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Possible prediction of taste quality using a liquid membrane

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Abstract

Oscillations of electric potential across a liquid membrane consisting of picric acid in nitrobenzene between two aqueous layers were studied. When fully described the oscillations were found to be characteristic of the structural class of a tastant present in the RHS of the liquid membrane. Smaller variations were observed in the pattern of oscillations and were apparently related to variations in the taste qualities within that class.

Keywords: Liquid membrane; Tastant; Sweetener

1. Introduction

The mechanisms of chemoreception are not well understood and the taste of new compounds is not easy to predict. The salty taste response is affected by both the anions and cations of ionic salts [1] while sour taste is related to the H^+ ions of acids. Sweet and bitter are the least understood of the four primary taste groups, and each can be elicited by structurally diverse compounds that, on first inspection, have little in common. Until recently, the only method available for determining the sweetness or otherwise of a compound was to taste it. It was not possible to predict which of a series of closely related compounds are going to be sweet although Douglas and Goodman [2] have developed a predictive model that can be used for assessing potential glucophores (taste eliciting groups).

Owing to the potentially harmful nature of some new compounds, the routine determination of their taste qualities by actual tasting is not recommended. Thus it would be desirable to develop a mechanism or experiment which allows for the prediction of taste quality. Hayashi et al. investigated the effects of tastants on electric oscillations across synthetic lipid membranes. The oscillations across the diolelyl phosphate (DOPH) membrane were induced by the application of an electric current to the membrane [3]. Recently a multichannel taste sensor has been developed where the transducer is composed of lipid membranes [4,5]. This sensor is reported to detect taste in a similar manner to human gustation.

Yoshikawa and Matsubara [6,7] reported a simple experiment involving an artificial membrane which exhibited self-sustaining rhythmic oscillations of electric potential across the membrane, not driven by

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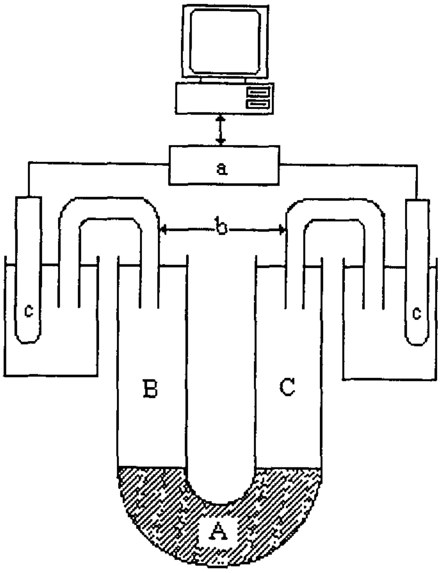

Fig. 1. Experimental apparatus. (a) mV meter, (b) salt bridges, (c) Ag/AgCl electrodes. (A) Organic layer, (B) surfactant/alcohol, (C) tastant in aqueous solution.

any external force such as pressure, voltage or electric current. The response of the liquid membrane to various sugars was reported to be characteristic of their chemical structures [7,8] and was further reported to possibly mimic the taste mechanism [7–9].

In the present study the range of chemical species added to the liquid membrane is extended and a fuller description of the oscillation pattern is used to characterise the tastants, with a view to using the procedure to predict the taste quality of new compounds without the need for tasting.

2. Experimental

Experiments were performed in a glass U-tube (12 mm inner diameter). The apparatus is shown schematically in Fig. 1. The organic phase consisting of 1.5 mM picric acid in nitrobenzene (solution A; 4 ml) was placed in the bottom of the U-tube, and aqueous solutions B and C (10 ml each) were simultaneously introduced into the arms of the U-tube above the organic layer, without stirring. Solution B, the left-hand side (LHS) solution, contained the surfactant cetyltrimethylammonium bromide (5 mM) and ethanol (5% v/v), while solution C, in the right-hand side (RHS) of the U-tube, contained the tastant (0.1 M) for each experiment.

A second liquid membrane, also reported to give oscillations [9,10], was studied. This consisted of 5 mM 2,2′-bipyridine in nitrobenzene (solution A; 4 ml) as the organic phase, with sodium oleate (0.1 mM) and propanol (5% v/v) in the LHS aqueous solution (B) and the RHS (C) unchanged. No oscillations were observed when this liquid membrane was used.

An analogue record of the oscillations was taken using a Toshin electron chart recorder, operating at a chart speed of 60 cm h^{-1}. The oscillations were also recorded digitally on a computer with a sampling rate of 5 Hz. The ADC unit was the PC-LabCard PCL-812 enhanced multi-lab card, from Laboratory Technologies Corporation, using PC-LabCard application software model PCLS-702 'LabTech Acquire' as the software. To ensure reproducibility, three experimental runs were performed for each set of conditions.

Programmes were written to allow the oscillation peaks and bases to be determined. The statistical analysis, as described in Section 3, of the peak data and the graphical display was carried out using Lotus 1-2-3, Version 3.1 from Lotus Development Corporation Ltd.

All reagents were commercial samples. Nitrobenzene was purified by vacuum distillation and picric acid was dried in vacuo.

3. Results and discussion

Yoshikawa et al. [8,9] investigated the response of the liquid membrane in the presence of representatives of the four taste groups and a range of sugars. It was reported that differences in the pattern of oscillations were observed for the four taste groups [9] and also within the range of sugars [8].

In the present study the tastants investigated were extended to include sugars with a range of taste qualities, and a number of non-carbohydrate sweeteners. The response of the liquid membrane in the absence of any tastant and in the presence of a representative of each taste group were also studied.

Yoshikawa et al. [8] described the manner of the oscillations using histograms of the frequency, f, of the oscillation (where f (s^{-1}) is the inverse of the period, T (s), between the pulses).

The present study attempted to characterise the pattern of the oscillations more fully by considering the amplitude, time and frequency domains. No one parameter was an adequate descriptor for the observed oscillations and a range of quantities were considered as a whole.

The useful quantities were found to be the average, standard deviation, and frequency distribution of the period (T), and the average amplitude (A). The frequency (f), in the form of $-\log f$ as utilised by Yoshikawa et al. [8], provided an alternative view of the data provided by the period (T). The changes in the period and amplitude of the peaks with elapsed time were of further use in characterising the pattern of the oscillations. The relative averages and standard deviations of tmp and tpm (time from minimum to following peak and time from peak to following minimum, respectively) gave a simple quantified description of the peak shapes.

The pattern of oscillations for each tastant showed a number of similarities. In each case the baseline potential slowly became less negative over the course of the experiment. As the experiment progressed there was usually an increase in the period, T, a decrease in the amplitude, A, and the peaks became less regular. A positive potential was rarely achieved, with most oscillations reaching a maximum potential at 0 V or just below. The oscillations were sustained for at least 3000 s and in some cases persisted for upwards of 8000 s.

Examination of the analogue traces (Fig. 2) showed that there were clear differences in the pattern of oscillations. The bitter tastant quinine gave a noisy baseline, which did not register on the chart record, with no large peaks. Lactose and maltose, disaccharides considered to be nearly tasteless, had traces which were very similar to each other but quite different from those of the other carbohydrates. Owing to the small number of peaks these three traces were unable to be analysed in the same manner as the other results.

The HCl, cyclamic acid, acesulfam-K, and saccharin traces had peaks of much smaller amplitudes than did the other tastants. The period of the KCl oscillations was more irregular than was generally observed for the other tastants.

The pattern of the oscillations were described using the quantities discussed earlier and these are summarised in Table 1.

The carbohydrates elicited similar responses in the liquid membrane. The average periods fell between 130.0 s and 196.5 s and the amplitudes of the oscillations were all around 0.50–0.55 V. The period tended to increase with elapsed time, the amplitude slowly decreased and tmp was usually larger than tpm. The regularity of the peaks, as shown by the standard deviations, decreased as the intensity of the sweet taste became less. Sucrose and fructose are of similar sweetness intensity and their average periods

Table 1
Summary of quantities describing the pattern of the oscillations

Tastant	Period (T)/s		Average $-\log f$	Average amplitude (A)/V	Peak shape	
	Average	St. deviation			tmp > tpm	tmp/tpm
None	111.1	32.6	2.03	0.530	No	0.85
HCl	78.8	33.4	1.87	0.295	No	0.47
KCl	181.5	147.7	2.17	0.467	Yes	3.23
Sucrose	136.0	64.8	2.09	0.550	Yes	1.18
Fructose	155.1	63.6	2.16	0.549	Yes	1.48
Glucose	196.5	105.4	2.23	0.537	Yes	2.02
Galactose	175.9	135.2	2.17	0.512	Yes	1.59
Mannose	109.6	51.4	2.01	0.536	No	0.92
Glycine	205.4	123.6	2.26	0.545	Yes	1.80
Acesulfam-K	84.7	29.4	1.87	0.055	No	0.36
Saccharin	100.4	26.9	1.99	0.102	No	0.64
Cyclamic acid	90.6	30.5	1.94	0.339	No	0.77

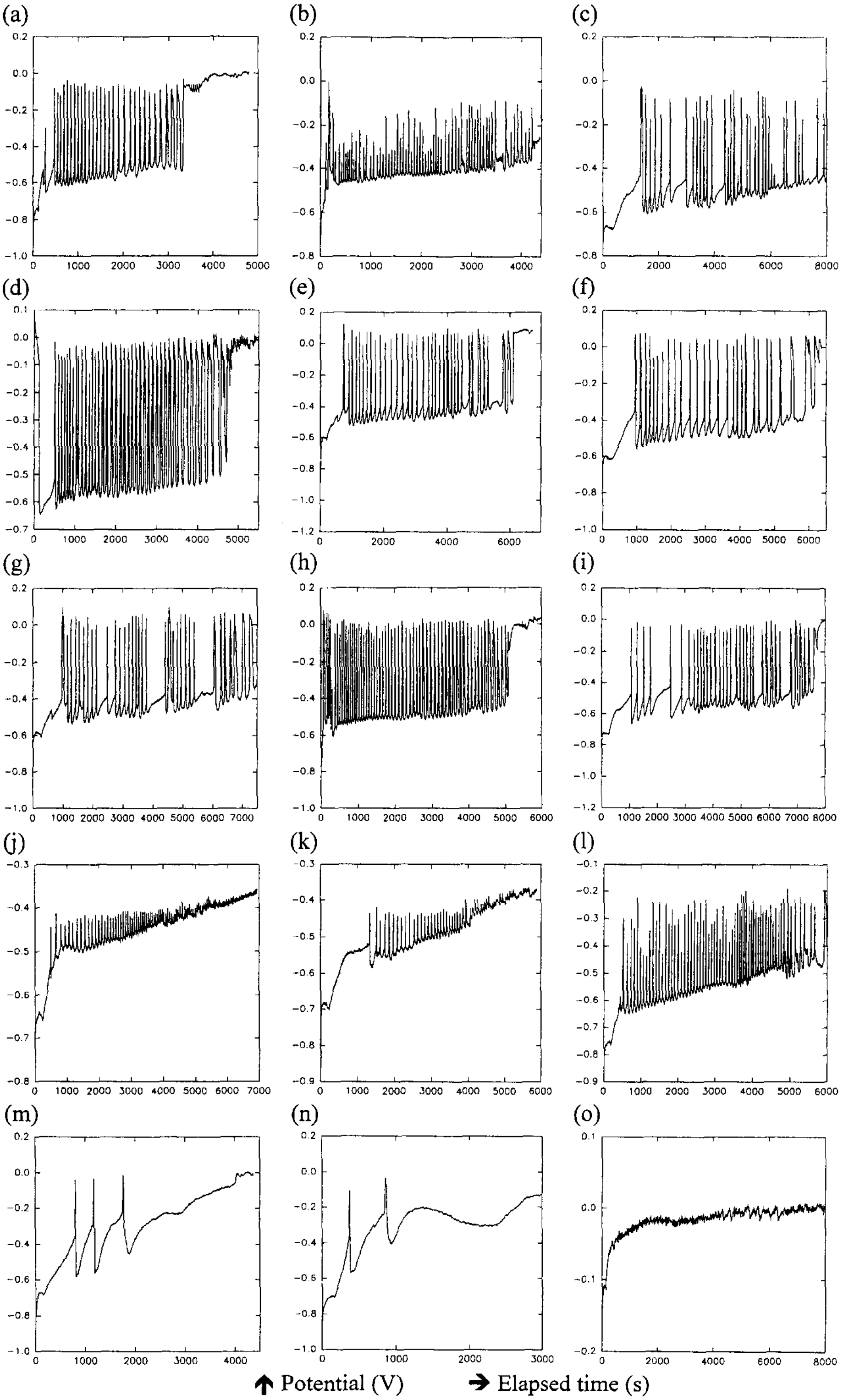

Fig. 2. Analogue traces of oscillation of the electric potential across the organic phase. (a) No tastant, (b) HCl, (c) KCl, (d) sucrose, (e) fructose, (f) glucose, (g) galactose, (h) mannose, (i) glycine, (j) acesulfam-K, (k) saccharin, (l) cyclamic acid, (m) lactose, (n) maltose, and (o) quinine.

and standard deviations were similar. Lactose and maltose are also of similar sweetness intensity and although the statistics were not calculated, it can be seen (Fig. 2) that the period between the peaks was much longer than for any of the other carbohydrates. Mannose was an exception to these trends. The regularity and period of the oscillations were more like those seen for sucrose and fructose than for any of the less sweet carbohydrates. Mannose was the only carbohydrate for which tmp/tpm was less than unity. β-D Mannose is bitter but α-D mannose is slightly sweet. Mannose was the only monosaccharide studied where the predominant species in solution is the a-pyranose species rather than the β-pyranose form. As α-D mannose is slightly sweet and will be the major species in solution in the time-scale of this experiment the oscillations may not reflect the presence of a bitter tastant.

Acesulfam-K and saccharin are both ionic sweeteners and had very similar responses in the liquid membrane, whilst being quite different to those of any other tastants. The periods and amplitudes were much smaller than those seen for the carbohydrates and both of these quantities decreased over time.

The pattern of the oscillations for cyclamic acid was like that seen for the sour tastant, HCl. The averages and standard deviations of the periods were similar (90.6 ± 30.5 s and 78.8 ± 33.4 s, respectively) as were the amplitudes.

4. Conclusions

The major differences in the response of the liquid membrane appeared to be due to structural differences. It is clear that the carbohydrates behaved in a different manner than the ionic compounds which in turn behave in a different manner to the acids.

Within each structural type there were smaller differences which may be related to taste characteristics of the compounds. An example of this was the increased irregularity of the oscillations as the carbohydrates became less sweet.

The liquid membrane systems gave oscillations that, when adequately described, were characteristic of different structural classes. Less obvious were the smaller variations within a structural class that may give a measure of the relative sweetness intensities within that class.

Further work is required to extend the selection of compounds studied. Studies of a series of closely related compounds which exhibit a range of taste qualities would be useful in determining the efficacy of relating the smaller differences to taste quality. Further examples of salty and bitter compounds need to be investigated to see if the results already observed can be extended to include other members of those taste categories.

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References

[1] R.S. Shallenberger in G. Ohloff and A.F. Thomas (Editors), Gustation and Olfaction, Academic Press, New York, 1971, p. 126.

[2] J. Douglas and M. Goodman in D.E. Walters, F.T. Orthoefer and G.E. DuBois (Editors), Sweeteners: Discovery, Molecular Design and Chemoreception, American Chemical Society, 1991, Ch. 10.

[3] K. Hayashi, K. Toko and K. Yamafuji, Jpn. J. Appl. Phys., 28 (1989) 1507.

[4] K. Toko, T. Matsuno, K. Yamafuji, K. Hayashi, H. Ikezaki, K. Sato, R. Toukubo and S. Kawarai, Biosensors and Bioelectronics, 9 (1994) 359.

[5] Y. Kikkawa, K. Toko, T. Matsuno and K. Yamafuji, Jpn. J. Appl. Phys., 32 (1993) 5731.

[6] K. Yoshikawa and Y. Matsubara, Biophys. Chem., 17 (1983) 183.

[7] K. Yoshikawa and Y. Matsubara, J. Am. Chem. Soc., 106 (1984) 4423.

[8] K. Yoshikawa, T. Omochi and Y. Matsubara, Biophys. Chem., 23 (1986) 211.

[9] K. Yoshikawa, M. Shoji, S. Nakata, S. Maeda and H. Kawakami, Langmuir, 4 (1988) 759.

[10] K. Yoshikawa, S. Maeda and H. Kawakami, Ferroelectrics, 86 (1988) 281.