres, sweet proteins, D-aminoacids





Receptor	$T1R_{2+3}$ (heterodimer)	$T1R_3$ (homodimer)
Detection threshold	**Sucrose (10 mM)**	Lactose (30 mM)
	5-nitro-2-propoxyaniline (2 μM)	



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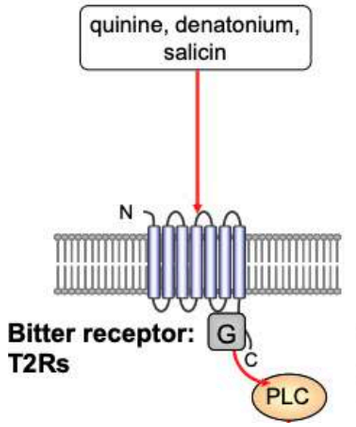
Anatomy and Physiology of Taste

Transduction in the Taste Cells



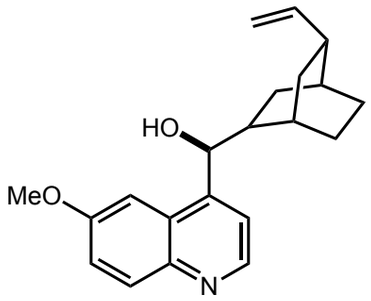
Type II: Sweet, Bitter and Umami

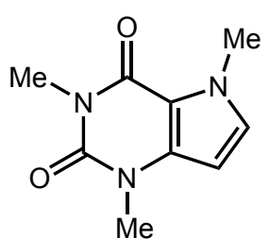
G-Protein-Coupled Receptor (GPCR)

Bitter

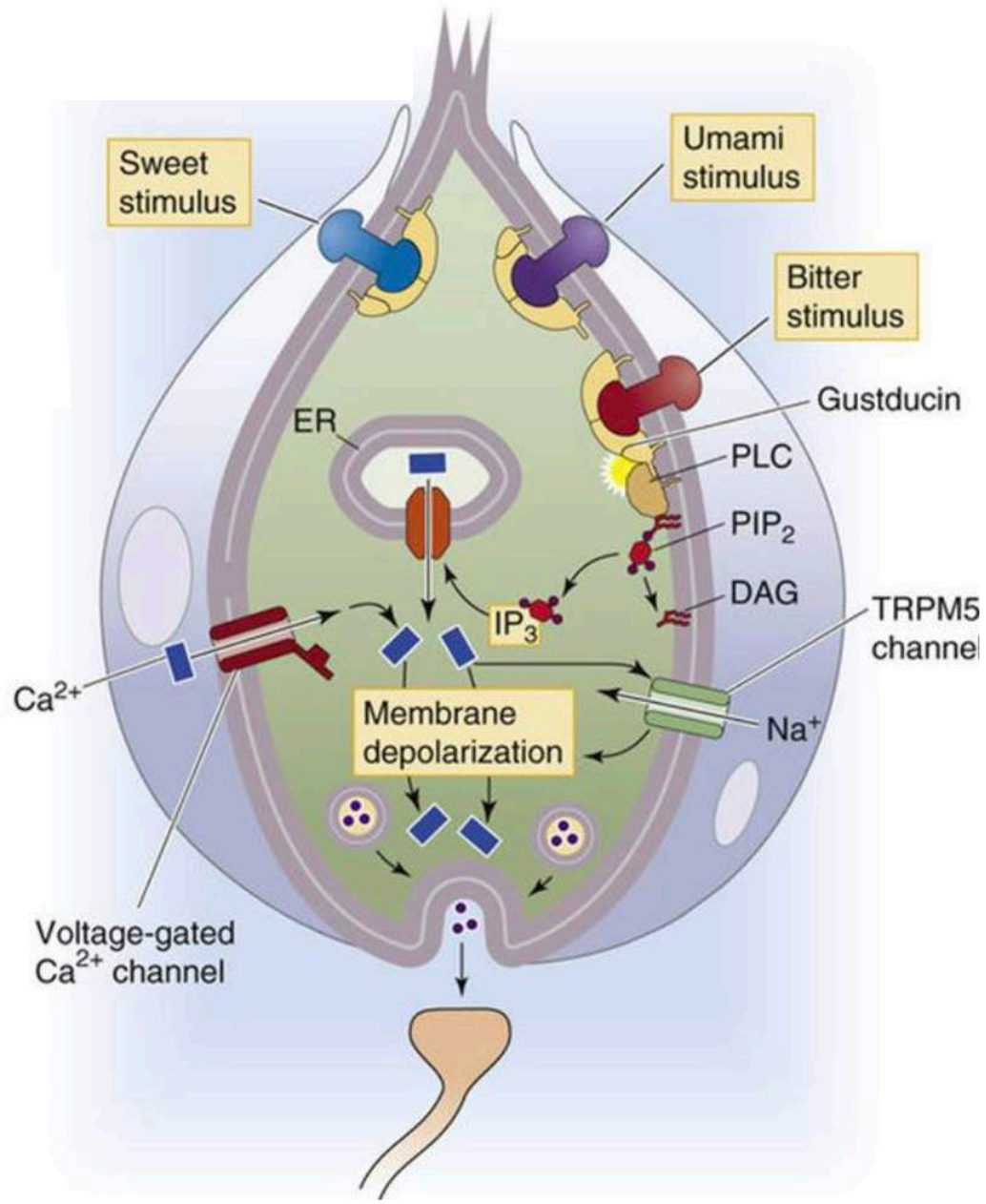
many organic molecules: Quinine, caffeine, acetaminophen

(foods: cocoa, mate, chicory, olives)





Receptor	T2R or TAS2R
Detection threshold	**Quinine (8 μM)** Brucine (0.7 μM)
	amarogentin (8 nM)



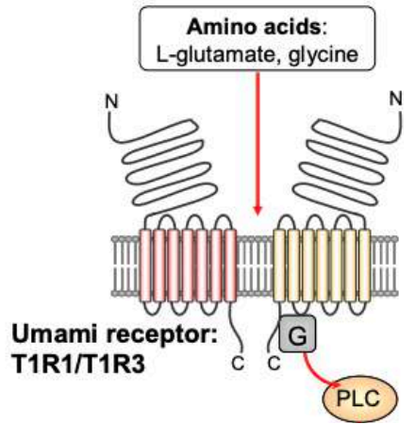
Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11

Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348

Doty, R. L. *WIREs Cogn. Sci.* **2012**, *3,* 29-46

Anatomy and Physiology of Taste

Transduction in the Taste Cells

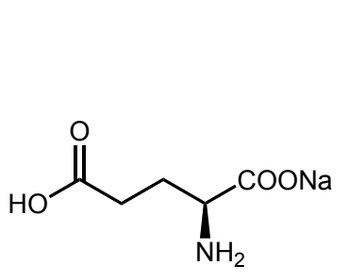


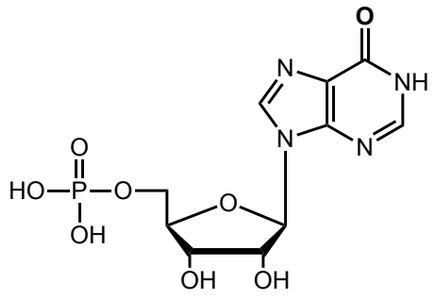
Type II: Sweet, Bitter and Umami

G-Protein-Coupled Receptor (GPCR)

Umami

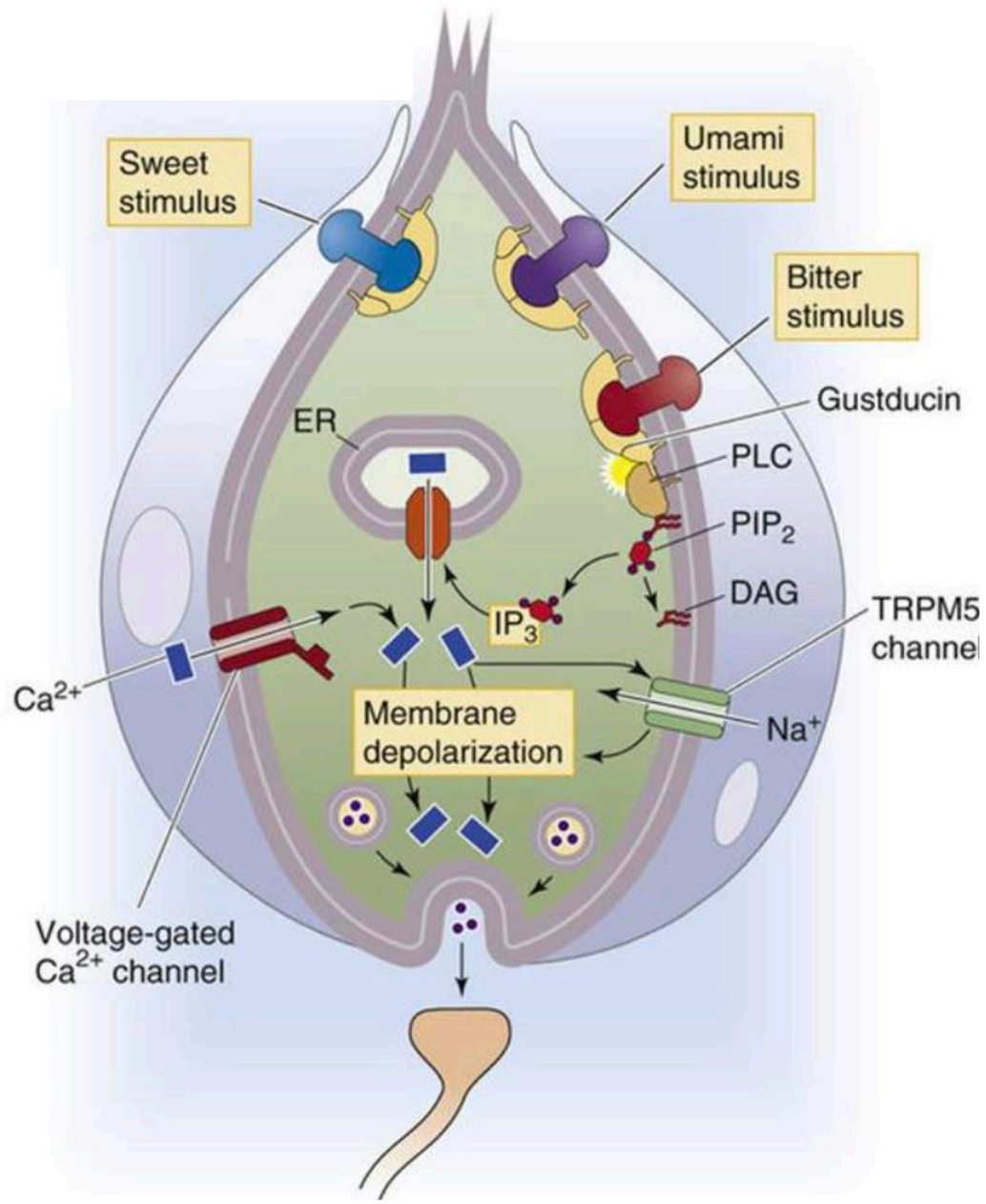
L-Amino acids, nucleotide enhancer (AMP, IMP)





Receptor $T1R_1$–$T1R_3$ (heterodimer)

Detection threshold **Glutamate (0.7 mM)**



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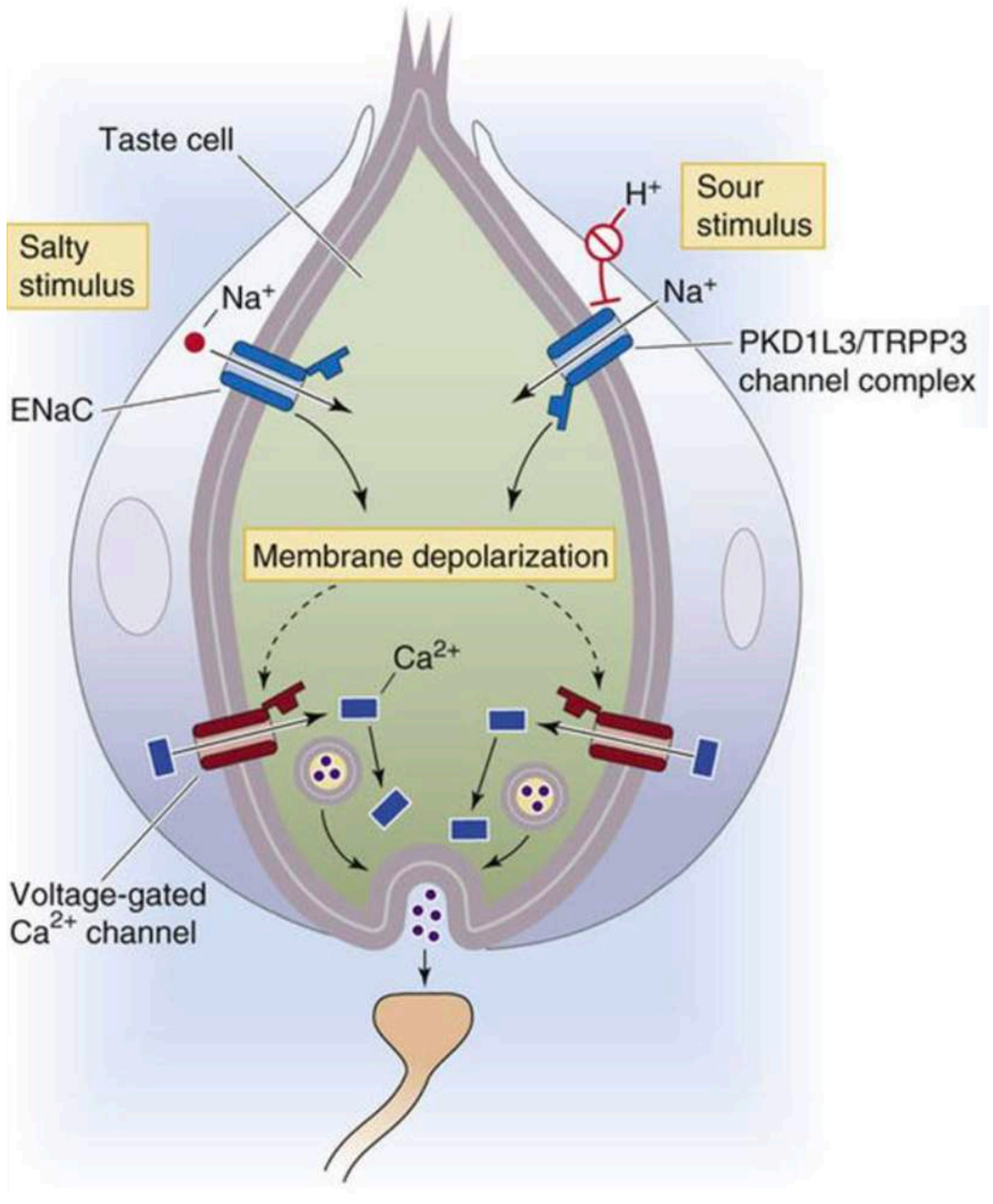
Anatomy and Physiology of Taste

Transduction in the Taste Cells

Type I: Salty **Type III: Sour**



ion channel receptors

Na^+ open ion channel *H^+ block potassium channels*

increase Ion concentration

Ca^{2+} ions

activation/stimulation nerve

Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019***, 164,* Chapter 11

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Anatomy and Physiology of Taste

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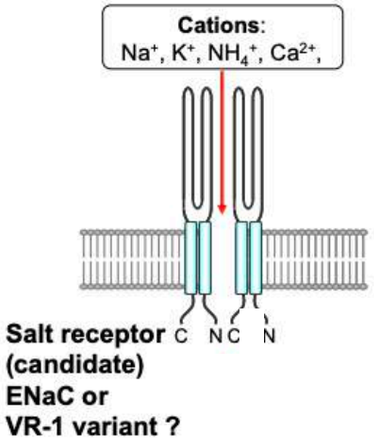
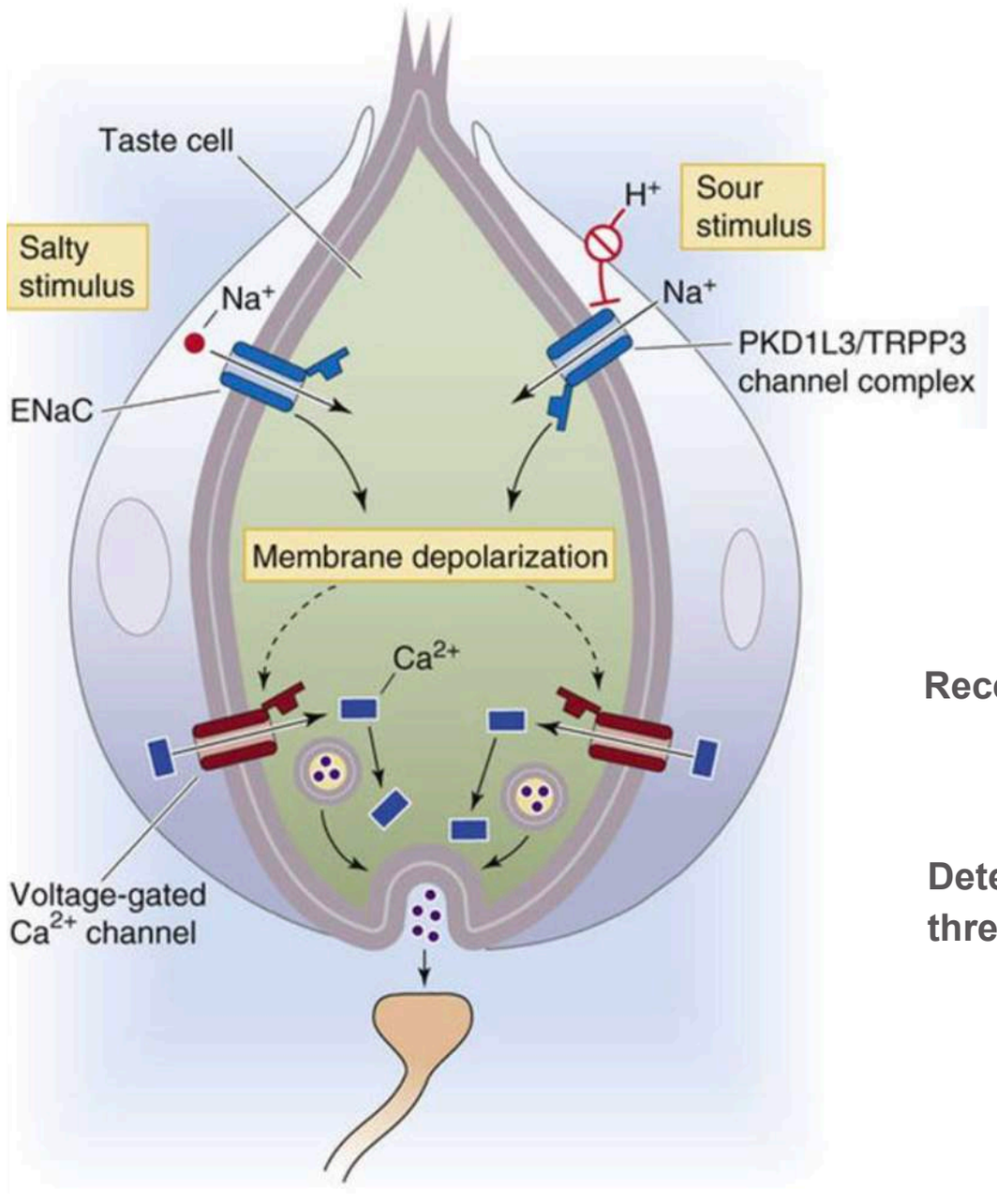




ion channel receptors

Salty

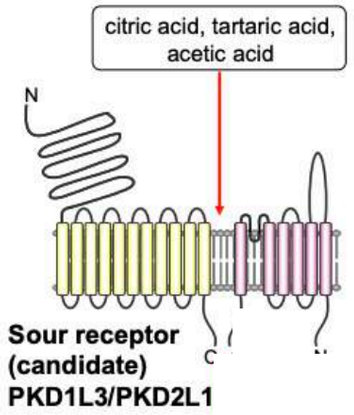
NaCl, other salts (LiCl, KCl, NH_4Cl)

Receptor	Epitelial sodium channel (ENaC)	
Detection threshold	**NaCl (10 mM)**	KCl (6 mM)

Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11

Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348

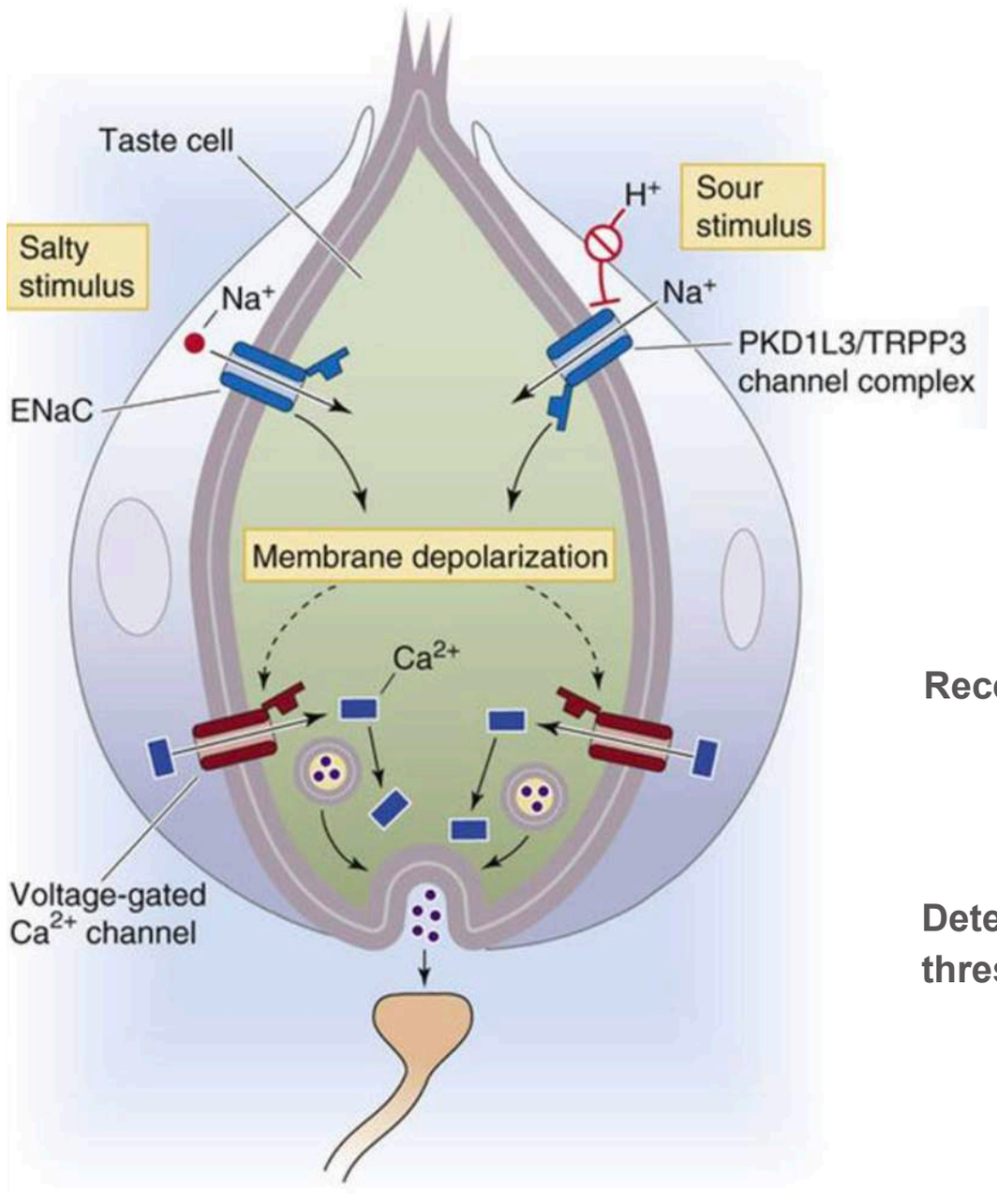
Doty, R. L. *WIREs Cogn. Sci.* **2012**, *3,* 29-46



Anatomy and Physiology of Taste

Transduction in the Taste Cells

Type I: Salty **Type III: Sour**



ion channel receptors

Sour

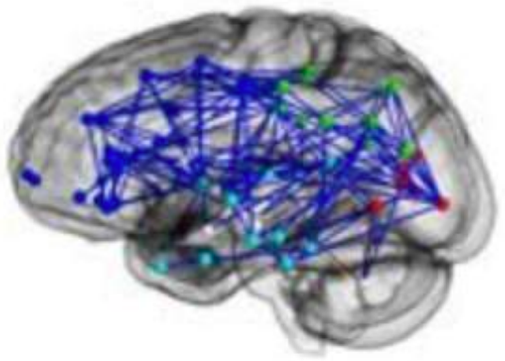
acid molecules

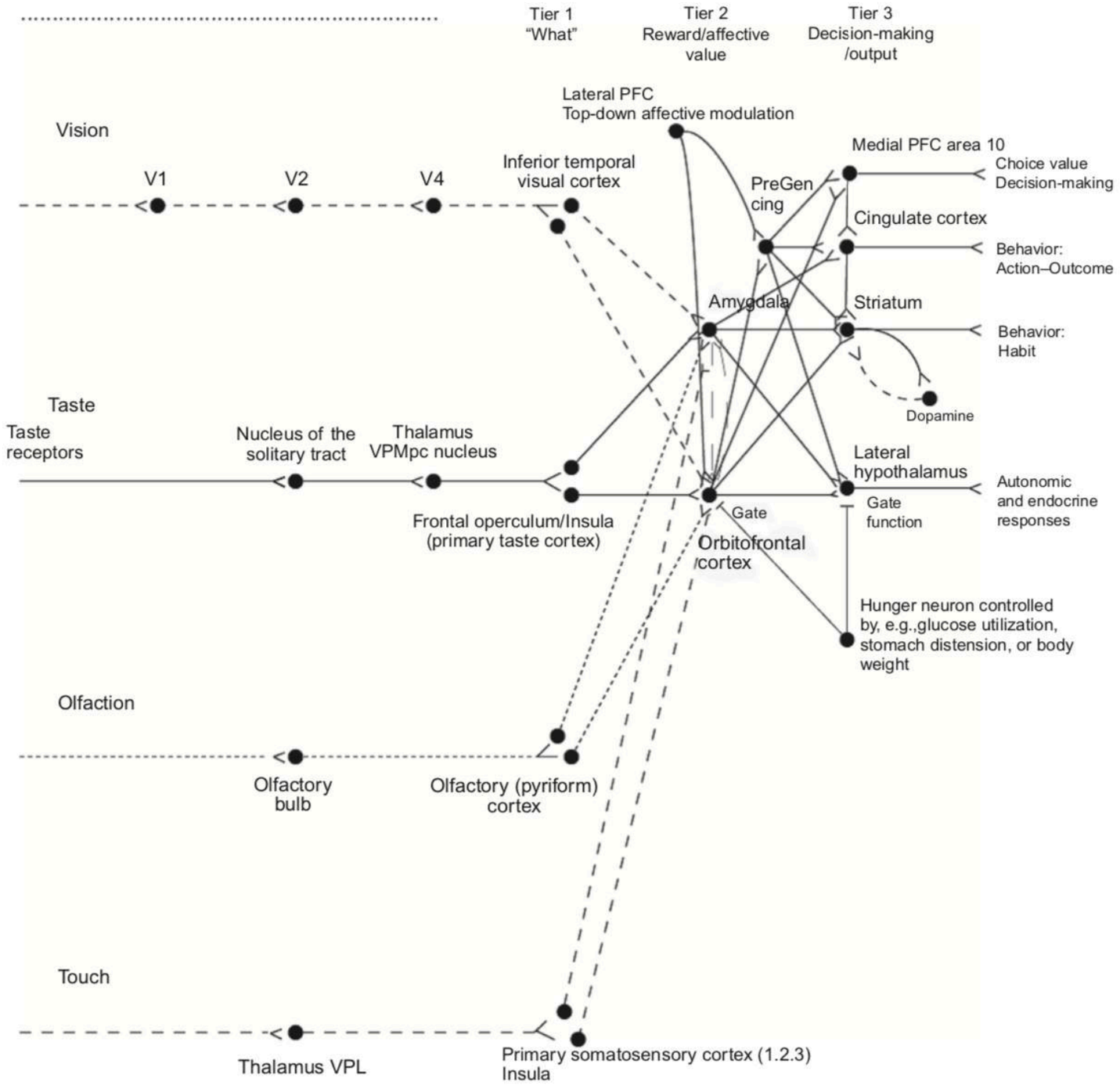
HCl, citric acid, tartaric acid, carbonic acid

Receptor	PKD2L1 or PKD1L3 Proton-elective ion channel otopetrin (Otop 1)
Detection threshold	**HCl (0.9 mM)** citric acid (0.41 mM) carbonic acid (54 μM)

Töle, J. C.; Behrens, M.; Meyerhof, W. *Handbook of Clinical Neurology.* **2019**, *164,* Chapter 11
Yamamoto, T. et al. *Jpn. J. Pharmacol.* **1998**, *76,* 325-348
Doty, R. L. *WIREs Cogn. Sci.* **2012**, *3,* 29-46

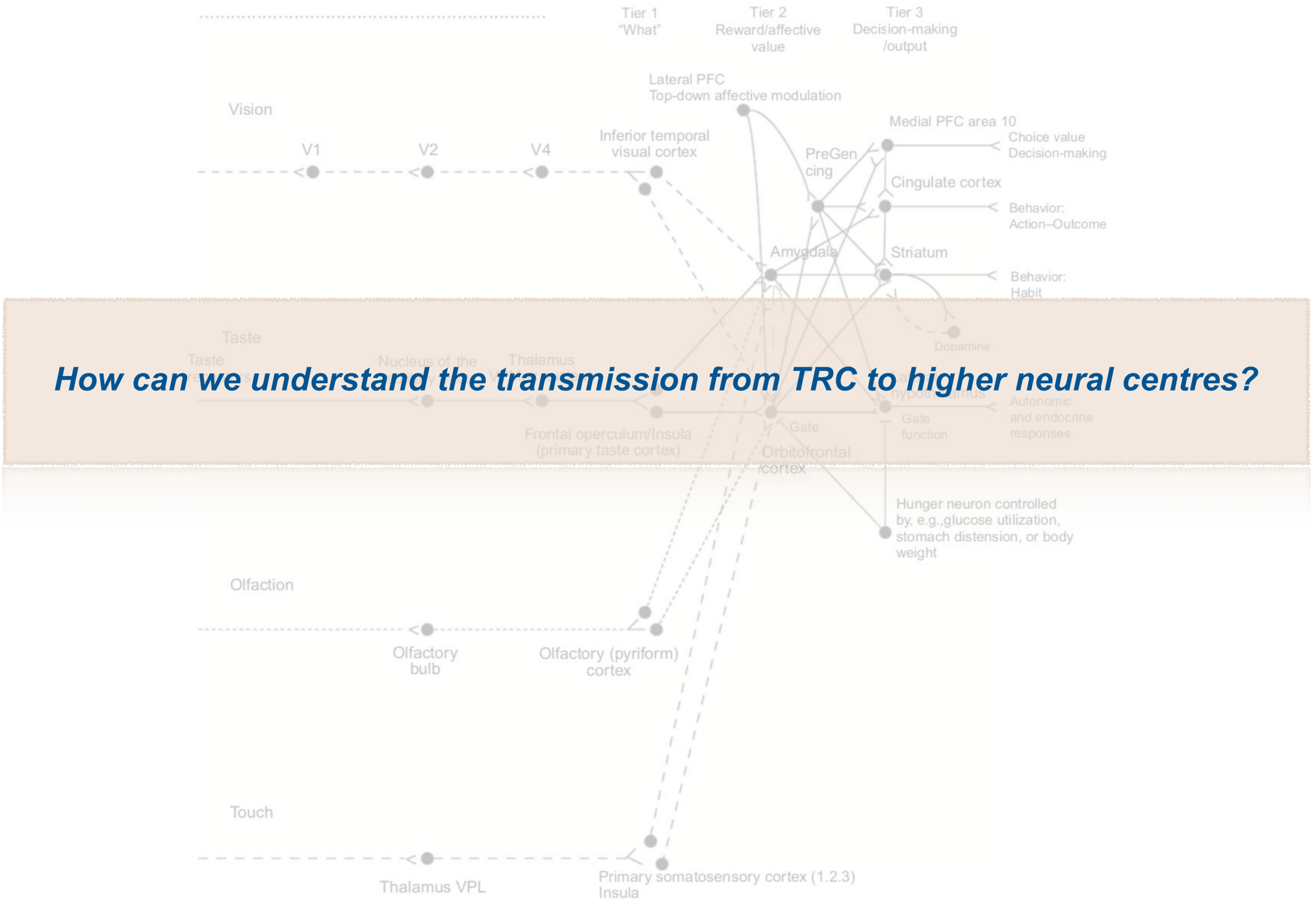
Coding channels for taste perception





Rolls, E. T. *Handbook of Clinical Neurology* **2019***, 164,* Chapter 7

Coding channels for taste perception



How can we understand the transmission from TRC to higher neural centres?

Rolls, E. T. *Handbook of Clinical Neurology* **2019***, 164,* Chapter 7

Coding channels for taste perception

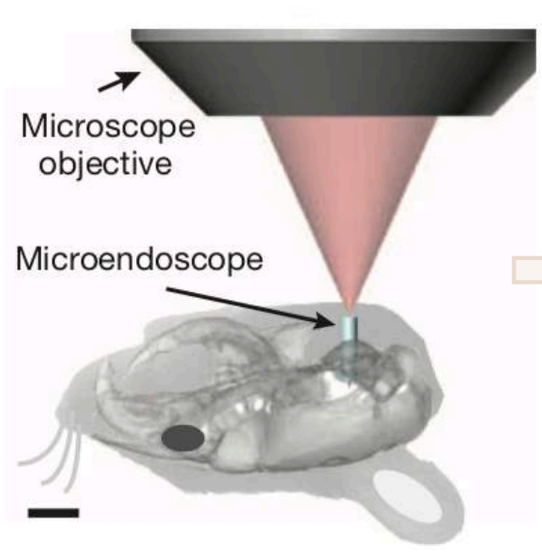
Taste buds (TRC) → **Nerves** → *synapsis in brainstem and thalamus* → **Primary cortex**

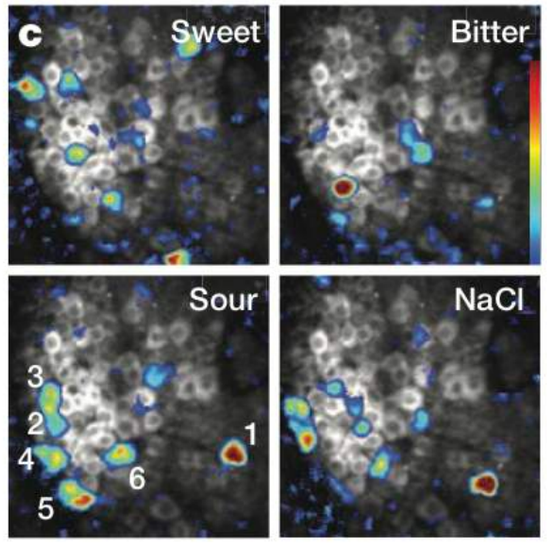
simple model
one taste–one set of neurons

Focused on **genicculate ganglion**

neurons innervate all taste buds

two-photon calcium imaging
to monitore tastant activity in vivo





31 neuronal classes: 5 tuned to single taste qualities, 10 doubly tuned
10 respond 3 tastes, fove to four tastes and one all tastes.

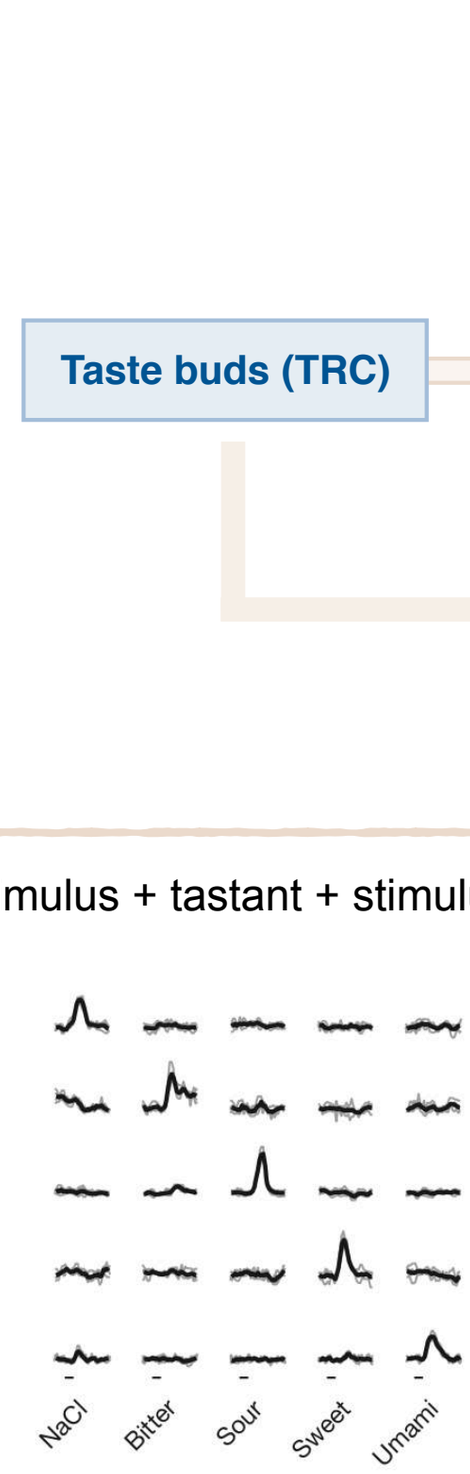
Barretto, R. P. J. *Nature* **2015**, *517,* 373-376

Coding channels for taste perception

Taste buds (TRC) → **Nerves** → *synapsis in brainstem and thalamus* → **Primary cortex**

simple model
one taste–one set of neurons

pre-stimulus + tastant + stimulus wash



1000 neurons

strongly activated by only one taste

other combinations?

inconsistent results?

26 “multi-tuned” combinations:
10 doubly tuned, 10 respond 3 tastes,
5 to four tastes and one all tastes.

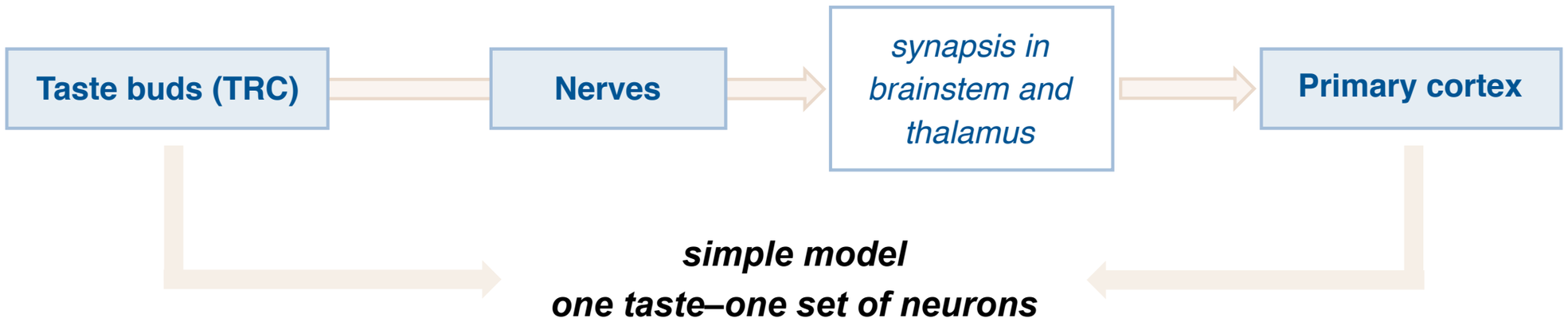
binary combinations

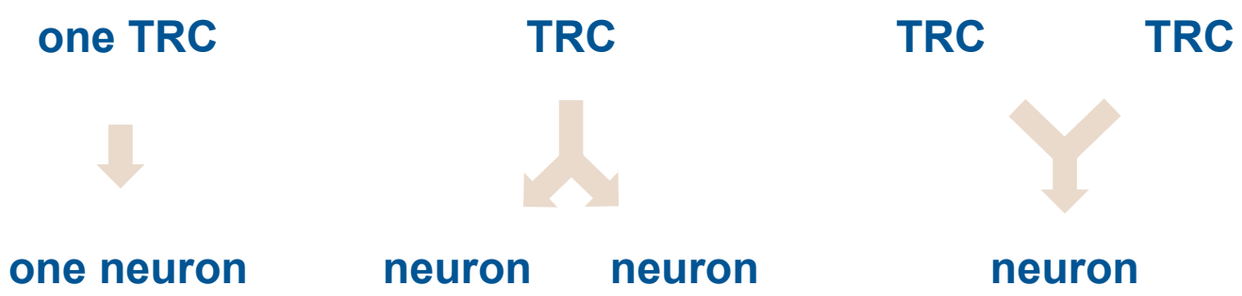
same behavior

mostly single neurons
1% multi-tuned neurons

Barretto, R. P. J. *Nature* **2015**, *517,* 373-376

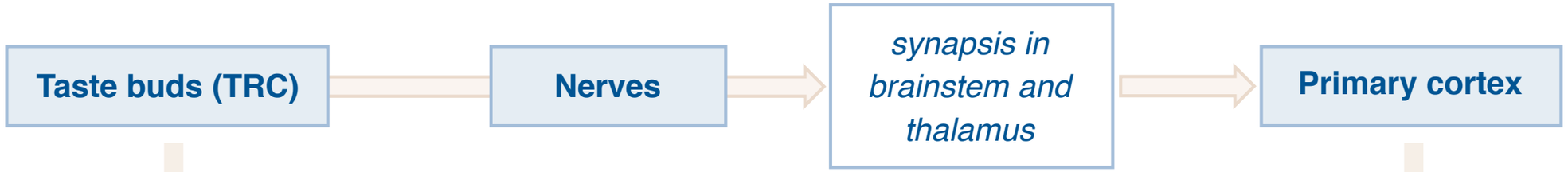
Coding channels for taste perception





Barretto, R. P. J. *Nature* **2015***, 517,* 373-376

Coding channels for taste perception

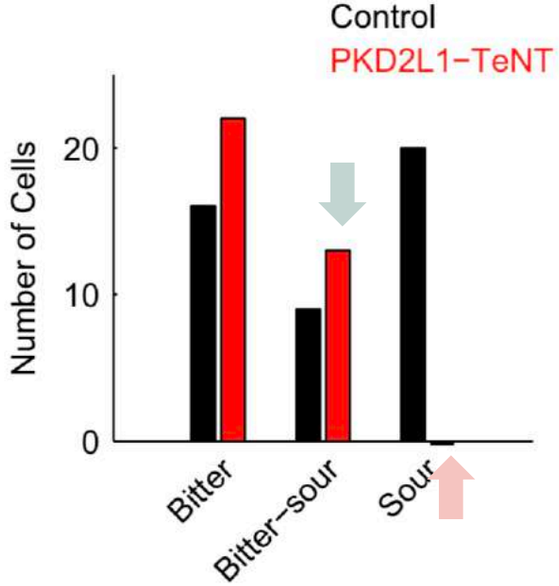


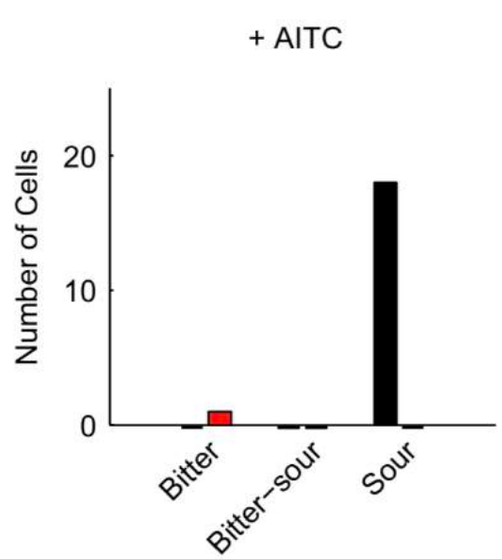
bitter *sour*

TR2 **PKD2L1**

bitter-sour neuron

supresion PKD2L1





Barretto, R. P. J. *Nature* **2015**, *517,* 373-376

Coding logic for bitter taste

Genetic, behavioural and physiological studies

Genetically engineered mice to express Human T2R receptors

expand the bitter taste repertoire?

Modified mice lacking a specific T2R

responses to bitter compound?

T2Rs

(~ 30 GPC Receptors)

Mices and Humans

Supresion of sweet, umami and bitter taste function restoring only T2R expressing cells

specificity of bitter taste response

Ectopically expressing a T2R bitter taste receptor in sweet-sensing cells

Role of cells and receptors

Mueller, E. T. *Nature* **2005** *434,* 225-229

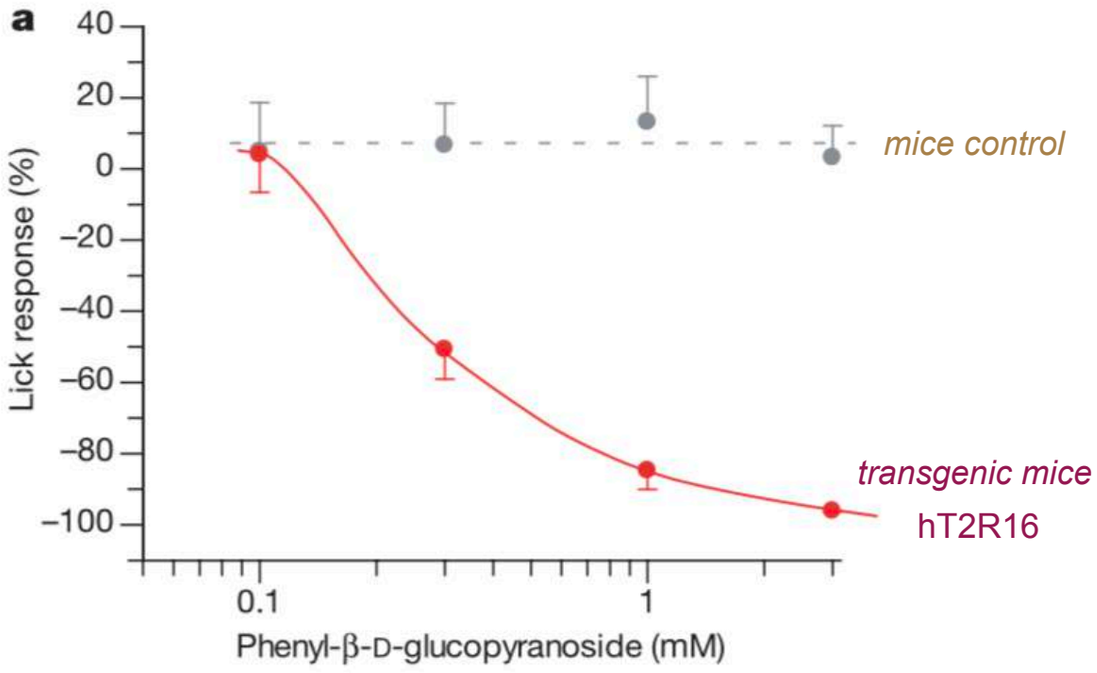
Human bitter receptors in mice

Genetic, behavioural and physiological studies

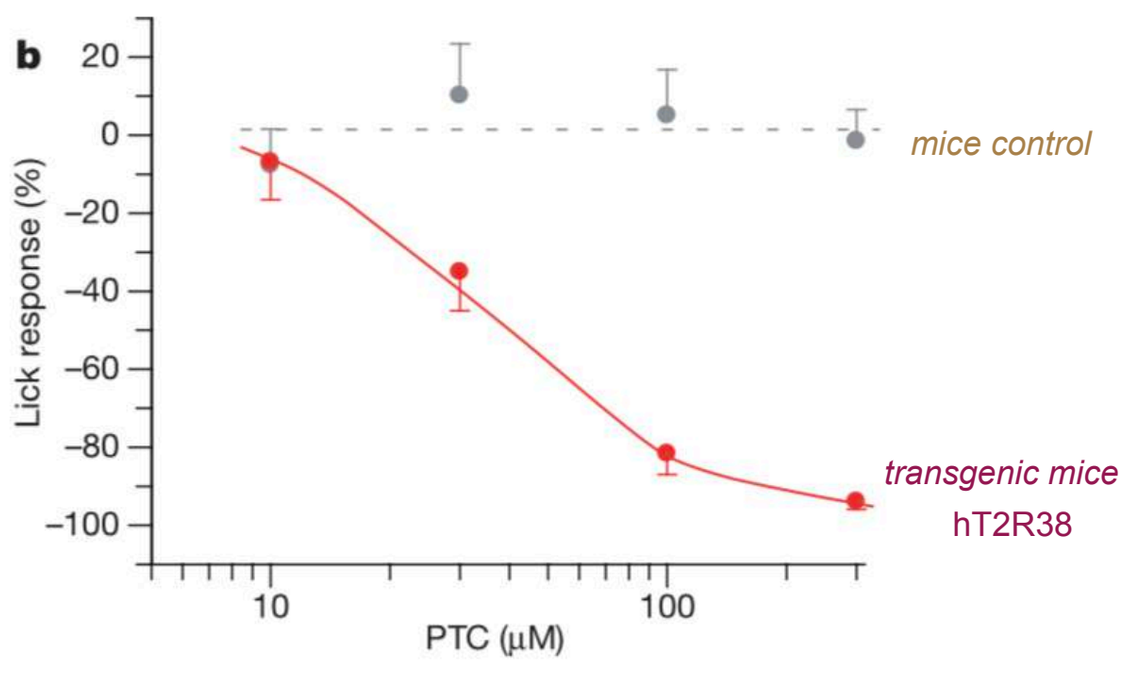
*β-glucopyranosides (**hT2R16**) and phenylthiocarbamide (PTC) (**hT2R38**) evoke strong bitter taste in humans and indifferent for mice*

Evaluation Methods

two-bottle intake preferences assays



counting of licking responses in a multi-channel gustometer



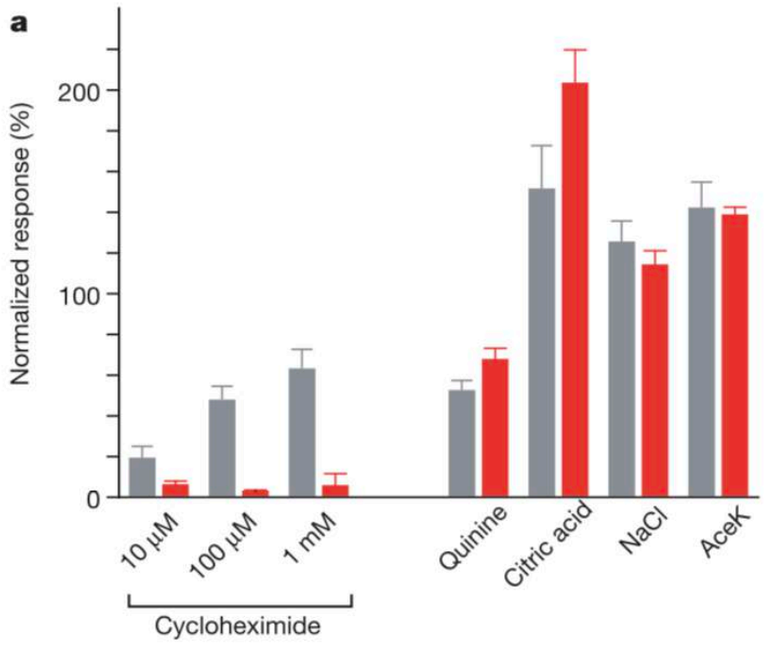
Mueller, E. T. *Nature* **2005** *434,* 225-229

Lacking a specific T2R receptor

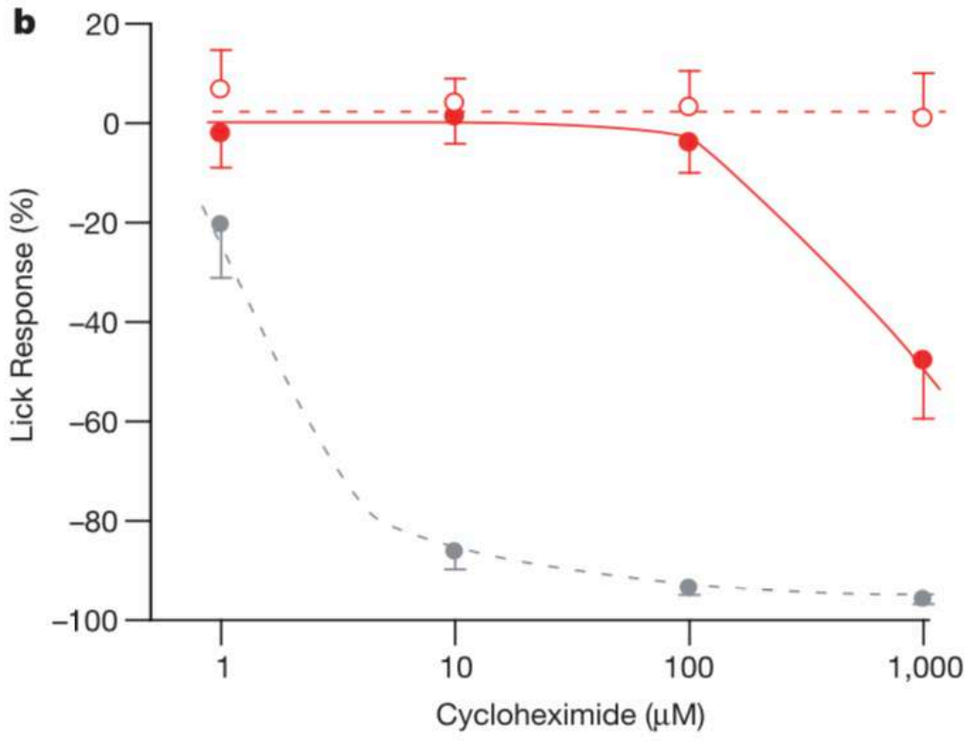
Genetic, behavioural and physiological studies

*animals lacking **mT2R5** (principal Cycloheximide receptor, Cyx)*

mice control *Knockout mice*



mT2R5 knockout only affects this taste receptor T2R5



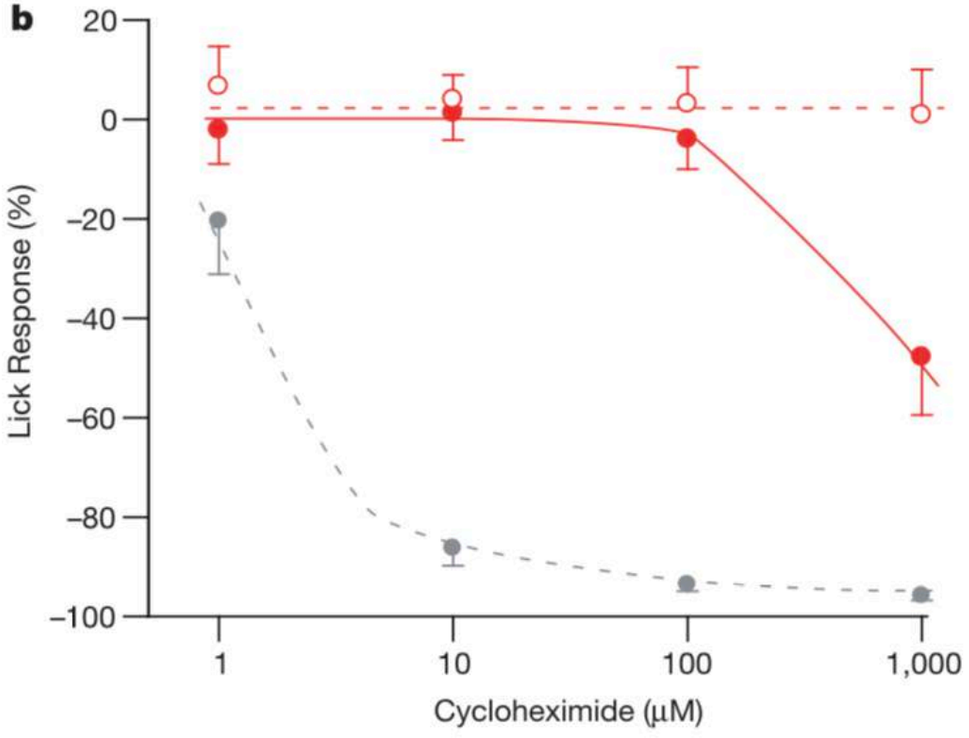
mT2R5 knockout animals with no aversion to Cyx

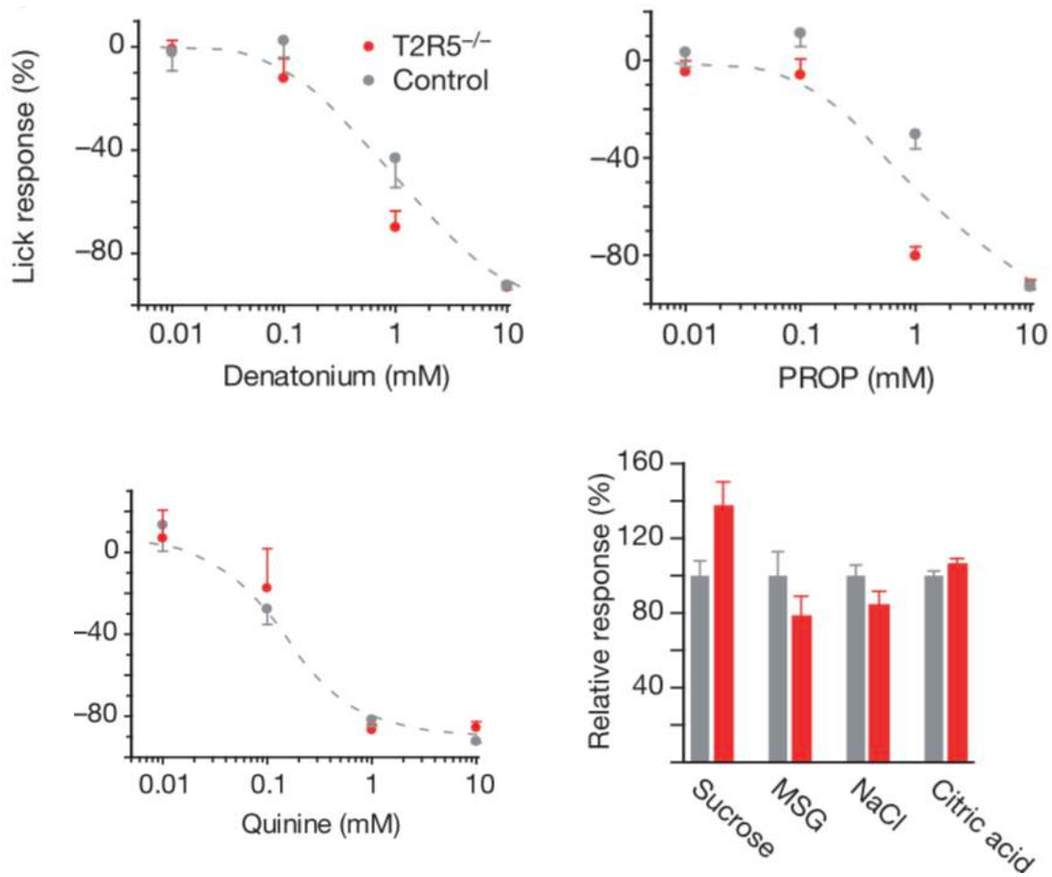
Mueller, E. T. *Nature* **2005** *434,* 225-229

Lacking a specific T2R receptor

Genetic, behavioural and physiological studies

*animals lacking **mT2R5** (principal Cycloheximide receptor, Cyx)*





mT2R5 knockout only affects this taste receptor T2R5

no bitter taste signalling (PLC) completely loss of Cyx sensitivity

any other tastants (bitter, sweet, salty…)

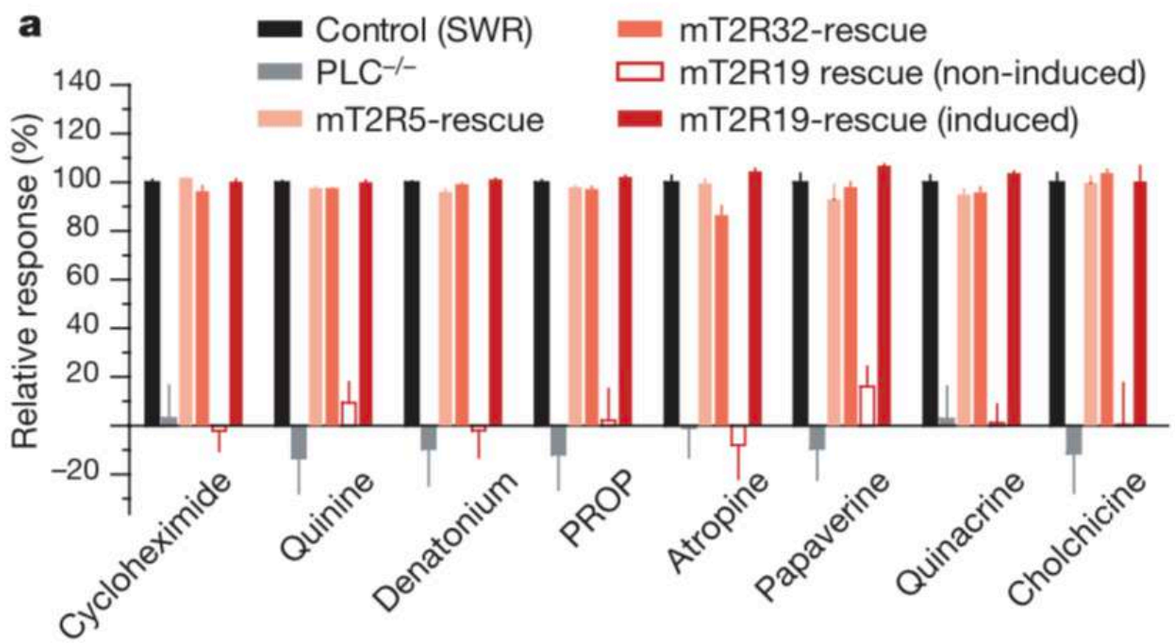
are not affected

Mueller, E. T. *Nature* **2005** *434,* 225-229

T2R expressing cells as mediators of bitter taste

Genetic, behavioural and physiological studies

Mice deficient in sweet, umami and bitter taste by Phodpholipase C β2 knockout (PLCβ2)



All rescued animals showed completely normal bitter taste

Bitter taste circuitry can be established without bitter sensory input, and demonstrate an individual T2R cell operate as broadly tuned bitter sensor.

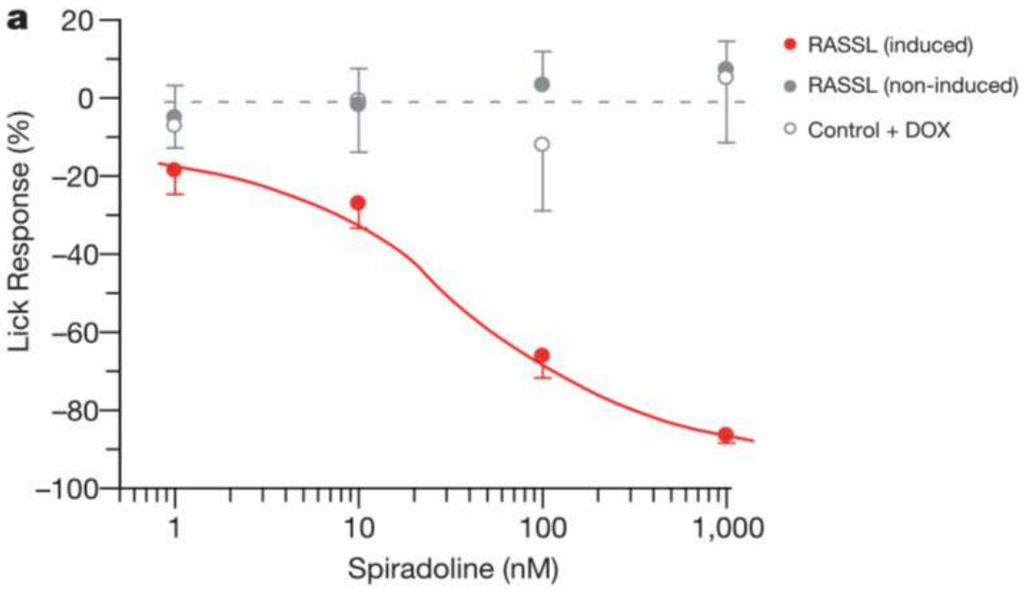
Mueller, E. T. *Nature* **2005** *434,* 225-229

Bitter receptor expressed into a sweet cell

Genetic, behavioural and physiological studies

Inducible RASSL receptor (k-opioid receptor)

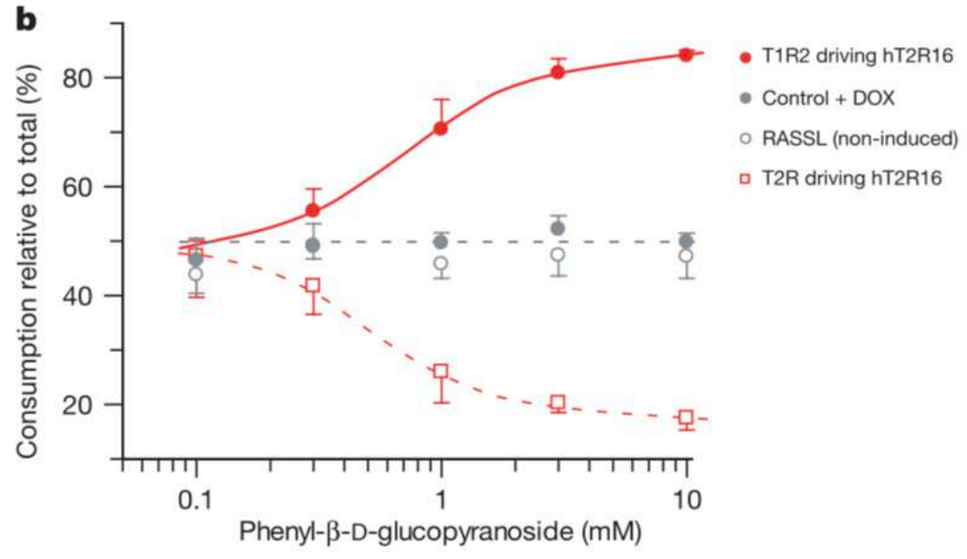
sweet receptor in bitter cells



control and non-induced are insensitive to RASSL agonist spiradoline

mice expressing RASSL in bitter cells show strong aversion to spiradoline

bitter receptor in sweet cells



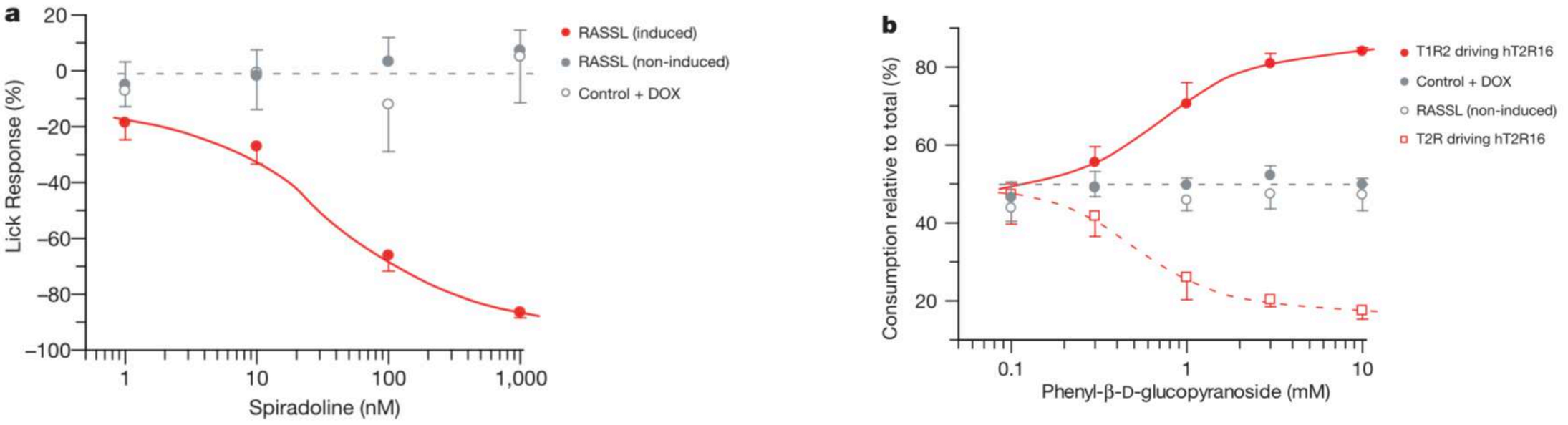
attraction to bitter compounds when bitter receptor is in sweet cells

Mueller, E. T. *Nature* **2005** *434,* 225-229

Bitter receptor expressed into a sweet cell

Genetic, behavioural and physiological studies

Inducible RASSL receptor (k-opioid receptor)



The perception of sweet or bitter is a reflection of the selective activation of T1R and T2R cells, ratherr than a property of the receptors or even the tastant molecules

Mueller, E. T. *Nature* **2005** *434,* 225-229

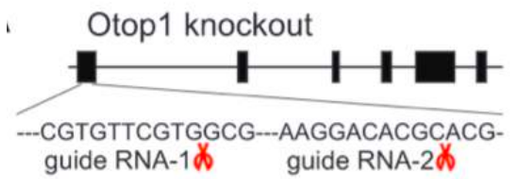
Rewiring the Taste System

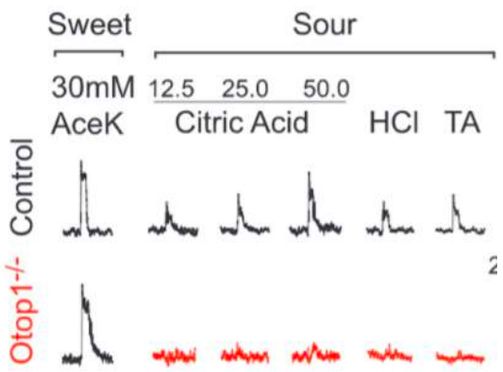
Sour Response

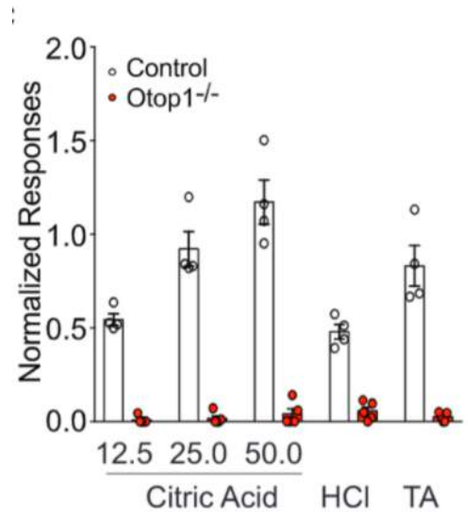
Otop 1
(proton-selective ion channell)

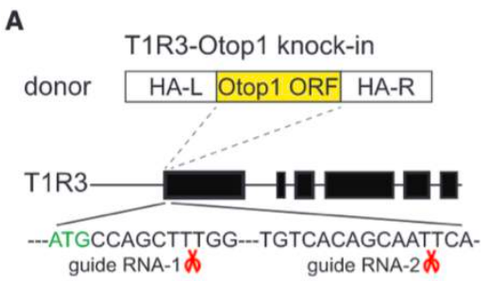
Knockout Otop-1
using CRISP-Cas9

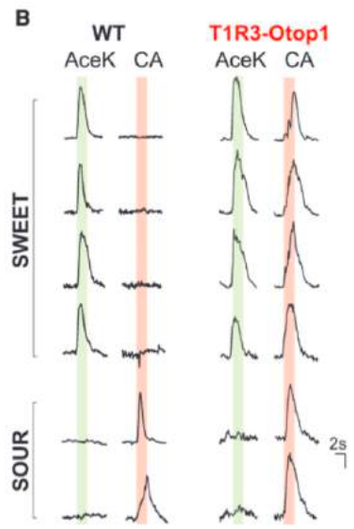
Otop-1
in sweet TRC cells
respond to stimuli









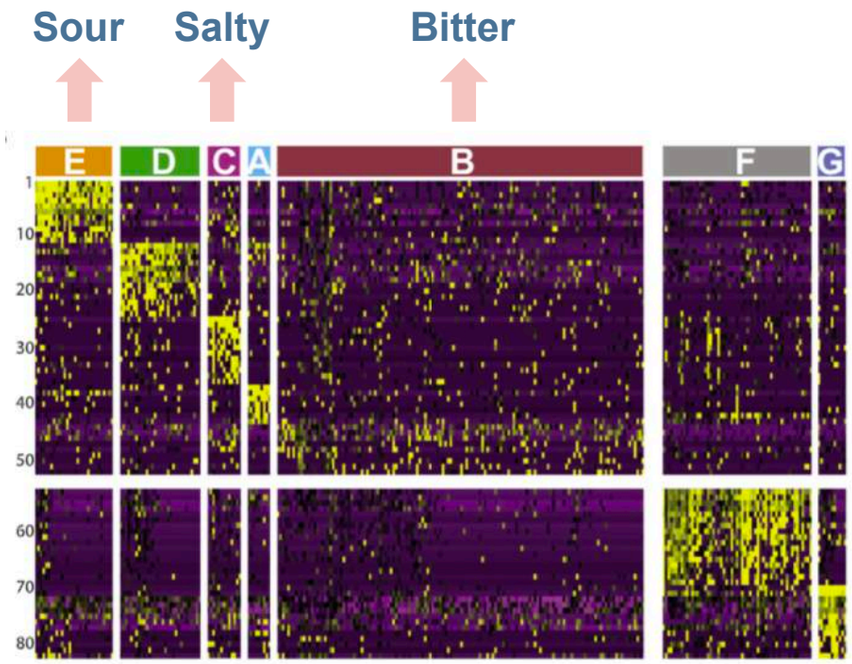


Zhang, J. *Cell* **2019** *179,* 392-402

Rewiring the Taste System

Sour Response

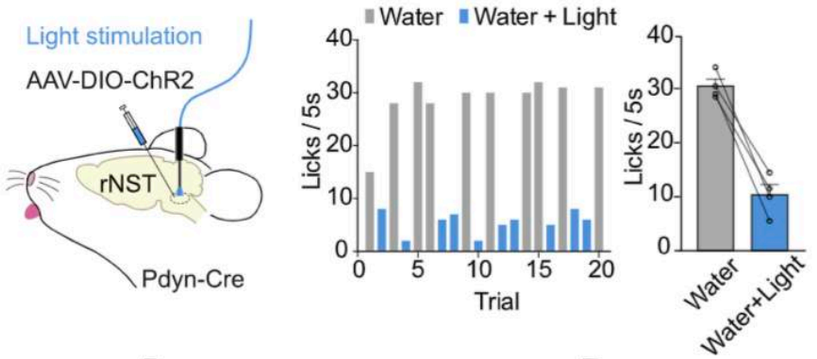
Otop 1 (proton-selective ion channell) → **Knockout Otop-1** using CRISP-Cas9 → **Otop-1 in sweet TRC cells** *respond to stimuli* → **identification of taste**



taste neurons identification

associated by knocking or expression of specific markers

Sour neurons stimulation by light



Light activate the sour neurons

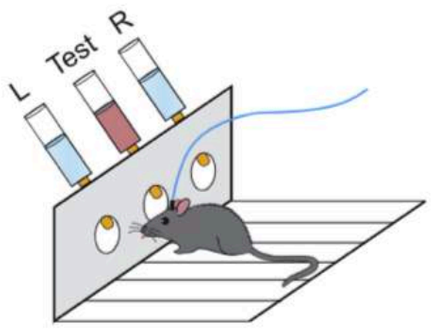
Zhang, J. *Cell* **2019** *179,* 392-402

Rewiring the Taste System

Sour Response

Otop 1 (proton-selective ion channell) ⇒ **Knockout Otop-1** using CRISP-Cas9 ⇒ **Otop-1 in sweet TRC cells** *respond to stimuli* ⇒ **identification of taste**

Training

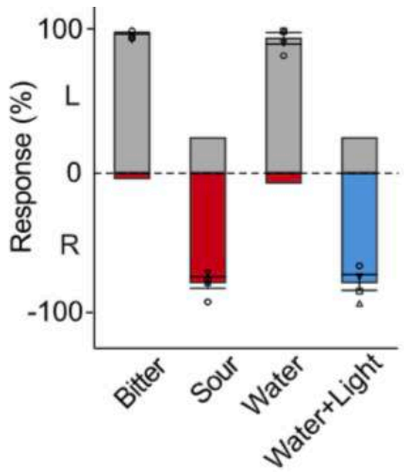


Sour *Water* *Bitter*

success *fail*

rewarded time-out

20-30 sessions of training



> 80% accuraccy

Zhang, J. *Cell* **2019** *179*, 392-402

Modifying the Taste System

Natural or Caused Process

Is the taste system changing or adapting naturally or do we need external stimulus?

Modifying the Taste System

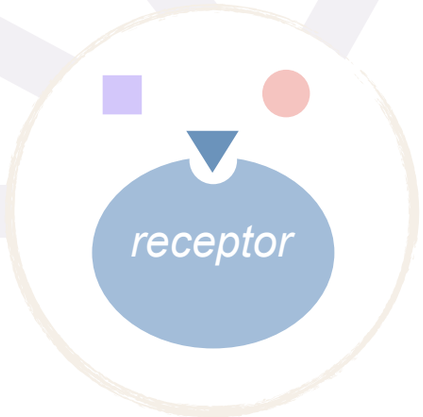
Natural or Caused Process

age

diseases

training or adaptation

drugs



stimulation or lock

Miraculin and Miracle Berry

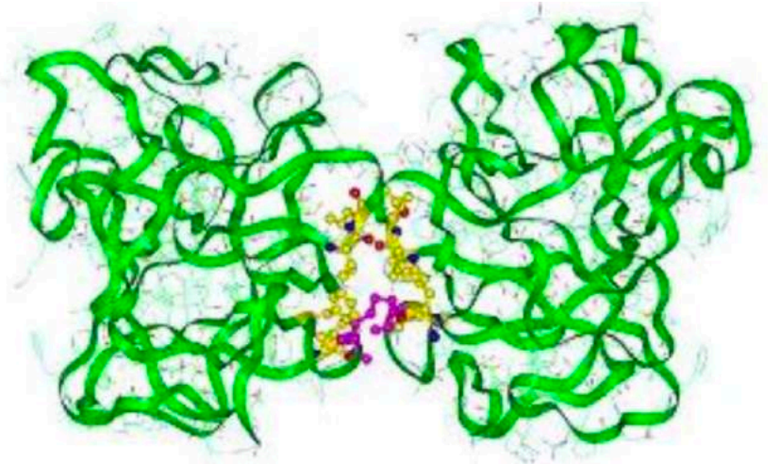
Phamaceutical, Therapeutic and Additive Potential

Richardella dulcifica or Synsepalum dulificum: ***Miracle fruit***

Family sapotaceae *From tropical West Africa*

Collection: December to June

It acts as a taste modifier



Miraculin

43000 D

Glycoprotein: 191 amino acid with two glycosylated poypeptides (Asn-186, Asn-42) cross-linked by disulphide bond (14% sugars)

not a sweetener → **make the sour products taste sweet**

Mangla, B. *Trop. J. Nat. Prod. Res.* **2018**, *2,* 12-17

Miraculin and Miracle Berry

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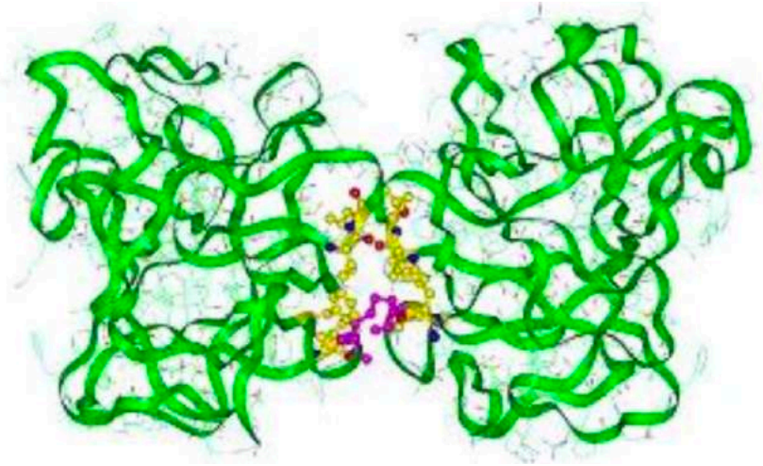
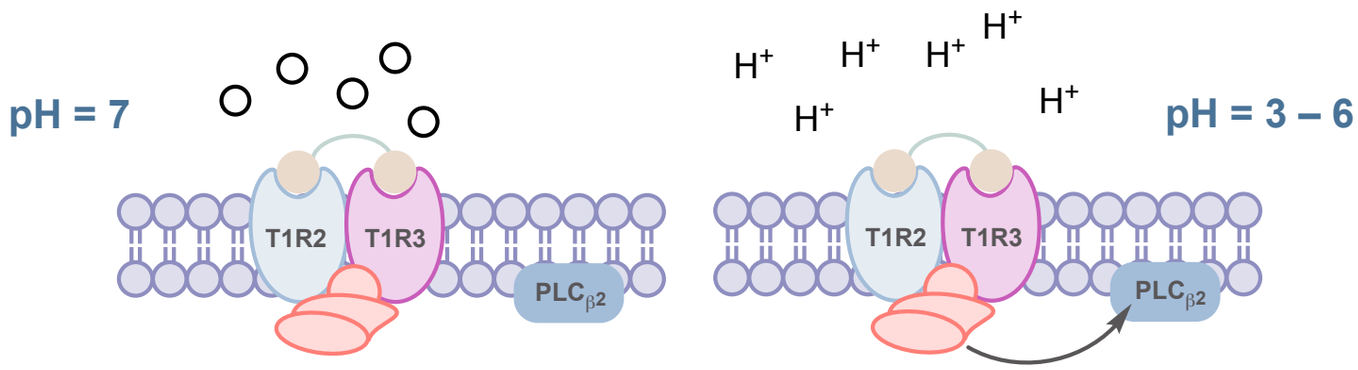


Miraculin

43000 D

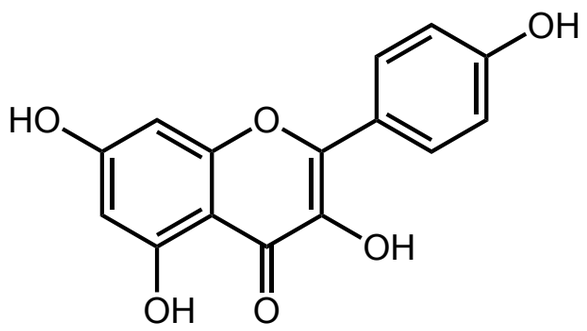


Mangla, B. *Trop. J. Nat. Prod. Res.* **2018**, *2,* 12-17

Miraculin and Miracle Berry

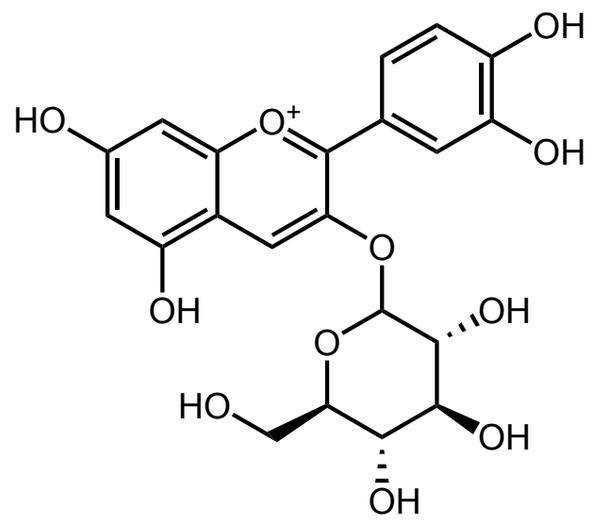
Phamaceutical, Therapeutic and Additive Potential

phenolics



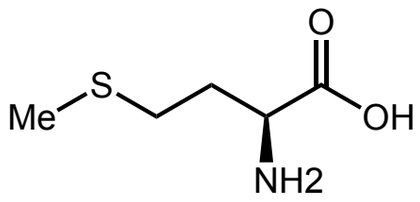
Kaempferol

anthocyanins

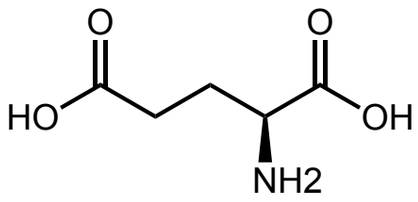


Cyanidin-3-*O*-glucoside

essential and non-esential amino accis

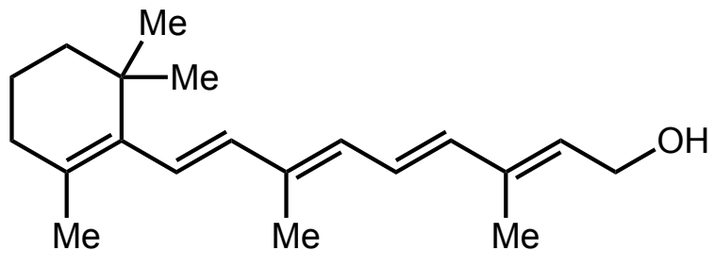


Methionine



Glutamic acid

vitamins



Vitamine A

Mangla, B. *Trop. J. Nat. Prod. Res.* **2018**, *2,* 12-17

Miraculin and Miracle Berry

Phamaceutical, Therapeutic and Additive Potential

health benefits

rich in antioxidants, carbohydrates, fibres, tannis, cardiac glycosides, polyphenos, flavonoids and minerals

prevention several chronic diseases *cardiovascular* *obesity* *diabetes* *cancer*

anti hyperuricaemia agent *improve dysguesia* *change horrible taste of certain medicines*

food enhancer

Marketed formulation

15 patents using Miracle berry (2018)

Wine industry

sugar concentration *inocculum level*

yeast strain *temperature and* ***pH***

Miracle berry tablet/power

Agbenorhevi, J. K. *J. Food Nut. Res.* **2019**, *7,* 148-154

Mangla, B. *Trop. J. Nat. Prod. Res.* **2018**, *2,* 12-17

Mimicking Taste Sense

Artificial Taste Sensors Using Biotechnology

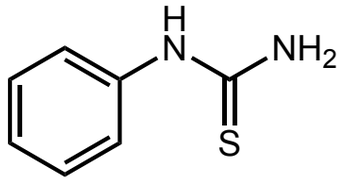
Can we merge the function of the taste sense with the new technology?

Mimicking Taste Sense

Human-Like Nanobioelectronic Tongue

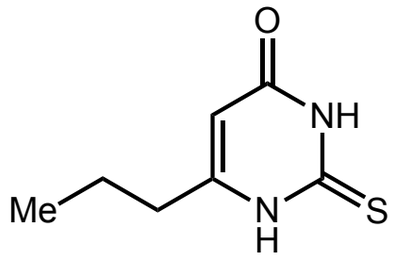
Nano-technology can be use as biological taste receptor → *Identification of toxic substances: mimicking bitter taste*

hTAS2R38
(from E. Coli)



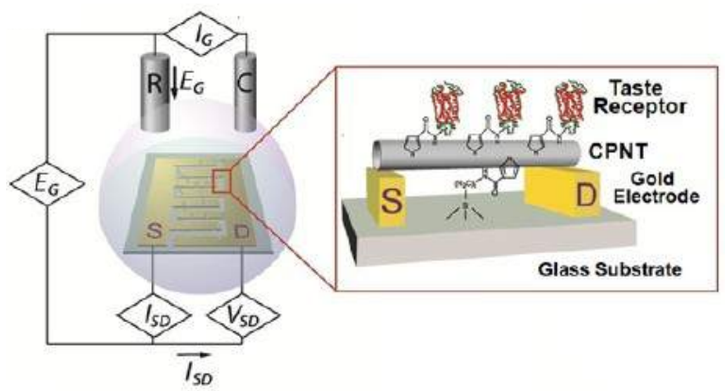
phenylthiocarbamide

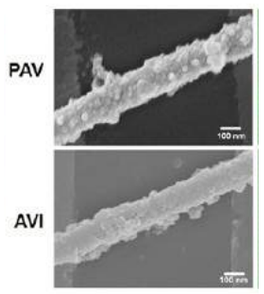
PTC

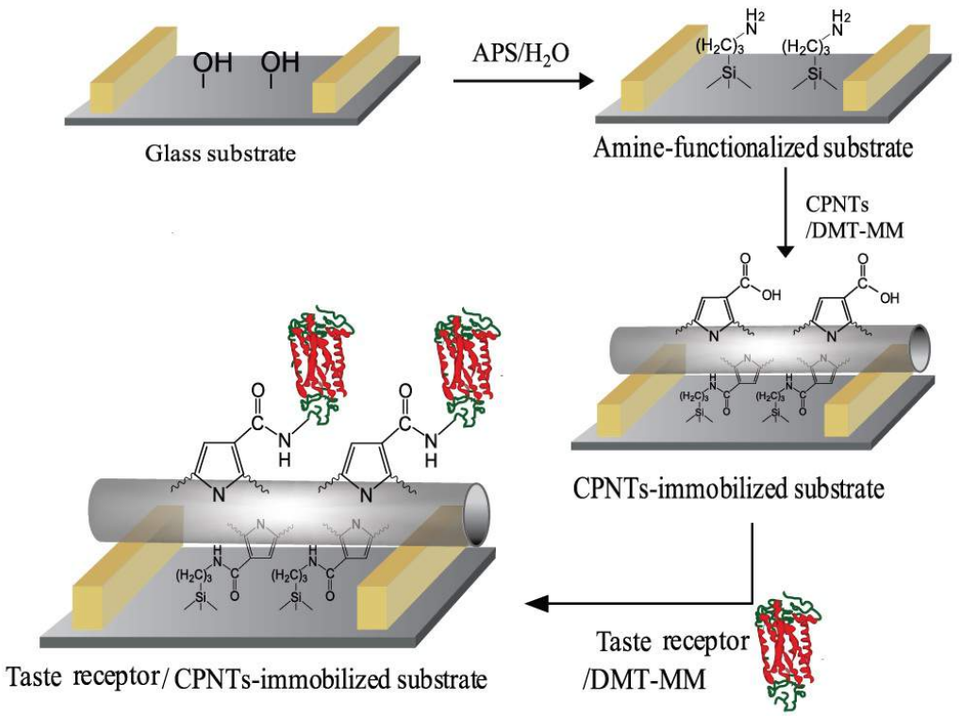


propylthiouracil

PROP



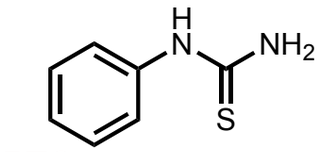




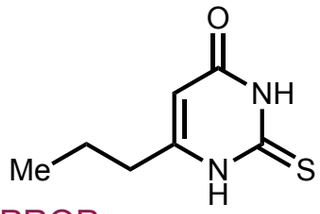
Song, H. S. *Nano Lett.* **2013**, *13,* 172-178

Mimicking Taste Sense

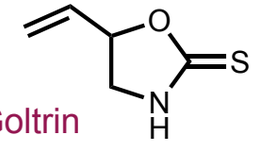
Human-Like Nanobioelectronic Tongue



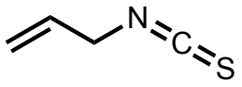
PTC



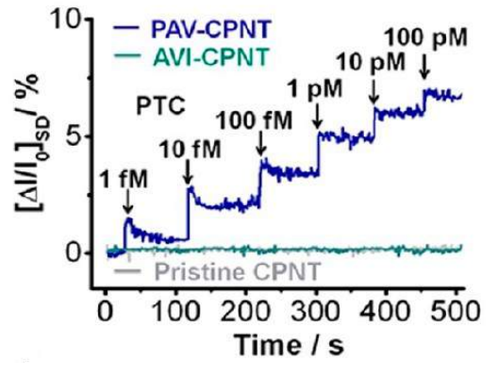
PROP

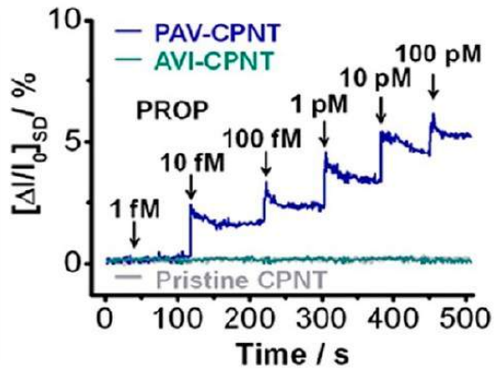


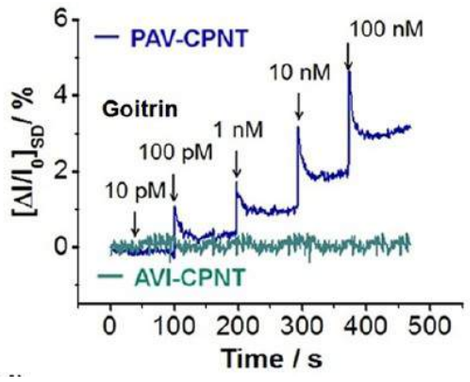
Goltrin

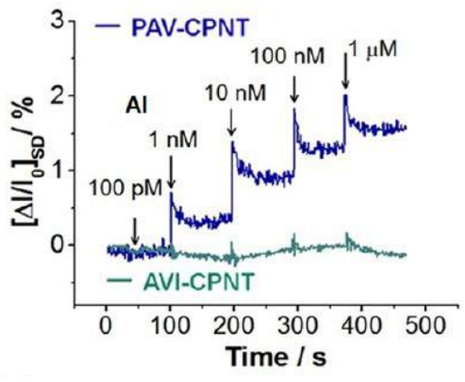


Allyl isothiocyanate (AI)

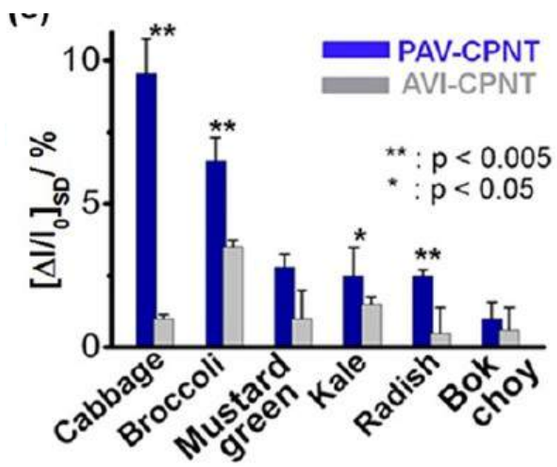








CPNT hybrid interface allows high sensitivity

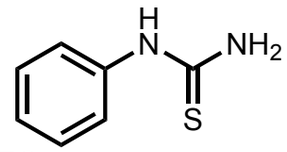


high selectivity in the detection of target tastants in mixtures and real food

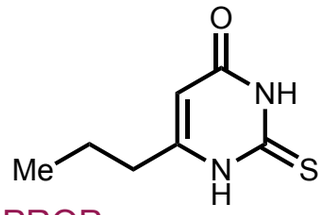
Song, H. S. *Nano Lett.* **2013**, *13,* 172-178

Mimicking Taste Sense

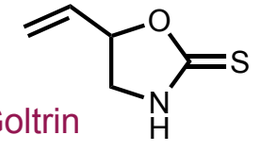
Human-Like Nanobioelectronic Tongue



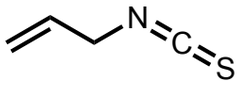
PTC



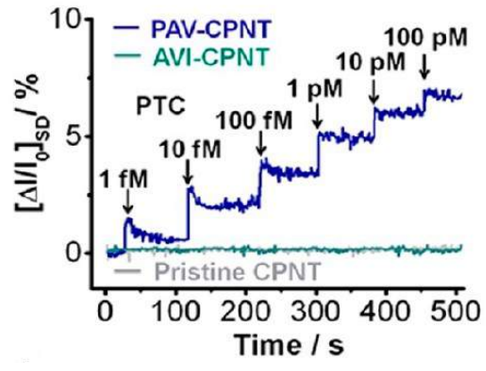
PROP

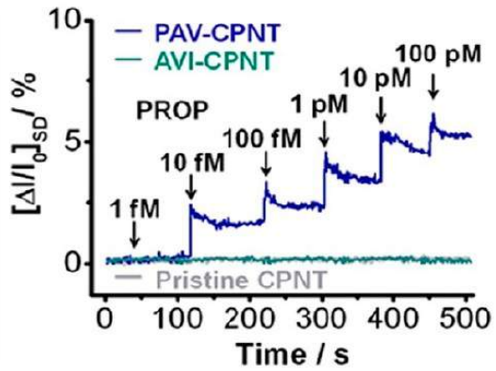


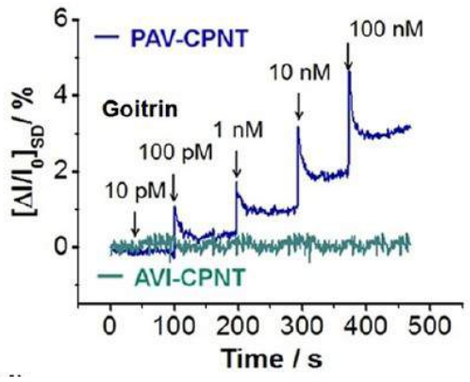
Goltrin

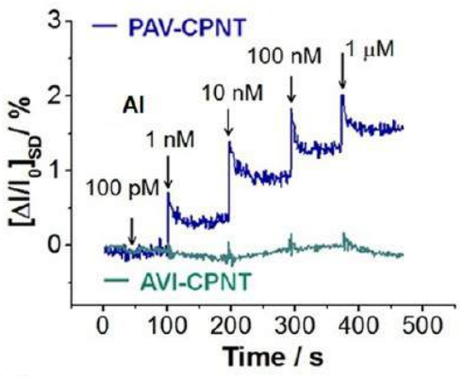


Allyl isothiocyanate (AI)

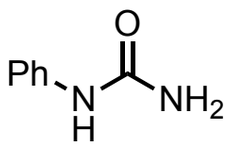




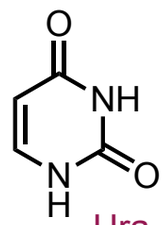




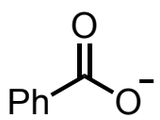
Bitter compounds



Phe



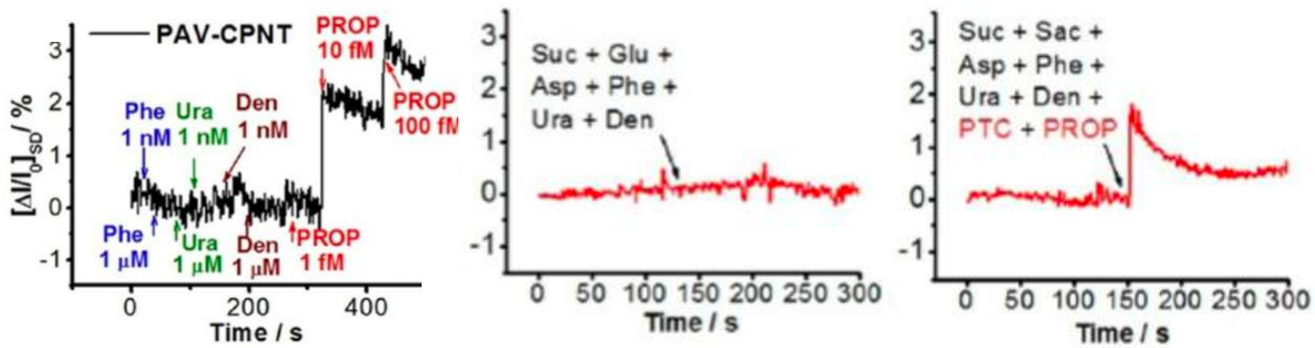
Ura



Den

other GPC compounds

Glu Suc Asp Sac



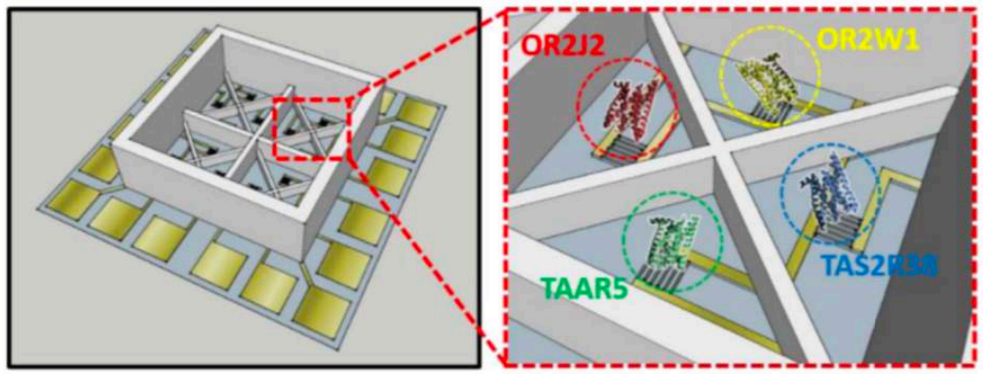
high sensitivity for chemical sensing ***some limitation: detection biological analytes***

Song, H. S. *Nano Lett.* **2013**, *13,* 172-178

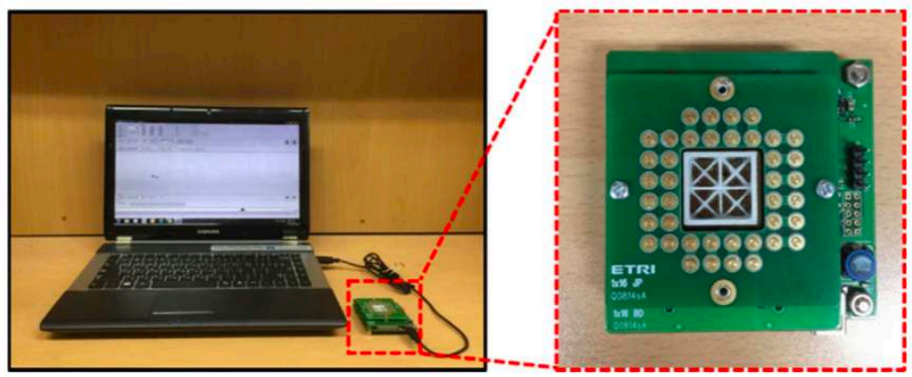
Portable Bioelectronic Sensor

Human Olfactory and Taste Receptors

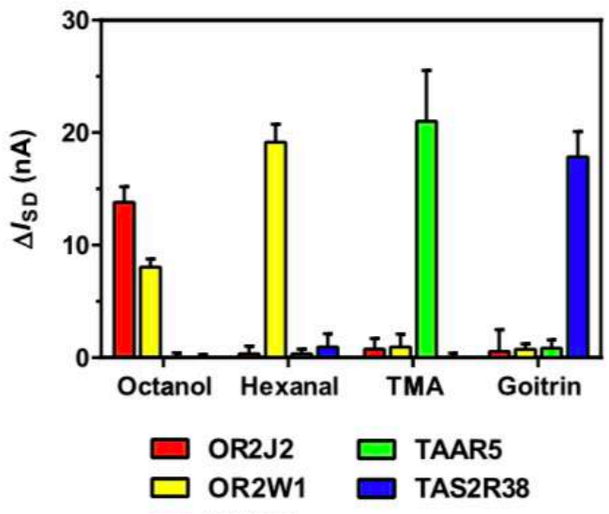
Four olfactory and taste sensory receptors



4 sets with 4 receptors



for liquids and gas samples



proteins/receptor	***target molecule***	***indicator***
OR2J2	Octanol	*bacterial contamination (beef)*
OR2W1	Octanol and Hexanal	*lipid oxidation in dairy products*
TAAR5	Triethylamine	*seafood decomposition*
TAS2R38	Goitrin	*antihyroid toxin*

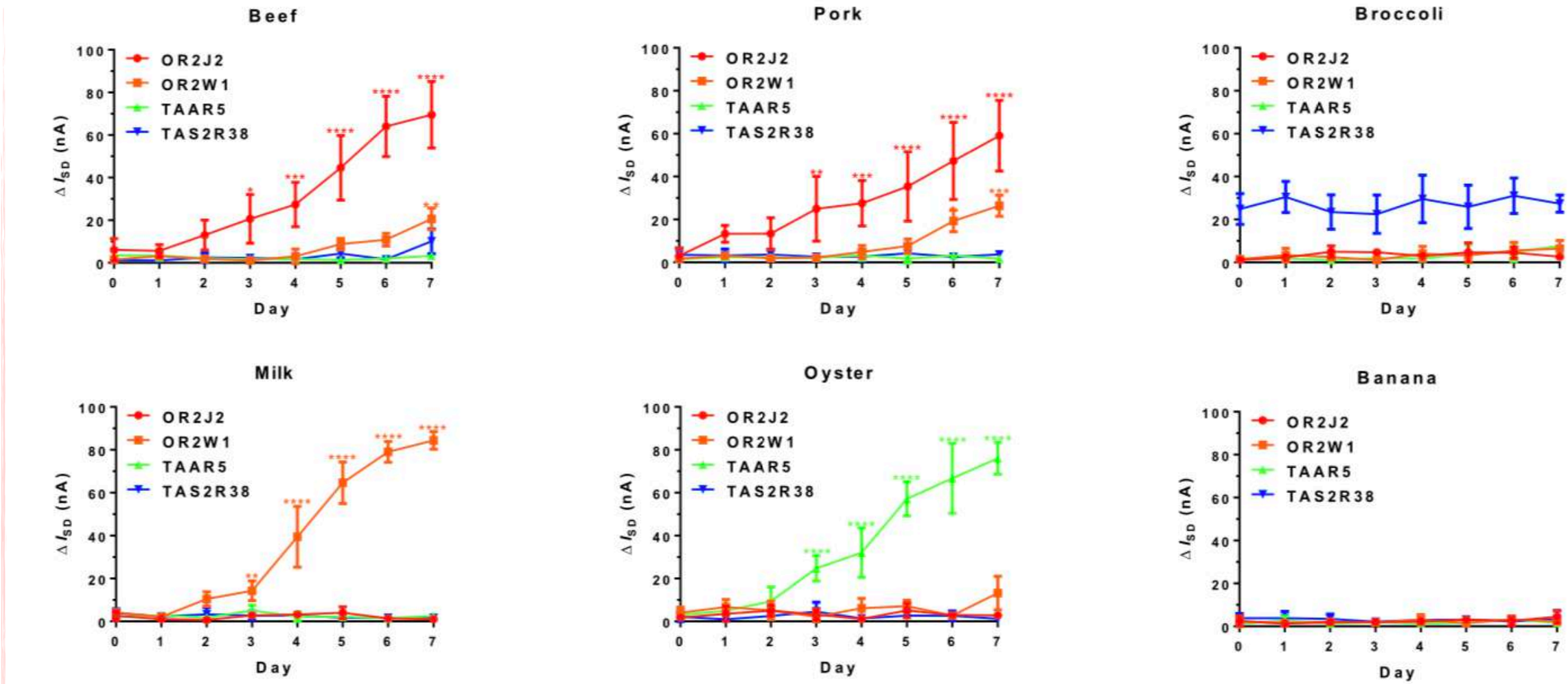
enables to distinguish taste molecules in individual or mixture samples

Son, M. *Biosensors and Bioelectronics* **2017**, *87,* 901-907

Portable Bioelectronic Sensor

Human Olfactory and Taste Receptors

Portable ⇨ *combine miniaturized measurement system with carbon nanotube*



diverse on-site detection for the quality of foods

Changing the receptors ⇨ *different sensing platforms*

Son, M. *Biosensors and Bioelectronics* **2017**, *87*, 901-907

Food, Food Chemistry and Gustatory Sense

María González Esguevillas

MacMillan Group Meeting

May 12th, 2020